ABSTRACT

TERBLANCHE, ALET, A. Geology of the Wilderness Area, VA: Evaluation of a Purported Paleozoic Successor Basin. (Under the direction of committee chair James Hibbard.)

Rocks referred to herein as the Wilderness rocks were previously mapped as a synclinal successor basin on top of the Chopawamsic fault, a fundamental structure that separates probable Laurentian rocks of the Potomac terrane from rocks of unknown crustal affinity of the Chopawamsic arc. The fault has been considered a candidate for the main Iapetus suture in the southern Appalachians. Clearly, if the Wilderness rocks were deposited atop the Chopawamsic fault, they provide the potential to place constraints on the timing of significant motion on the fault. The interpretation that the Wilderness rocks represent a successor basin atop the fault was predicated on reconnaissance (1:1000 000 scale) geological mapping and potential field data (Mixon, et al., 2000), with little solid evidence given for this interpretation. This study employs detailed, 1: 24,000 scale, mapping with the goals of i) determining the relationship between Wilderness rocks with surrounding units in order to evaluate the interpretation of a successor basin, ii) identifying potential sampling sites for geochronological studies, and iii) making new observations on the Chopawamsic fault.

Although contacts between the Wilderness rocks and the surrounding units are not exposed, sufficient circumstantial evidence in the form of lithology, petrology, mineral content, age, structure, metamorphism, and geophysical and geomorphic expression to allow for an evaluation of the successor basin interpretation.

Geologic mapping identified two distinct rock types within the Wilderness rocks that

were each identical to rocks on either side of the purported basin. Mine Run Complex or Chopawamsic Formation rocks. The one rock type at the northern end of the 'basin', phyllite consisting of quartz and feldspar grains in a biotite, muscovite, and chlorite matrix, is identical to rocks in the Mine Run Complex in the Potomac terrane. In contrast, the second type, which forms the bulk of the Wilderness rocks, consists of saprolitic sequences of metamudstones to metasandstones and volcaniclastics. Features of a synclinal basin were not observed, nor do they exhibit simpler structure than the surrounding rock units. Available age constraints indicate that the Wilderness rocks are either older or coeval with surrounding rock units. Based on these lines of circumstantial evidence, this study reveals a new interpretation of the geology of the Wilderness area in Virginia in which the Wilderness rocks do not represent a unique rock unit, but can be assigned to existing units within the Potomac and Chopawamsic terranes. This interpretation implies that the Chopawamsic fault, although unexposed, lies at the west side of the Wilderness rocks. This study also provides geological context for a detrital zircon sample of the Wilderness rocks that was analyzed by Dr. Jeff Pollock from Mount Royal University in Alberta, Canada.

Geology of the Wilderness Area, VA: Evaluation of a Purported Paleozoic Successor Basin

by
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A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Master of Science

Marine, Earth and Atmospheric Sciences

Raleigh, North Carolina

2013

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DEDICATION

This thesis is dedicated to my husband, Jonathan Whittington.

BIOGRAPHY

The author was born in Paarl, South Africa, on April 2, 1986, and grew up in the small coastal town of Great Brak River. As a teenager she moved westward to Hermanus, an old fishing village bound by the Atlantic Ocean to the south and mountains to the north.

In the summer of 2007 the author graduated with a BSc degree, and 2008 with an Honours degree, in Geology at the University of Stellenbosch, South Africa, after which she became an exploration geologist, searching for manganese in the Kalahari Desert in northern South Africa. She became interested in pursuing a Master's degree and found herself intrigued with North American, specifically Appalachian, geology. It was in 2010 that the author enrolled in a Master's program in geology under the direction of Dr. James Hibbard where she concentrated on structural geology, tectonics, and Geographical Information Systems. Upon the completion of her Master of Science degree at North Carolina State University she hopes to further pursue her career in structural geology and mapping.

ACKNOWLEDGEMENTS

I would like to thank Dr. James Hibbard, Dr. Helena Mitasova, Dr. Delwayne Bohnenstiehl, and Dr. Karl Wegmann for their participation on my advisory committee and for teaching me more about geology and GIS. I would especially like to thank Dr. James Hibbard, chief advisor of my thesis committee, for his advice, constructive criticism, patience, and for giving me the opportunity to be a part of his research project. I am also grateful to my fellow graduate students, Stephen Hughes and Dillon Nance in particular, for their friendship and discussions regarding my thesis. I would also like to extend my deepest thanks to God, my field assistants, and my family and friends near and far for their love and support. Special thanks also to my husband for all his love, patience, and encouragement during my career as a student and for being my field assistant on weekends.

