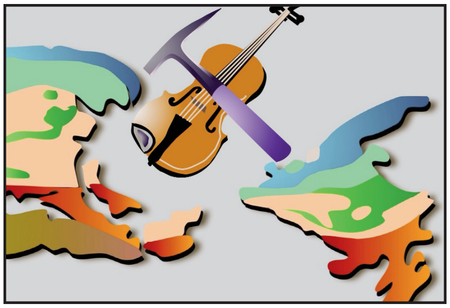
HAROLD WILLIAMS SERIES



Detrital Zircon Geochronology Across the Chopawamsic Fault, Western Piedmont of North-Central Virginia: Implications for the Main Iapetan Suture in the Southern Appalachian Orogen

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SUMMARY
The Chopawamsic fault potentially represents the main Iapetan suture, previously unidentified in the southern extent of the Appalachian orogen. The fault trends through the north-central portion of the western Piedmont of Virginia and separates the composite metaclastic Potomac terrane, commonly interpreted to be of Laurentian affinity, from the Chopawamsic terrane, the remains of a Middle Ordovician volcanic arc of uncertain crustal affinity. To gain insight on the first-order orogenic significance of the Chopawamsic fault, we report the results of LA–ICP–MS U–Pb analyses of 1,289 detrital zircons from 13 metasedimentary rock samples collected from both sides of the fault.

The near exclusivity of Middle Ordovician zircon grains (ca. 470 – 460 Ma) in four sampled metasedimentary rocks of the Chopawamsic Formation likely represents the detrital recycling of syndepositional Chopawamsic volcanic rocks. A subset of Cambrian and older grains hint at one or more additional, older sources.

Samples from the Potomac terrane include mostly Mesoproterozoic zircon grains and these results are consistent with previous interpretations that the metaclastic rocks are Laurentian-derived. The youngest zircons (ca. 550 – 500 Ma) and the age of cross-cutting plutons indicate that at least some parts of the Potomac terrane are Late Cambrian – Early Ordovician. The results imply temporally discrete and geographically isolated sedimentary systems during deposition of sedimentary rocks in the Chopawamsic and Potomac terranes.

Metasedimentary rocks near Storck, Virginia, previously identified as a successor basin, contain detrital zircon populations that indicate they are actually peri-Gondwanan derived metasedimentary rocks unrelated to a successor basin system; their geographic position between the Laurentian-derived Potomac terrane and the Chopawamsic terrane suggests a peri-Gondwanan affinity for the Chopawamsic arc and geographic separation of the Chopawamsic and Potomac terranes in the Middle Ordovician. Consequently, we tentatively support the hypothesis that the Chopawamsic fault system represents the main Iapetan suture in the southern Appalachian orogen.

Most detrital zircons from samples of the Arvonia successor basin crystallized in the Ordovician – Silurian or Mesoproterozoic. These data suggest that the Arvonia basin was deposited in the latest Ordovician to Early Silurian only after the Late Ordovician accretion of the Chopawamsic arc to Laurentia.

SOMMAIRE
La faille de Chopawamsic représente peut-être la principale suture japétienne, non-reconnue dans prolongement sud de l'orogène des Appalaches. La faille traverse la portion nord du centre du piedmont ouest de Virginie et sépare le terrane métaclastique de Potomac, d'affinité laurentienne pensait-on, du terrane de Chopawamsic, vestige d'un arc volcanique de l'Ordovicien moyen d'affinité crustale

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incertain. Afin de mettre en lumière la signification orogénique première de la faille de Chopawamsic, nous présentons les résultats d'analyses U-Pb par ICP–MS par AL sur 1 289 zircons détritiques provenant de 13 échantillons de roches métasédimentaires prélevés de chaque côté de la faille.

L'existence quasi-exclusive de grains de zircon de l'Ordovicien moyen (env. 470 – 460 Ma) dans quatre roches métasédimentaires de la Formation de Chopawamsic représente vraisemblablement le recyclage détritique des roches volcaniques synsédimentaires de Chopawamsic. Un sous-ensemble de grains cambriens et plus anciens, évoque l'existence d'une ou plusieurs sources plus anciennes additionnelles.

Les échantillons du terrane de Potomac renferment principalement des grains de zircon du Mésoprotérozoïque, ce qui correspond avec les interprétations antérieures voulant que les roches métaclastiques soient d'origine laurentienne. Les zircons les plus jeunes (env. 550 – 500 Ma) ainsi que l'âge des plutons qui recoupe l'encaissant indiquent qu'au moins certaines parties du terrane de Potomac sont de la fin du Cambrien ou du début de l'Ordovicien. Les résultats impliquent l'existence de systèmes sédimentaires distincts au cours du temps, et isolés géographiquement durant le dépôt des roches sédimentaires dans les terranes de Chopawamsic et de Potomac.

Les roches métasédimentaires près de Storck en Virginie, jadis interprétées comme bassin successeur, renferment des populations de zircons détritiques qui indiquent qu'ils proviennent en fait de roches métasédimentaires péri-gondwaniennes sans rapport avec un système de bassin successeur; leur localisation géographique entre le terrane de Potomac issu des Laurentides et le terrane de Chopawamsic porte à penser que l'arc de Chopawamsic est d'affinité péri-gondwanienne, et que les terranes de Chopawamsic et de Potomac à l'Ordovicien moyen étaient séparés géographiquement. En conséquence il nous semble justifié de proposer que le système de faille de Chopawamsic représente la principale suture japétienne dans le sud de l'orogène des Appalaches.

La plupart des zircons détritiques des échantillons du bassin successeur d'Arvonia ont cristallisés entre l'Ordovicien et le Silurien ou au Mésoprotérozoïque. Ces données suggèrent que le bassin d'Arvonia s'est rempli de la fin entre l'Ordovicien et le début du Silurien, seulement après l'accrétion de l'arc de Chopawamsic à la Laurentie, à la fin de l'Ordovicien.

INTRODUCTION

The Chopawamsic fault is a Late Ordovician structure that bisects the western Piedmont of Virginia into two distinct crustal tracts known as the Potomac and Chopawamsic terranes (Fig. 1; Pavlides 1989, 1990, 1995; Horton et al. 1989; Virginia Division of Mineral Resources 1993; Pavlides et al. 1994; Mixon et al. 2000, 2005; Hughes et al. 2013a; Hibbard et al. 2014). Whereas the majority of previous research involving the Chopawamsic fault has been focused on identifying the local feature and its timing (Pavlides 1989, 1990, 1995; Mixon et al. 2000, 2005; Hughes et al. 2013a), little has been done to ascertain its regional significance within the Appalachian orogen.

The Chopawamsic fault is of broad significance because it potentially marks the orogen-scale main Iapetan suture, the fundamental Appalachian boundary between native Laurentian and exotic peri-Gondwanan elements (Hibbard et al. 2007, 2014). It is generally accepted that the early Paleozoic Potomac terrane represents Laurentian-derived metaclastic rocks (e.g. Pavlides 1989; Hibbard et al. 2014), but the cratonic affinity of the Middle Ordovician Chopawamsic terrane has not been determined. Most previous

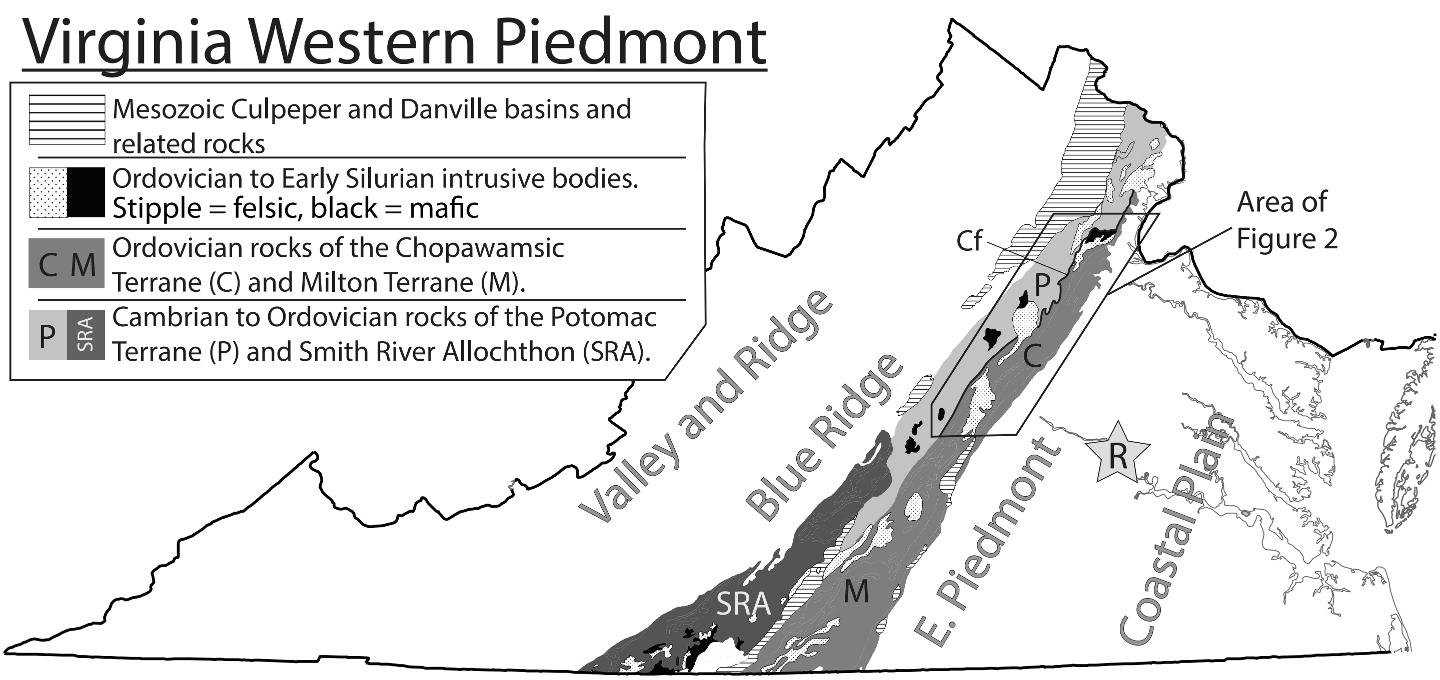


Figure 1. Lithotectonic elements of the western Piedmont of Virginia. Map modified from Hibbard et al. 2006. Cf = Chopawamsic fault; R = Richmond.

workers have coupled the Chopawamsic terrane arc rocks with the Potomac terrane accretionary rocks as part of a peri-Laurentian system in tectonic models due to their current geographic positions and the interpretation that some sedimentary rocks and 'exotic blocks' in the Potomac terrane were derived from the Chopawamsic terrane (Drake and Morgan 1981; Pavlides 1989; Hibbard et al. 2014). This interpretation implies that the main Iapetan suture likely lies to the east of the Chopa-wamsic terrane. Other researchers have interpreted the Chopawamsic terrane to be peri-Gondwanan, implying that the Chopawamsic fault between the Potomac and Chopawamsic terranes is the main Iapetan suture (Hibbard et al. 2007).

In order to garner information about the provenance and timing of sedimentary dispersal systems active during deposition of the Potomac and Chopawamsic terranes, we present the results of laser ablation—inductively coupled plasma—mass spectrometry (LA–ICP–MS) U–Pb analyses of 1,289 detrital zircon grains from 13 metasedimentary samples on both sides of the Chopawamsic fault, as well as purported younger successor basins. The results clarify the supra-crustal relationships between sedimentary units in the early Paleozoic and augment our understanding of the location of the main Iapetan suture in the southern Appalachians.

This contribution is particularly relevant to this volume dedicated to Hank Williams. It has been 50 years since Williams recognized the two-sided geologic nature of the Appalachian orogen (Williams 1964) and 25 years since his identification of the fundamental boundary between native Laurentian and exotic peri-Gondwanan elements in Newfoundland. This boundary, termed the Red Indian Line, was defined on the marked stratigraphic, structural, faunal, and isotopic contrasts in Ordovician–Silurian Iapetan realm rocks in central Newfoundland (Williams et al. 1988). The Red Indian Line is accepted as the main suture zone in the northern Appalachian orogen in that it separates peri-Laurentian ophiolitic sequences in the northwest from arc-related volcanic and sedimentary rocks with Gondwanan affinities in the southeast (Williams et al. 1999; Zagorevski et al. 2008). Because first order latitudinal differences in the evolution of the orogen have been recognized (Sinha et al. 1996; Sinha and McLelland 1999; Loewy et al. 2003; Tohver et al. 2004; Hibbard et al. 2007, 2010; Fisher et al. 2010; McLelland et al. 2010; Hibbard and Karabinos 2014), identifying the timing and style of the main Iapetan suture zone in the southern Appalachians is important to further our understanding of the Iapetan cycle along the entire length of the orogen, rather than only in the Canadian Appalachians (e.g. Williams et al. 1988; Zagorevski et al. 2006, 2007a, b; Zagorevski and van Staal 2011).

GEOLOGIC SETTING

The western Piedmont of Virginia (Fig. 2) is chiefly comprised of the Potomac and Chopawamsic terranes. The two terranes have been intruded by various igneous bodies and are also overlain by younger sedimentary units. The western Piedmont is bordered to the west by the Blue Ridge province and Mesozoic Culpeper basin; it is bordered to the east by the eastern Piedmont and Atlantic coastal plain provinces.

The Chopawamsic fault is the most important structure in the western Piedmont because it marks the boundary between the two primary crustal tracts in the domain (Hibbard et al. 2014). Studies focused specifically on the Chopawamsic fault have been limited, although it has long been known that the fault, marked by "steeply dipping mylonite at a number of places," (Pavlides 1989, 2000) separates two distinct tracts of bedrock (Pavlides 1981, 1989, 1990, 1995, 2000). The Chopawamsic fault has also been identified as a crustal-scale structure in seismic profile (Harris et al. 1982, 1986; Pratt et al. 1988; Glover 1989; Pratt 2012), as well as in other regional mapping (Brown 1979; Duke 1983; Evans 1984; Wehr and Glover 1985; Brown 1986; Marr 1990; Hughes 2011). Based upon the youngest high-precision volcanic crystallization TIMS age of the fault-bounded Chopawamsic Formation (465 ± 1 Ma, Hughes et al. 2013b) and the relationship and age of the cross-cutting Ellisville granodiorite (444 ± 4 Ma, Hughes et al. 2013a) it can be deduced that the fault was active between 465 and 444 Ma. Recognition of the Chopawamsic fault as a latest Middle to Late Ordovician structure is important in order to distinguish it from common younger faults in the region (e.g. Gates 1986, 1997; Pavlides et al. 1994; Pavlides 2000; Spears and Bailey 2002; Bailey et al. 2004; Spears et al. 2004; Carter et al. 2006; Spears 2010; Spears and Gilmer 2012).

In the study area, the metaclastic Potomac terrane is comprised of the Mine Run Complex and the Lunga Reservoir Formation (Fig. 2). These units, along with their correlatives along strike, have been interpreted as a collection of metasedimentary rocks deposited offshore of Laurentia in the early Paleozoic (Evans 1984; Drake 1989; Pavlides 1989; Horton et al. 1989, 2010; Carter et al. 2006; Bailey et al. 2008; Hibbard et al. 2014). Detailed thermochronology in the terrane along and near the Potomac River (Kunk et al. 2005; Wintsch et al. 2010) has emphasized the composite nature of the terrane. The Mine Run Complex includes 4 greenschist facies sub-units (I–IV) of mostly folded phyllite and lesser metagreywacke that are identified on the basis of slight compositional variation and airborne magnetic properties (Pavlides 1989). Pavlides (1989) interpreted numerous granitoid, felsic volcanic, mafic, and ultra-mafic blocks within the Mine Run Complex to represent exotic debris that were derived from a nearby, syn-depositional Chopawamsic arc system. The Lunga Reservoir Formation, which was originally mapped as a granite body (Lonsdale 1927; Milici et al. 1963), was later recognized as a metadiamictite (Pavlides 1989). This metamorphosed immature sedimentary rock most commonly consists of poorly sorted pebble- to cobble-size vein quartz 'lumps,' dark schist 'chips,' and granitoid clasts in a fine-grained quartz-feldspar-muscovite-biotite matrix. Both the Mine Run Complex and the Lunga Reservoir Formation were previously thought to have been deposited between the Laurentian continent and an accreting, peri-Laurentian Chopawamsic arc (Pavlides 1989; Hibbard et al. 2014). The only age controls for the Mine

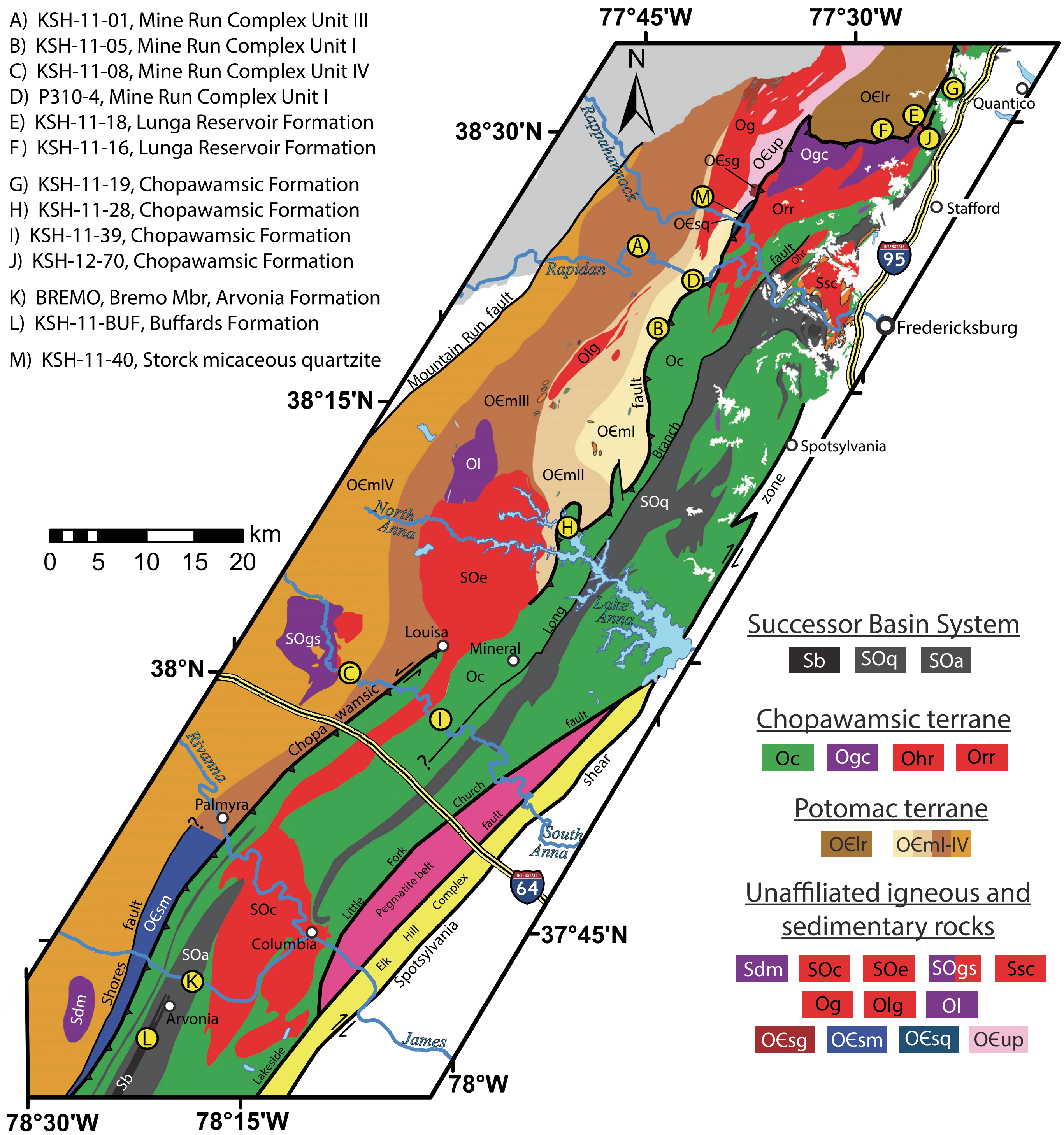


Figure 2. Geologic map of the study area. Red units are felsic intrusive bodies. Purple units are mafic intrusive bodies. Detrital zircon samples are listed from A) to M) and their locations are shown on map. Geology modified from Pavlides 1990, 1995; Virginia Division of Mineral Resources 1993; Mixon et al. 2000; Spears and Bailey 2002; Bailey et al. 2005; Hughes 2011; Spears et al. 2013; Terblanche 2013; and our reconnaissance mapping. Map unit abbreviations: *Arvonia/Quantico successor basin system*: Sb—Buffards Formation, SOa—Arvonia Formation, SOq—Quantico Formation. *Rocks not related to a terrane*: Og—Goldvein pluton, Ol—Lahore pluton, Olg—Locust Grove pluton, OЄup—unassigned phyllite, Sdm—Diana Mills body, SOc—Columbia pluton, SOe—Ellisville pluton, SOgs—Green Springs intrusive suite, Ssc—Salem Church complex, OЄsg—Storck granitoid, OЄsm—Shores mélange, OЄsq—Storck quartzite. *Chopawamsic arc terrane*: Oc—Chopawamsic Formation, Ogc—Garrisonville mafic complex, Ohr—Hunting Run pluton, Orr—Richland Run pluton; *Potomac metasedimentary terrane:* OЄlr—Lunga Reservoir Formation, OЄmI–IV—Mine Run complex units I–IV.