Funding for this project was provided by the National Science Foundation, NSF grant number EAR-1048476 to Dr. James Hibbard.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Motivation For This Study

This study was undertaken to evaluate the geology of rocks in the area of Wilderness, Virginia (Figure 1 Figure 2) that were previously interpreted to represent a successor basin on top of the Chopawamsic fault (Pavlides, 1990), the most significant structure in the Western Piedmont of Virginia (Hibbard et al., 2013). These rocks are herein termed the 'Wilderness rocks'. Clearly, if the Wilderness rocks were deposited atop the Chopawamsic fault, they provide the potential to place constraints on the timing of significant motion on the fault. However, the interpretation that the Wilderness rocks represent a successor basin atop the fault was predicated on reconnaissance (1:000000 scale) geological mapping and potential field data (Mixon, et al., 2000), with little solid evidence given for this interpretation. This study employs detailed, 1: 24,000 scale, mapping with the goals of i) determining the relationship between Wilderness rocks with surrounding units, ii) identifying potential sampling sites for geochronological studies, and iii) making new observations on the Chopawamsic fault. Determining the relationship between the Wilderness rocks and surrounding rock units will allow for the assessment of the previous interpretation that they form a successor basin. This study will therefore also give evidence for the difference between the previous mapped geology in Figure 1 and my interpretation of the geology in Figure 4 (as well as the Geologic Map attached at the end of the document). Identification of appropriate rocks for sampling and future geochronological studies will be a step towards placing age constraints on the Chopawamsic fault. Also, mapping during this study is anticipated to provide geologic context for a sample of Wilderness rocks, collected near Ely's Ford for detrital zircon geochronological analysis by Jeff Pollock from Mount Royal University in Calgary, Alberta. Finally, new observations on the Chopawamsic fault may provide kinematic data, which to date have been sparse for the fault.

The Wilderness rocks were previously assigned to a northeast-trending, synclinal basin (Pavlides, 1990). The purported basin lies roughly 11 km west of Fredericksburg and is approximately 12 km in strike length by approximately 3 km wide. Basin rocks were previously mapped as undivided metasedimentary rocks composed of mainly phyllite, metasiltstones, and quartzite, lying unconformably on rocks of the Potomac terrane, to the east, and Chopawamsic terrane, to the west and overlapping their mutual contact, the Chopawamsic fault (Pavlides, 1995).

This timely study is part of a broader project aimed at determining the kinematics, timing, and the tectonic significance of the Chopawamsic fault. The fault separates Paleozoic accretionary complex rocks of the Potomac terrane along the eastern flank of Laurentia from Ordovician rocks of the Chopawamsic volcanic arc that has unknown crustal affinity. Considering its timing and spatial positioning, the fault may well represent the Main Iapetus Suture (MIS) and thus, the boundary between Laurentian and peri-Gondwanan crustal blocks in the south-central U.S. Appalachians (Hibbard et al., 2007, 2013). The broader project involves PhD candidate Stephen Hughes, MS candidate Dillon Nance, and advisor, James Hibbard.

Regional Setting

This study focuses on the Wilderness rocks in the western Piedmont of northern Virginia (Figure 1). The area consists of three major lithotectonic units that all trend NNE. The western-most unit is part of the metaclastic-dominated Potomac terrane, the central unit, herein named the Wilderness rocks (previously mapped as a successor basin) and the eastern most, the Chopawamsic arc; the Chopawamsic fault separates the Potomac terrane from the Chopawamsic magmatic arc (Hibbard et al., 2013). The Wilderness rocks were thought to be correlative with the more extensive, Late Ordovician Quantico and Arvonia successor basins atop the Chopawamsic arc (Pavlides, 1995)(Figure 1). In the area of study, all rocks are metamorphosed to greenschist facies and exhibit at least one penetrative fabric. In addition, all terranes are intruded by numerous plutons.

The Potomac terrane in this area consist of metaclastic mélanges, named the Mine Run Complex (Pavlides, 1989). The complex contains blocks of volcanic, plutonic and metaclastic rocks within a metaclastic matrix and has been interpreted to represent an early Paleozoic accretionary complex (e.g. Drake, 1989; Pavlides, 1989; Horton et al., 1989). The complex has been subdivided into four units, Mine Run I – IV, based on their distinct magnetic signatures and lithological differences (Pavlides, 1989; 1990). These units have been interpreted to be separated from each other by thrust faults, for which there is little physical evidence (Pavlides, 1989; 1990). The eastern most unit, Mine Run I , is adjacent to the Wilderness rocks under investigation. The complex is intruded by plutons that range in age from 472±4 Ma (Occoquan Granite; Aleinikoff et al., 2002) to 444±12 Ma (Ellisville granodiorite; Wilson, 2001); thus, the mélange rocks are Ordovician or older.