Run Complex and Lunga Reservoir Formation are provided by U–Pb zircon data from plutonic bodies that cross-cut its metaclastic units. Among others, these include the ca. 472 Ma Occoquan pluton, the ca. 456 Ma Goldvein pluton, and the ca. 444 Ma Ellisville pluton (Wilson 2001; Aleinikoff et al. 2002; Hughes et al. 2013a).

The Chopawamsic Formation (Southwick et al. 1971) is the primary component of the Chopawamsic terrane. Named after exposures along Chopawamsic Creek in northern Virginia, greenschist-facies metavolcanic and metavolcaniclastic rocks of the Chopawamsic Formation have been shown to extend into central Virginia (Pavlides et al. 1974; Marr 1980a, b; Pavlides 1990; Bailey et al. 2005). Multiple samples of Chopawamsic magmatic rocks have been dated to have crystallized between 474 and 465 Ma (U–Pb TIMS on zircon: Coler et al. 2000; Hughes et al. 2013b). On the basis of these zircon ages, xenocryst ages, and an evolved isotopic signature (Coler et al. 2000), the Chopawamsic terrane has been interpreted to represent a Middle–Late Ordovician suprasubduction magmatic arc that developed on Mesoproterozoic continental crust (Pavlides 1981; Coler et al. 2000; Hibbard et al. 2014).

The Arvonia/Quantico successor basin system metasedimentary rocks consist of slate, phyllite, quartzite, and local metaconglomerate and metavolcanic layers. In this study, we focus only on the Arvonia basin. Stratigraphy within the Arvonia successor basin has been debated throughout the 20th century; however, it is accepted to include the Arvonia Formation phyllite, slate and schist, the Bremo Member quartzite of the Arvonia Formation and the Buffards Formation metaconglomerate, quartzite, and phyllite. Some workers have favoured the Buffards Formation as the basal unit to the basin (Stose and Stose 1948) and others have interpreted it as the highest exposed unit in the basin, lying unconformably over the Arvonia Formation (Brown 1969). The Arvonia and Quantico formations are the only known fossiliferous Paleozoic rocks in the western Piedmont of Virginia; similar fauna are found in both units and the general paleontological consensus is that they are Late Ordovician deposits (Darton 1892; Dale 1906; Watson and Powell 1911; Stose and Stose 1948; Smith et al. 1964; Brown 1969; Tillman 1970; Pavlides 1980; Pavlides et al. 1980; Kolata and Pavlides 1986; Hibbard et al. 2014). The Late Ordovician interpretation of these fossils appears to be at odds with the unconformable relationship of the Arvonia basin over the ca. 444 Ma (latest Ordovician) Carysbrook phase (U–Pb SIMS zircon: Sinha et al. 2012) of the Columbia pluton, which has been shown to be geographically and geochemically linked to the ca. 444 Ma Ellisville pluton (Hopkins 1960; Milici et al. 1963; Smith et al. 1964; Good et al. 1977; Duke 1983; Spears and Bailey 2002; Hughes et al. 2013a). Because the Ellisville pluton stitches the Potomac and Chopawamsic terranes, the Arvonia basin could have only been deposited after the juxtaposition of the Chopawamsic and Potomac terranes. With all data considered, it appears that the Arvonia/Quantico system was deposited in the latest Ordovician (fossil ages) to earliest Silurian. Using major element and isotope geochemistry, Owens et al. (2013) showed that the Arvonia basin was similar to post-450 Ma deposits elsewhere in the orogen and could have been derived from either Laurentian, Chopawamsic terrane, or mixed source areas.

Rocks to the west of the Richland Run pluton were previously mapped as outliers of the greater successor basin system that were deposited over the Chopawamsic fault (e.g. Pavlides 1990, 1995; Mixon et al. 2000). Detailed mapping in these areas has shown that rocks near Wilderness, Virginia, previously interpreted to be related to the successor basin system, are actually part of the Chopawamsic Formation (Terblanche 2013) and rocks near Storck, Virginia, which were targeted in this study, are known to be distinct from the Potomac terrane and Chopawamsic Formation (Hughes et al. 2012). Their connection to the greater Arvonia/Quantico system has not been conclusively established.

PREVIOUS DETRITAL ZIRCON STUDIES

Previous detrital zircon studies in the western Piedmont of Virginia have been limited to the Arvonia/Quantico successor basin system and rocks correlative to the Potomac terrane with no samples taken from the Chopawamsic terrane. These previous studies have not focused on the specific significance of the Chopawamsic fault; however, some results from these investigations are pertinent to this study.

Metasedimentary samples within the Potomac terrane, to the north of our focus area, yielded mostly Mesoproterozoic detrital ages (Horton et al. 2010; Martin et al. 2013; Bosbyshell et al. 2013) and indicate that these parts of the Potomac terrane were deposited adjacent to an older continental margin. Most of these data, when considered with the depositional interlayering of Potomac terrane rocks and those of the Blue Ridge province (Evans 1984), are consistent with a Laurentian source for the Potomac terrane. In contrast, detrital zircons from the Shores mélange (Fig. 2), which some geologists consider a part of the Potomac terrane, include a population of early Mesoproterozoic (1.55 – 1.50 Ga) zircons that may be indicative of an Amazonian source exotic to Laurentia (Bailey et al. 2008). The Smith River allochthon (see Fig. 1), part of the overall metaclastic tract in the western Piedmont that includes the Potomac terrane (Hibbard et al. 2014), has been determined to be of similar Laurentian, rift-related paleogeographic crustal affinity as the metasedimentary Lynchburg Group in the Blue Ridge province (Carter et al. 2006; Merschat et al. 2010). Rocks of the Smith River allochthon appear to be coeval with metaclastic rocks of the Potomac terrane; their Laurentian affinity is consistent with the interpretation that the Potomac terrane along strike was deposited peripherally to the Laurentian continent after the breakup of Rodinia.

Samples interpreted to be from basal units of the Arvonia and Quantico formations have yielded a dominant population of Middle–Late Ordovician detrital zircon grains and reportedly lack considerable Mesoproterozoic zircon (Bailey et al. 2008); this distribution of ages led to the conclusion that the Arvonia/Quantico system and the underlying Chopawamsic terrane were not derived in any part from Laurentian crust (Bailey et al. 2008).

By sampling new target outcrops in the terranes and successor basin system of the western Piedmont, we aim to assess the supra-crustal relationships within and between constituent rock units. Specifically, we seek to: (1) explore the inferred depositional relationship between the Chopawamsic and Potomac terranes, (2) refine our understanding of the cratonic affinity and depositional age of units in the Potomac terrane, (3) assess and connect any older, non-Chopawamsic volcanic zircon in the Chopawamsic terrane to a Proterozoic cratonic or micro-continental source, and (4) gain insight into the depositional age and source of sediments in the Arvonia successor basin system.

METHODS

Thirteen metasedimentary samples were selected from the western Piedmont of Virginia for LA–ICP–MS detrital zircon U–Pb analysis. Crushing, disc-milling, Wilfley table separation, magnetic separation, and methylene-iodide separation were carried out on nine samples at the Department of Geological Sciences at the University of North Carolina at Chapel Hill. Samples BREMO and P310-04 were processed at Memorial University, Newfoundland. Samples KSH-11-16 and KSH-12-70 were processed at Texas A&M University in College Station, Texas. With the exception of sample KSH-11-16, which was analyzed at Washington State University following the procedure described by Chang et al. (2006), heavy mineral fractions were processed at the Micro-Analysis Facility at Memorial University. A portion of the heavy mineral fraction from each sample was mounted in epoxy and polished. To avoid any potential bias, zircon grains were not hand-picked with optical microscopy. Zircon grains in the heavy mineral fraction were subsequently identified and imaged with an automated MLA–SEM and then analyzed using laser ablation–inductively coupled plasma–mass spectrometry. All analyses were performed with a 10 μm beam that scanned over a 40x40 μm area on each grain. Laboratory zircon standards—Plešovice ($^{206}Pb/^{238}U$ age of 337.13 ± 0.37 Ma; Sláma et al. 2008) and Harvard 91500 ($^{206}Pb/^{238}U$ age of 1062.4 ± 0.4 Ma; Wiedenbeck et al. 1995)—were analyzed after sets of 8 unknowns were analyzed. The aggregate age of 180 analyses of the Plešovice standard in this study is 335.1 ± 1.2 Ma; the aggregate age of 186 analyses of Harvard 91500 standard in this study is 1062.2 ± 4.4 Ma (both ages are reported at the 2σ confidence level and also include decay constant errors). Analyses and concordia plots for the reference material analyses can be found in Appendix 1 (available at GAC's open source GC Data Repository at http://www.gac.ca/wp/?page_id=306). More detailed information on the methodology and laser ablation system can be found in Pollock et al. (2007) and references therein.

Signal processing and data analysis were performed with 'in-house' software at Memorial University. In most instances, the preferred age is the concordia age of Ludwig (2012); however, if the concordia age for any given grain younger than 1.5 Ga has a probability of fit value of <50%, the $^{206}Pb/^{238}U$ age is reported, but only if it is between 85 and 110% concordant with the $^{207}Pb/^{206}Pb$ age. For zircons older than 1.5 Ga, when concordia ages have a low probability of fit value, the $^{207}Pb/^{206}Pb$ age was reported because sufficient ^{207}Pb is present in these older zircon grains for a precise age determination. This methodology for reporting detrital zircon ages is similar to previous studies (e.g. Pollock et al. 2007, 2009). All age uncertainties are reported at the 2σ confidence level. Histograms and cumulative probability plots were prepared with the Isoplot software (Ludwig 2012) in Microsoft Excel.

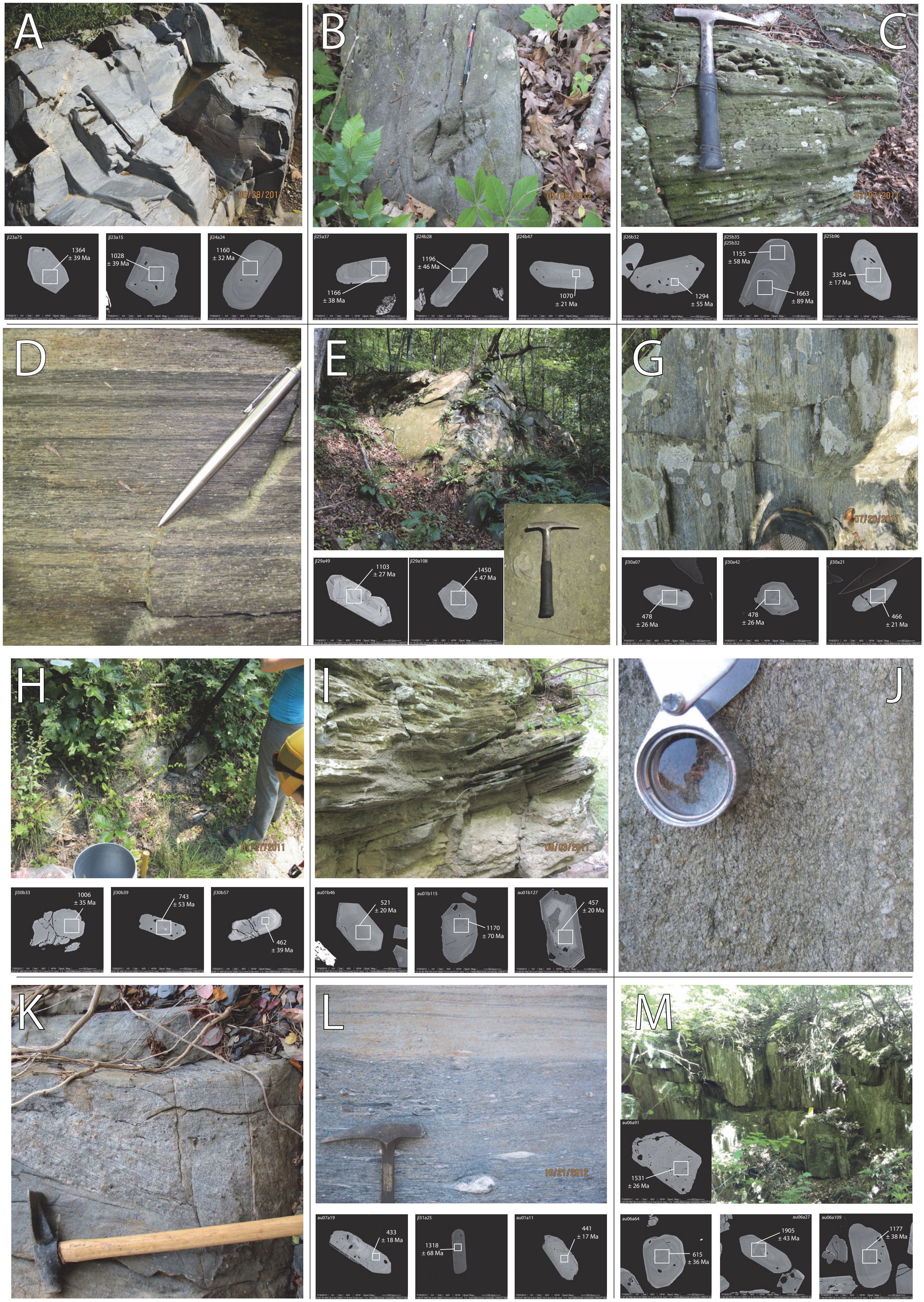
SAMPLES AND RESULTS

Of 13 samples, six are from the Potomac terrane, four are from the Chopawamsic terrane, two are from the Arvonia successor basin, and one sample is from a package of metasedimentary rocks near Storck, Virginia, formerly interpreted to be part of the successor basin system. Sample locations are shown in Figure 2 and photographs are shown in Figure 3. Histograms of the resultant data from each individual sample are shown in Figure 4. The results of all analyses, including discordant data not used in histograms, are reported in Table 2.1 of Appendix 2. A detailed explanation of results from individual samples is also included in Appendix 2 (see GC Data Repository website).

AGE AND PROVENANCE OF LITHOTECTONIC COMPONENTS IN THE WESTERN PIEDMONT OF VIRGINIA

From the 1,289 detrital zircon analyses conducted, we can make interpretations on the provenance of the selected samples and begin to understand any supra-crustal interactions during the time of deposition of these metasedimentary rocks. These interpretations are made with consideration of individual samples, combined data for each terrane (Fig. 5A, 5B), and regional geological relationships and rock compositions.

Figure 3. *(next page)* Field photos of selected detrital zircon samples and backscatter images of example detrital zircon grains. A. Site of sample KSH-11-01, hammer for scale is 30 cm long; B. Site of sample KSH-11-05, mechanical pencil for scale is 14 cm long; C. Site of sample KSH-11-08, hammer for scale is 30 cm long; D. Site of sample P310-4, pen for scale is 15 cm long; E. Site of sample KSH-11-18, hammer for scale in centre of photo is 30 cm long; G. Site of sample KSH-11-19, tip of boot for scale is 10 cm wide; H. Site of sample KSH-11-28 being extracted, manual jackhammer for scale is 4 cm across; I. Site of sample KSH-11-39 taken from upper beds in photo, ferns in upper right for scale; J. Site of sample KSH-12-70, hand lens for scale measures 2 cm across; K. Cross-bedding near sample BREMO, handle of geo-tool for scale measures 4 cm across; L. Bedding near sample KSH-11-BUF, head of hammer for scale measures 18 cm across; M. Site of sample KSH-11-40, yellow field notebook in centre-right for scale measures 12x19 cm. See Figure 2 for sample locations.


A
jl23a75
1364 ± 39 Ma
jl23a15
1028 ± 39 Ma
jl24a24
1160 ± 32 Ma
B
jl25a37
1166 ± 38 Ma
jl24b28
1196 ± 46 Ma
jl24b47
1070 ± 21 Ma
C
jl26b32
1294 ± 55 Ma
jl25b35
jl25b32
1155 ± 58 Ma
1663 ± 89 Ma
jl25b96
3354 ± 17 Ma
D
E
jl29a49
1103 ± 27 Ma
jl29a108
1450 ± 47 Ma
G
jl30a07
478 ± 26 Ma
jl30a42
478 ± 26 Ma
jl30a21
466 ± 21 Ma
H
jl30b33
1006 ± 35 Ma
jl30b39
743 ± 53 Ma
jl30b57
462 ± 39 Ma
I
au01b46
521 ± 20 Ma
au01b115
1170 ± 70 Ma
au01b127
457 ± 20 Ma
J
K
L
au07a19
433 ± 18 Ma
jl31a25
1318 ± 68 Ma
au01a11
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615 ± 36 Ma
au06a27
1905 ± 43 Ma
au06a109
1177 ± 38 Ma

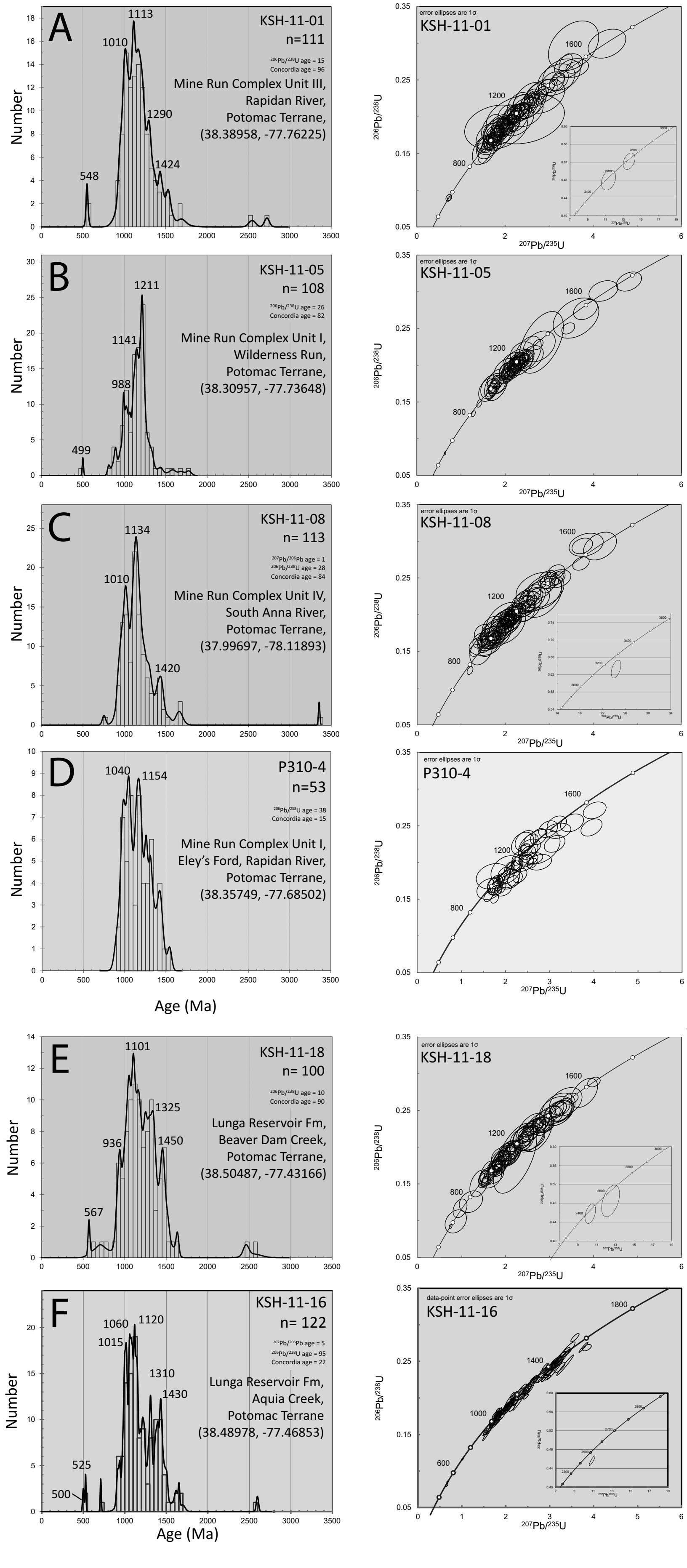

Figure 4. *(opposite and following page)* Histogram and concordia plots for detrital zircon samples. Thick black line in histogram plots represents the cumulative probability of detrital ages and was calculated using 2σ uncertainties for each analysis. Note that the x-axis in the histogram plots is the same but the y-axis scale varies. Some concordia plots include small inset plots to show analysis ellipses for older zircon grains analyzed. Concordia ellipses are drawn to the 1σ confidence level. See Figure 2 for sample locations.

Potomac Terrane

The majority of detrital zircon grains in samples from the Potomac terrane are Mesoproterozoic with peak modes at 1.015 Ga and 1.120 – 1.150 Ga. A cumulative histogram of statistically viable analyses (n=607) from the Potomac terrane (Fig. 5B) indicates that the ages present in these samples are consistent with Grenvillian (ca. 1.08 – 1.0 Ga), Adirondian (ca. 1.18 – 1.08 Ga), and, to a lesser extent, Elzeverian (ca. 1.23 – 1.18 Ga) and Elsonian (ca. 1.46 – 1.23 Ga) events in Laurentia (Gower and Krogh 2002). Some Tonian zircon grains present may be derived from Laurentian rift-related rocks (Karabinos and Aleinikoff 1990; Graybill 2012). Some of these ages are also consistent with ages reported from the Sunsas belt (ca. 1.25 – 0.9 Ga) of the Amazonian craton (Sadowski and Bettencourt 1996) but the distribution of detrital zircon ages can be considered with other geologic factors to deduce cratonic affinity. Among other regional relationships, interlayering between rocks of the Laurentian Blue Ridge province and those considered part of the Potomac terrane (Evans 1984) supports the Laurentian affinity for at least part of the Potomac terrane. The absence of zircon populations potentially derived from the Ventuari-Tapajos orogen (ca. 2.10 – 1.87 Ga) in Amazonia (Tassinari et al. 2000; Juliani et al. 2002) and the Brasiliano/Pan-African orogen (ca. 660 – 600 Ma) in the detrital record also favour a Laurentian, rather than a Gondwanan source for the Potomac terrane.

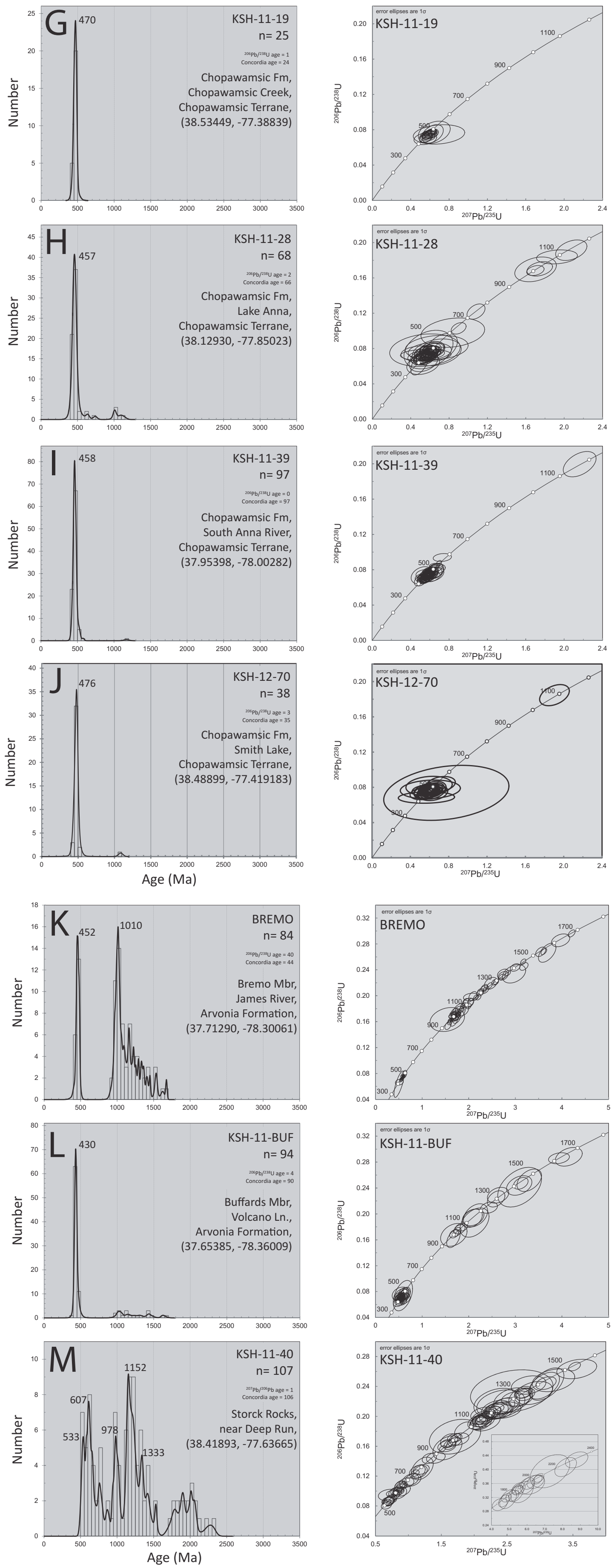

Figure 4. *(continued).*

With the caveat that the youngest detrital zircon grains in each sample may be significantly older than the depositional age (e.g. Moecher and Samson 2006), they do provide control for the depositional age of units within the Potomac terrane. The three youngest zircon grains in the Mine Run Complex have concordia ages (2σ) of 499 ± 15 Ma, 551 ± 19 Ma, and 554 ± 34 Ma. The youngest zircon grains present in the Lunga Reservoir Formation have concordia ages (2σ) of 502 ± 18 Ma, 527 ± 11 Ma, and 569 ± 21 Ma. The ca. 500 Ma grains from both units indicate that deposition in some sub-units of the Mine Run Complex and in the Lunga Reservoir Formation occurred after the Middle Cambrian. Cross-cutting Ordovician intrusions such as the Goldvein pluton (456 ± 9 Ma, Aleinikoff et al. 2002) and the Occoquan pluton (472 ± 4 Ma, Aleinikoff et al. 2002) place limits on the minimum possible age of deposition for the Potomac terrane. These data indicate that the youngest sampled units of the composite Potomac terrane were deposited in the Late Cambrian to Early Ordovician.

The Mine Run Complex and Lunga Reservoir portions of the Potomac terrane contain various sized blocks of debris that were formerly interpreted to be shed from the Chopawamsic volcanic arc (Pavlides 1989). Our samples, including those proximal to purported Chopawamsic-derived blocks, are all devoid of any zircon that would be consistent with a derivation from the Middle Ordovician volcanogenic Chopawamsic terrane. Thus the origin of these clasts, fragments, and map-scale bodies must be some previously unidentified source. A similar scenario exists in the Shores mélange complex at the James River; many of the blocks were considered to be derived from the Chopawamsic terrane (Bland and Blackburn 1979; Evans 1984; Brown 1986), however, no such statistically valid Ordovician zircon grains were identified in a metasedimentary sample from the Shores complex (Bailey et al. 2008). These observations and the range in

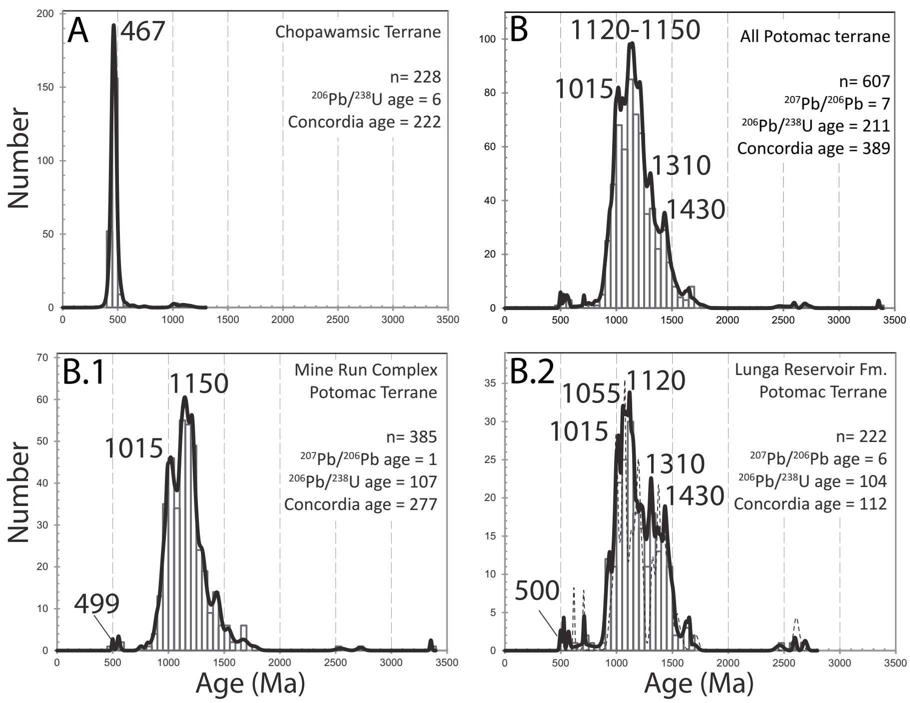

Figure 5. Compiled detrital zircon histogram plots. A. Data from 4 samples of the Chopawamsic formation. B. Data from 6 samples (including the Mine Run Complex and the Lunga Reservoir Formation) of the Potomac terrane. B.1. Data for only 4 samples of the Mine Run Complex. B.2. Data for only two samples of the Lunga Reservoir Formation. Dashed line is the probability curve from the Sykesville Formation (Horton et al. 2010). Note variations in the y-axis scales of the plots.

depositional age discussed above contradict the long-standing interpretation that parts of the Potomac terrane were deposited concurrent with Chopawamsic arc accretion to Laurentia (Pavlides 1989; Drake 1989; Pavlides et al. 1994; Hibbard et al. 2014). If any part of the Middle Ordovician Chopawamsic arc was a source for the Potomac terrane, such an influence was not recognized in any of the Potomac terrane samples analyzed in this study. It seems that the Chopawamsic arc did not feed any part of the Potomac terrane, parts of which were buried and intruded (e.g. at ca. 472 Ma by the Occoquan pluton) by the time of Chopawamsic arc activity (474–465 Ma).

Although secondary to the investigation of the relationship between the Chopawamsic and Potomac terranes, the composite nature of the Potomac terrane (see Kunk et al. 2005; Wintsch et al. 2010) must be addressed when assessing cratonic affinity. The Mine Run Complex consists of four sub-units; previous mapping (Pavlides 1989, 1990, 1995; Mixon et al. 2000; Hughes 2011) and our reconnaissance mapping suggests that the four sub-units are compositionally similar and, in some places, separated by gradational and conformable contacts (Hopkins 1960; Hughes 2011), rather than faults. Because Ediacaran – Cambrian zircon is not present in all samples of the Mine Run Complex analyzed, it remains possible that some portions were deposited earlier than others; however, due to the shared characteristics of the four sub-units, we tentatively apply the youngest detrital zircon ages present to the whole complex (Fig. 6). Pavlides (1989) considered slightly different source areas for the Mine Run Complex and Lunga Reservoir Formation based upon differences in sedimentary facies. Our detrital zircon data may reflect the compositional dissimilarity that could arise from distinct source areas. In particular, the Lunga Reservoir Formation has a larger proportion of 1.25 – 1.60 Ga zircons relative to the Mine Run Complex (see Fig. 5B.1 and 5B.2). The Sykesville Formation metadiamictite, a correlative to the Lunga Reservoir Formation in northern Virginia and Maryland, has a detrital zircon signature that is remarkably similar to the Lunga Reservoir Formation (Horton et al. 2010; Fig. 5B.2).

The likely Laurentian affinity for the Mine Run Complex, based upon its detrital signature and correlation to rocks interlayered with Laurentian strata is fully supported by our data. The Lunga Reservoir Formation also appears to be Laurentian-derived and we interpret that the slight differences between the detrital signatures of the two units may be a result of the Lunga Reservoir Formation being a more proximal sedimentary depocentre to its source area than the mature, well-sorted sediment of the Mine Run Complex. These coeval units appear to demonstrate the effect that hydraulic sorting, zircon fertility, and sedimentary dispersal paths can have on detrital zircon signatures (e.g. Moecher and Samson 2006; Thomas 2011) in dissimilar sedimentary rocks derived from similar source areas.

Chopawamsic Terrane

The 228 detrital zircon grains analyzed from samples of the Chopawamsic Formation are strongly unimodal. The peak mode occurs at ca. 467 Ma (Fig. 5A). Most analyses are identical to this value within 2σ analytical uncertainty. A population of seven Mesoproterozoic zircons (ca. 1.17 – 1.01 Ga) is ambiguous in terms of cratonic affinity. U–Pb zircon TIMS ages from magmatic rocks in the Chopawamsic arc span 474 – 465 Ma (Coler et al. 2000; Hughes et al. 2013b). The concurrence of coeval volcanic and detrital ages indicates that interlayered sedimentary lenses of the Chopawamsic Formation were derived almost exclusively from contemporaneous volcanic activity. In support of this conclusion, most detrital zircon grains in Chopawamsic samples retain an angular, unmodified crystal shape, which is indicative of short-lived sedimentary transport. Detrital systems dominated by syndepositional volcanism have been documented as the typical result of deposition within and along the margin of an active volcanic arc (Pollock et al. 2007; Cawood et al. 2012).

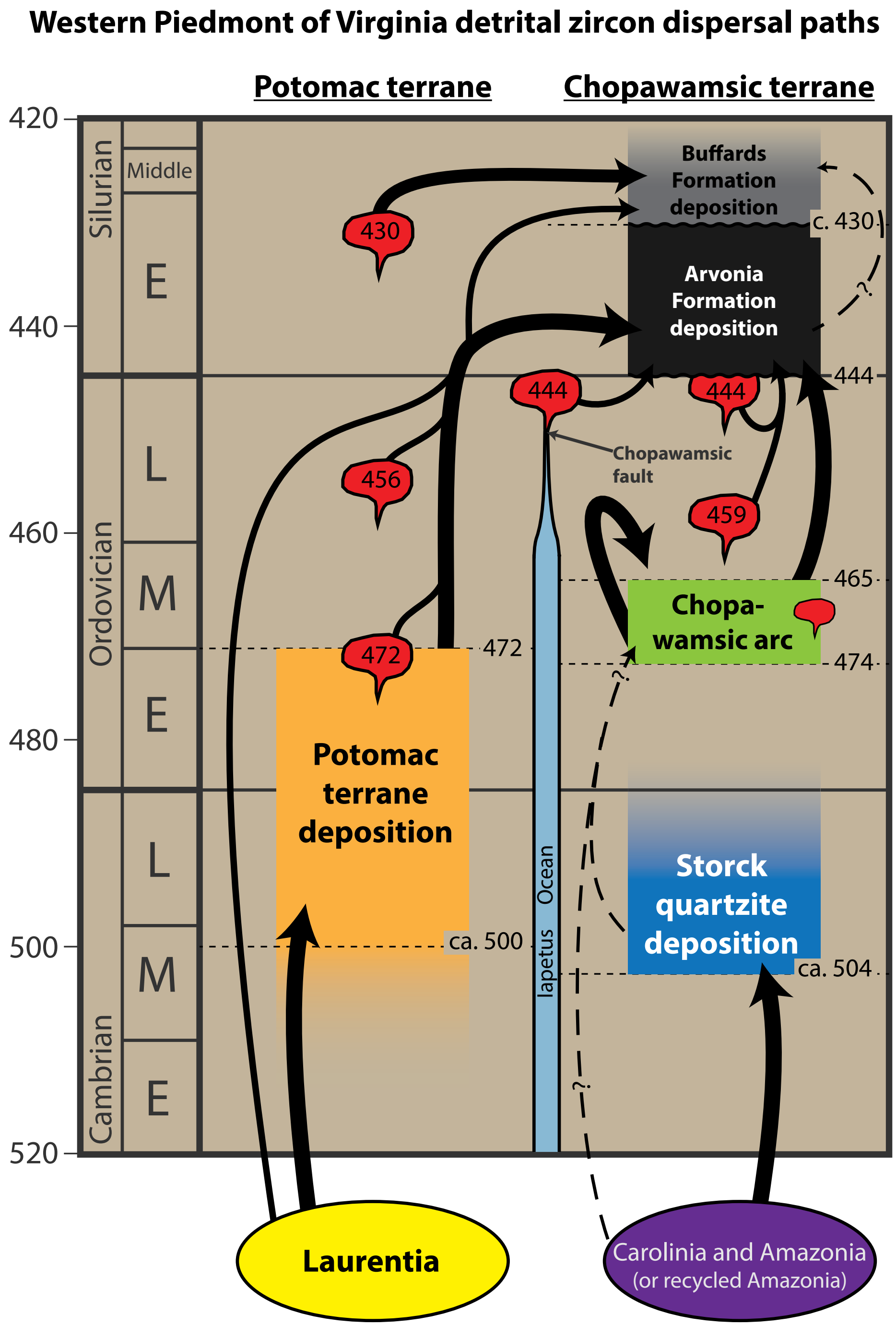

Figure 6. Timeline and potential sediment dispersal path figure as discussed in the text. Timescale is in millions of years. The Laurentian-derived Potomac terrane sedimentary rocks and peri-Gondwanan Storck and Chopawamsic rocks had no supra-crustal interaction until the accretion of the Chopawamsic arc, effectively closing the Iapetus Ocean sometime in the Late Ordovician. The Arvonia Formation was deposited unconformably over ca. 444 Ma granodiorite that is intrusive to the Chopawamsic terrane. The Arvonia and Buffards formations had access to both Chopawamsic and Potomac terrane debris when being deposited. Thickness of sedimentary dispersal arrows indicates the relative amount of detrital zircon input but isn't necessarily correlative with overall sedimentary input. Gradient shading for Storck quartzite and Buffards Formation indicates unknown minimum age of deposition. Gradient shading for the Potomac terrane indicates the possibility of some older, but still Laurentian, components within the composite Potomac terrane.

The 28 Cambrian and older detrital zircon grains represent sedimentary sources other than Chopawamsic magmatism, but little can be garnered in terms of cratonic affinity due to the overwhelming prominence of Ordovician ages. Isotopic studies have led other workers to propose that the Chopawamsic volcanics were built upon some form of Mesoproterozoic crust (Pavlides 1981; Coler et al 2000) but no known basement is exposed; for this reason, these Cambrian and older grains are important in characterizing such basement. Well constrained (concordia, 2σ uncertainties) Cambrian, Ediacaran, and Cryogenian ages include, among others, 510 ± 26 Ma, 512 ± 35 Ma, 521 ± 20 Ma, 537 ± 20 Ma, 575 ± 34 Ma, and 640 ± 43 Ma grains. Considered alone, 21 Cryogenian – Cambrian zircons are ambiguous in terms of cratonic affinity as they could potentially be attributed to peri-Gondwanan arc activity or Laurentian rift magmatism (e.g. ca. 570 Ma Catoctin and ca. 760 Ma Mount Rogers formations, Aleinikoff et al. 1995) related to the rifting of Rodinia, although many of the youngest Cambrian zircons in Chopawamsic samples are younger than the majority of Rodinian rift rocks and only coeval with the youngest rift-related rocks, which are geographically and volumetrically limited (ca. 532 Ma Mt. Rigaud and Chatham-Grenville stocks, McCausland et al. 2007). However, the Neoproterozoic – Cambrian population can be evaluated in conjunction with a general dearth of zircon potentially derived from the 1.08 – 1.0 Ga Grenville orogen (Gower and Krogh 2002) and the complete lack of any zircons related to post-Grenville Tonian rift rocks (Graybill 2012). The few Mesoproterozoic zircons present may be inherited from a source craton or recycled from metasedimentary rocks older than Chopawamsic magmatism, such as the Storck rocks (see discussion of Storck rocks below and Fig. 6).

Given the remarkable zircon fertility of some Mesoproterozoic magmatic provinces (Moecher and Samson 2006), the shortage of Mesoproterozoic zircon indicates that the Chopawamsic arc had no direct depositional or recycled access to Laurentian Mesoproterozoic and early Neoproterozoic source areas (as the Potomac terrane had). When considered with the shortage of Mesoproterozoic zircon and the youngest known Rodinian rift-related magmatic rocks, the presence of the population of Cambrian, Ediacaran, and Cryogenian zircon suggests that they are potentially derived from a source area that contains Cambrian, Ediacaran, Cryogenian, and Stenian rocks or one that consists of mostly Cambrian – Ediacaran units. Metasedimentary rocks in the peri-Gondwanan microcontinents of Carolinia (Pollock et al. 2010; Dennis et al. 2012) and Ganderia (Fyffe et al. 2009), and Ganderian-derived sedimentary rocks (Pollock et al. 2007) contain similar Cambrian, Ediacaran, and Cryogenian detrital zircons and generally lack ca. 1.2 – 1.0 Ga zircon. Cryogenian – Cambrian ages are also present in volcanic rocks of the Victoria Lake Supergroup of the peri-Gondwanan Penobscot Arc and its basement (Rogers et al. 2006; McNicoll et al. 2008; Zagorevski et al. 2010).

Arvonia Successor Basin and Storck Rocks

In contrast to previous sampling (Bailey et al. 2008), we found considerable Mesoproterozoic zircon within rocks of the Arvonia successor basin. This observation may be due to the stratigraphic position within the basin from which we sampled. While Bailey et al. (2008) sampled from basal units of the Arvonia and equivalent Quantico formations, we collected from stratigraphically higher portions in the Arvonia basin. It seems that basal units near an unconformable contact would likely contain considerable, if not complete, detrital contribution from the directly underlying Chopawamsic terrane. Because our samples are higher in the Arvonia section, they may well be better suited to evaluate any broader sedimentary source area for the successor basin system.

The Mesoproterozoic zircon grains present in the Bremo Member sample (Fig. 4K) of the Arvonia Formation are similar in age to those in the Mine Run Complex metasedimentary rocks (Fig. 5B). We interpret this similarity to reflect the recycling of detrital zircon from the Mine Run Complex and/or contribution from similar Laurentian source areas to the Arvonia basin (Fig. 6). The Paleozoic component of the Bremo Member detrital signature potentially represents a mixture of zircons from Chopawamsic arc activity (474 – 465 Ma) and post-Chopawamsic accretion magmatic activity (ca. 450 – 435 Ma) represented by intrusions such as the Ellisville pluton, Lahore pluton, Goldvein pluton, and Green Springs intrusive suite (Fig. 6). The bimodality of the detrital signature in the Bremo Member leads us to interpret that it was deposited with access to both Potomac and Chopawamsic sources, only after the Chopawamsic terrane was accreted to Laurentia in the Late Ordovician. This interpretation is consistent with the unconformable relationship of the Arvonia basin over granodiorite related to the ca. 444 Ma Ellisville pluton, which intruded both the Potomac and Chopawamsic terranes.

The Mesoproterozoic component of debris in the detrital signature of the Buffards Formation (Fig. 4L) of the Arvonia basin is muted compared to that in the Bremo Member, however, we interpret it to represent a similar recycling of debris from the metasedimentary Potomac terrane and/or direct contribution from Laurentia with possible recycling from the underlying Arvonia Formation below (Fig. 6). The unique ca. 430 Ma mode in the Buffards Formation data (Fig. 4L) appears to include analyses from some of the youngest zircon contributed to sampled metasedimentary rocks in the Arvonia basin and likely reflects a younger time of deposition than the Bremo Member sample. The Buffards Formation contains many volcanic clasts and this ca. 430 Ma age may represent the crystallization age of some of the volcanic rocks that produced these clasts. No volcanic rocks younger than ca. 450 Ma exist in the area but there are ca. 430 – 450 Ma intrusive rocks to the northwest in the Potomac terrane (Buckingham complex, Diana Mills body, Green Springs intrusive suite; Wilson 2001). Consistent with the Silurian plutonic bodies to the northwest, Brown (1969) interpreted the sedimentary source area for the Buffards Formation to be to the northwest. The overwhelming presence of Silurian grains in the Buffards Formation, but not in the Bremo Member of the Arvonia Formation, suggests (but doesn't prove) that the Buffards Formation is the younger of the two. The detrital zircon data presented here supports the model of Brown (1969), who proposed that the Buffards Formation is younger than and lies unconformably above the Arvonia Formation, rather than the alternate interpretation of Stose and Stose (1948).

In a regional perspective, the results of our analyses from the Arvonia basin are somewhat similar to reported detrital ages from the migmatitic Cat Square terrane in Georgia and North and South Carolinas (Fig. 7; Bream et al. 2004; Merschat et al. 2010). Like the Arvonia metasedimentary rocks, the Cat Square basin includes populations of Mesoproterozoic – Tonian debris with supplementary Ordovician – Silurian zircon that are interpreted to be detrital, rather than metamorphic. The purported Paleozoic detrital zircon from the Cat Square system indicates that it and the Arvonia/Quantico system could have been deposited coevally. However, in contrast to those studies, the Arvonia system data include considerably more Ordovician – Silurian zircon and do not include any zircon that is Ediacaran or any older than 1.7 Ga. With the limited data on hand, it is possible that the Arvonia/Quantico and the Cat Square systems may have had some shared source areas, but it seems they were not derived from identical regions.

The detrital zircon results from the Storck micaceous quartzite (Fig. 4M) are the most intriguing of this study, for these rocks contain a detrital signature dissimilar from the Potomac terrane, the Chopawamsic Formation, and the Arvonia successor basin system. The Storck sample contains considerable Cryogenian – Cambrian (ca. 800 – 500 Ma) material that is common in peri-Gondwanan terranes; the sample also contains a significant population of Paleoproterozoic (2.1 – 1.7 Ga) zircon not seen in any of the Laurentian-derived Potomac terrane metasedimentary rocks sampled in this study. Furthermore, the universal Stenian (1.1 – 1.0 Ga) zircon grains found in Grenville-related Laurentian sedimentary rocks are not prominent

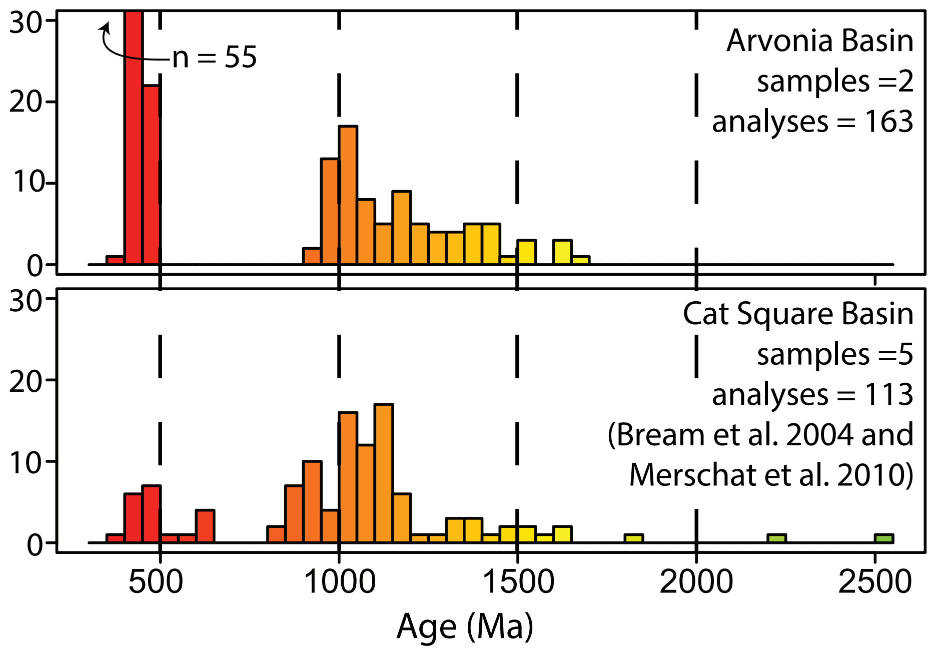

Figure 7. Histogram comparison of $^{206}Pb/^{238}U$ zircon ages from samples of the Arvonia and Cat Square basins. Data from this study and those of Bream et al. (2004) and Merschat et al. (2010) are only included for analyses with Th/U > 0.1 and when the $^{206}Pb/^{238}U$ age is ± 15% concordant with a corresponding $^{207}Pb/^{206}Pb$ age.

in the Storck sample. These important observations all suggest a peri-Gondwanan source for the Storck rocks. Because Middle Ordovician zircon potentially derived from the Chopawamsic arc (474 – 465 Ma) is also absent, we consider the Storck rocks to represent a tectonic sliver not derived from the Chopawamsic magmatic rocks. This observation may indicate that considerable tectonic telescoping of potential intra-Iapetan terranes occurred during the Chopawamsic accretion to Laurentia; alternatively, the Storck rocks could be an older, deeper part of the Chopawamsic terrane that was deposited before Middle Ordovician Chopawamsic arc magmatism initiated.

On the basis of the youngest zircon grains present in the sample (ca. 504 Ma), it appears that the Storck metasedimentary rocks may have been deposited coevally with the sampled Potomac terrane metasedimentary rocks, but were deriving sediment from a non-Laurentian source (Fig. 6). Neoproterozoic to Early Cambrian detrital zircon grains in the Storck sample are consistent with derivation from the peri-Gondwanan microcontinent of Carolinia which includes potential detrital zircon sources of the Virgilina (630 – 610 Ma; Samson et al. 1995; Wortman et al. 2000) and Albemarle (575 – 532 Ma; Hibbard et al. 2002) magmatic sequences. Furthermore, the Neoproterozoic to Early Cambrian population present in the Storck sample is similar to the detrital signature observed in metasedimentary samples from Carolinia (Pollock et al. 2010). Paleoproterozoic zircon in the Storck sample may have originally formed in magmatic events related to Amazonia in the Ventuari–Tapajos (ca. 2.10 – 1.87 Ga; Tassinari et al. 2000; Juliani et al. 2002) and parts of the Rio Negro–Juruena (ca. 1.80 – 1.75 Ga; Geraldes et al. 2001) orogens.

The lack of Ordovician – Silurian zircon and absence of a dominant population of Stenian grains, among lithological differences, indicates that the Storck rocks are not related to the Arvonia/Quantico system. Potential correlatives of the Storck rocks include the Shores mélange (Fig. 8; Bailey et al. 2008), along strike to the south at the James River and other enigmatic peri-Gondwanan derived metasedimentary rocks to the north (Bosbyshell et al. 2013; Martin et al. 2013; MacDonald et al. 2014). Specifically, both the Storck and Shores metasedimentary rock units lie just west of the main Chopawamsic fault and may represent semi-continuous, poorly exposed fragments of peri-Gondwanan metasedimentary rock that lie beneath the Chopawamsic arc or once existed between the Chopawamsic and Potomac terranes. Regardless of the connection to the Shores mélange or any other units, a peri-Gondwanan source for the Storck rocks is important for determining the affinity of the Chopawamsic terrane. Because they are bounded by the Late Ordovician Chopawamsic fault system, it is unlikely that the Storck rocks have been tectonically shuffled along the Chopawamsic–Potomac terrane interface during later Paleozoic deformational events; therefore, the current relative position of the Storck rocks to the Chopawamsic arc likely reflects their original paleogeographic configuration prior to the Late Ordovician.

DISCUSSION

The detrital zircon data presented here and regional geologic relationships indicate that the sedimentary packages of the Potomac terrane were most likely derived from a Laurentian source area. Contrary to previous models for the Virginia Piedmont (e.g. Pavlides 1989; Pavlides et al. 1994), the detrital zircon data show that Chopawamsic arc volcanic rocks were not a source for the Potomac terrane metasedimentary rocks. The lack of any Ordovician detrital zircon in the sampled metasedimentary rocks of the Potomac terrane and the presence of Middle Ordovician intrusive bodies in the Potomac terrane are consistent with a model wherein the Potomac terrane sediment was already deposited, buried, and intruded by the time the Chopawamsic arc was active (474 – 465 Ma; Fig. 6). With these observations in mind, we propose that the Potomac terrane is unrelated to the Middle Ordovician Chopawamsic arc. Additionally, there is no direct evidence for any older arc that could be related to the Potomac terrane metasedimentary rocks.

Detrital zircon data for the Chopawamsic Formation show that the main source for Chopawamsic sedimentary rocks was coeval Chopawamsic magmatic rocks. Limited Neopro-

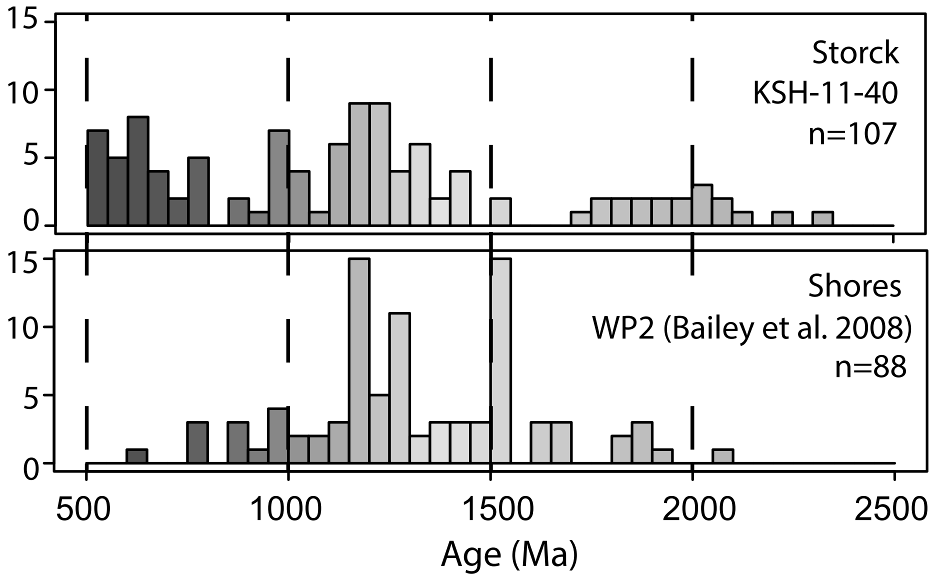

Figure 8. Histogram comparison of concordant detrital zircon ages from the Storck rocks and the Shores mélange (Bailey et al. 2008).

terozoic and Mesoproterozoic grains in samples of the Chopawamsic metasedimentary rocks hint at a possible peri-Gondwanan source area; they are also consistent with the possibility that there is an older basement to the Chopawamsic arc, as concluded by previous workers (e.g. Pavlides et al. 1994; Coler et al. 2000). The Storck metasedimentary unit lies between the Chopawamsic and Potomac terranes for at least 10 km along strike and includes a peri-Gondwanan detrital zircon signature. The position of the Storck rocks, considered in conjunction with older detrital zircon in the Chopawamsic Formation, provides circumstantial evidence to suggest that the Chopawamsic terrane is also peri-Gondwanan. The Storck rocks and other peculiar units along strike, including the Shores mélange, highlight the potential tectonic telescoping of intra-Iapetan terranes that may have occurred between the Chopawamsic and Potomac terranes. Similar to the Storck rocks, the Moretown Formation in Vermont and Massachusetts sampled a peri-Gondwanan source area and is associated with an Ordovician volcanic arc (Shelburne Falls arc) that accreted to Laurentia in the Ordovician (MacDonald et al. 2014). Furthermore, both the Moretown Formation and Chopawamsic arc sutures with Laurentian rocks were intruded by post-accretion plutons (Middlefield and Ellisville bodies) at 445 – 444 Ma (Hughes et al. 2013a; MacDonald et al. 2014).

New data from the Arvonia successor basin suggests that it was deposited with access to both recycled Potomac terrane and Chopawamsic terrane detritus after the Late Ordovician accretion of the Chopawamsic terrane to Laurentia (Fig. 6). This conclusion is supported by the unconformable relationship of the Arvonia basin over granodiorite related to the latest Ordovician Ellisville pluton, which stitches the Potomac and Chopawamsic terranes. Also in support of this conclusion, Nd isotope analyses by Owens et al. (2013) showed that rocks of the Arvonia Formation are most like sedimentary rocks in the Appalachians deposited after ca. 450 Ma (Late Ordovician). The youngest zircon grains in the Buffards Formation of the Arvonia basin indicate that sedimentation in the Arvonia basin continued until at least ca. 430 Ma and may reflect syndepositional magmatic activity.

SUMMARY AND CONCLUSION

Our new data lead to the following main conclusions concerning the tectonic development for Cambrian – Silurian metasedimentary rocks of the western Piedmont of north-central Virginia:

1. The youngest sampled units of the composite Potomac terrane metasedimentary rocks were most likely deposited along the margin of Laurentia sometime between ca. 500 – 470 Ma and most importantly were not derived from the Middle Ordovician Chopawamsic Formation.
2. The Storck metasedimentary rocks were deposited sometime after ca. 500 Ma and tapped a peri-Gondwanan source area. Their geographic position suggests a peri-Gondwanan affinity for the Chopawamsic arc.
3. Chopawamsic Formation sedimentary rocks were mostly derived from Chopawamsic terrane magmatic rocks during the Middle Ordovician (ca. 467 Ma). The oldest grains in these samples are not suitable for asserting Mesoproterozoic cratonic affinity, but the presence of Cryogenian – Cambrian grains and the general dearth of Mesoproterozoic zircon are consistent with a peri-Gondwanan source.
4. The Arvonia basin was only deposited after the Chopawamsic terrane accreted to Laurentia in the Late Ordovician and it derived sediment from both the Potomac and Chopawamsic terranes in addition to ca. 430 Ma magmatic rocks.

The Chopawamsic fault marks the main boundary between the Potomac and Chopawamsic terranes. We favour a peri-Gondwanan affinity for the Chopawamsic arc based upon the lack of data to tie it to Laurentia, its structural position above and outboard of peri-Gondwanan derived metasedimentary rocks (the Storck rocks), and Neoproterozoic – Cambrian zircons recovered from metasedimentary samples of the Chopawamsic Formation and Storck quartzite that are potentially derived from older peri-Gondwanan rocks. Because the Chopawamsic arc is interpreted as peri-Gondwanan, we advocate that the Late Ordovician Chopawamsic fault system demarcates the main Iapetan suture in the southern Appalachian orogen. A latest Middle to Late Ordovician Iapetan closure in the southern Appalachian orogen discussed here and illustrated by Hughes et al. (2014) is analogous to models proposed in the northern Appalachians (e.g. Zagorevski and van Staal 2011, and references therein; MacDonald et al. 2014). The results of the current detrital zircon study are limited to supra-crustal interactions that can be subject to the variability of sedimentary dispersal system dynamics. To fully evaluate the Chopawamsic fault as the main Iapetan suture in the southern Appalachians, future research will focus upon assessing and refining any intra-crustal relationships among terranes in the western Piedmont that can be deduced with Nd, Pb, and Hf isotopic analyses as well as whole rock geochemistry and supporting high-precision zircon crystallization ages.

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