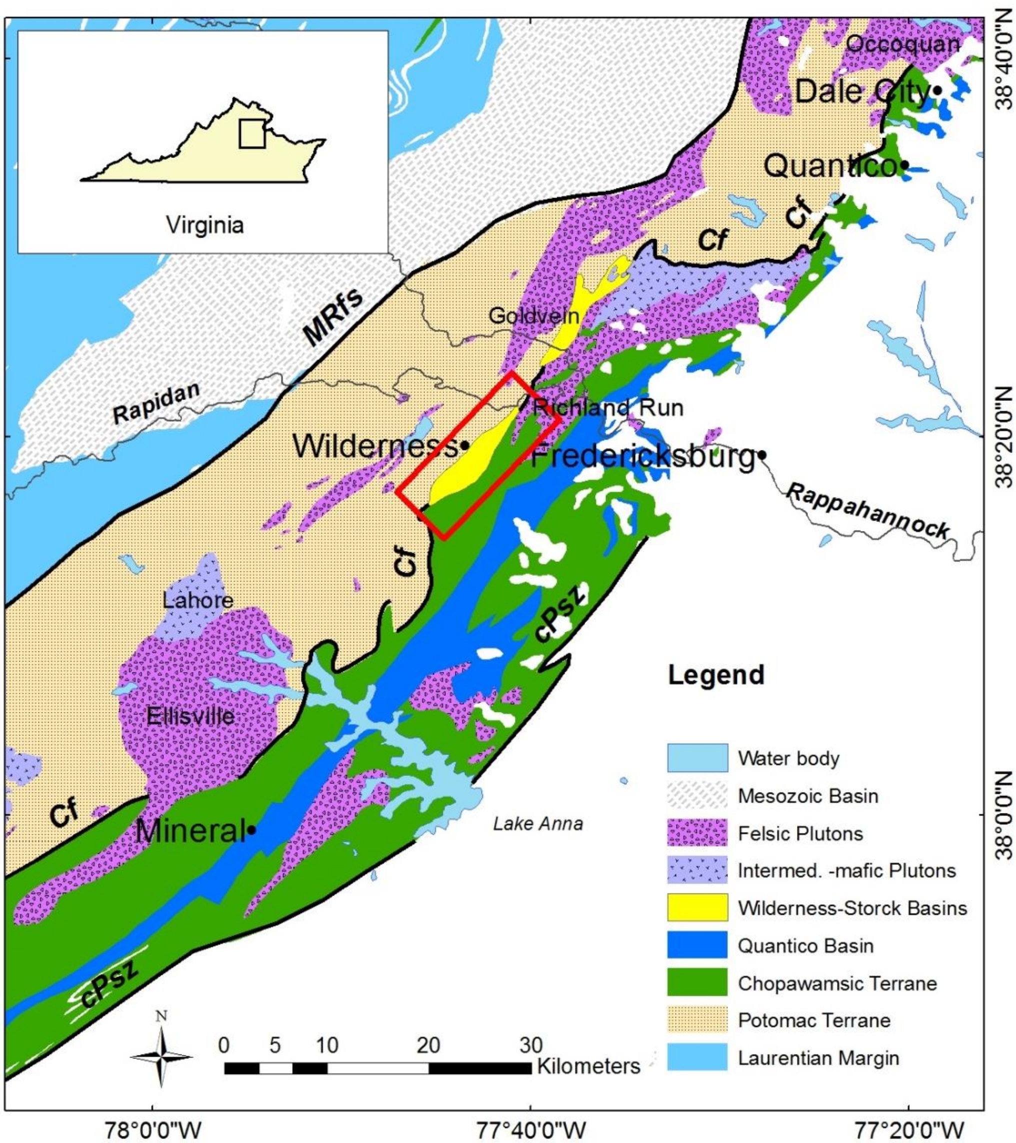

Figure 1: Geology of the western Piedmont of Virginia. Red box delineates focus area for detailed study (Wilderness area). Chopawamsic fault (Cf) as mapped by Hughes (Hughes, 2010), MRfs = Mountain run fault system, cPsz = central Piedmont shear zone, geology modified from Mixon, et al., 2000.

Though there is no known basement to the Potomac terrane, it is considered to be of Laurentian affinity on the basis of depositional layering with known Laurentian strata (Evans, 1984), its close proximity to Laurentian rocks directly to the west (Drake, 1989; Pavlides, 1989), and detrital zircon data from correlative rocks in Virginia (Carter et al., 2006; Bailey et al., 2008) and Maryland (Horton et al., 2010).

The Chopawamsic terrane is a magmatic arc named after the Chopawamsic Formation, the most prominent component of the arc terrane; the terrane also includes the Ta River Metamorphic Suite along its eastern side as well as numerous plutons. The Chopawamsic Formation consists of volcaniclastic rocks as well as felsic, intermediate, and mafic metavolcanics (Southwick et al., 1971; Pavlides, 1981). Volcanic rocks of the terrane show geochemical characteristics of a suprasubduction zone, magmatic arc setting and on the basis of U-Pb zircon dating, range in age from 471 Ma in the south to 453 Ma in the north of the arc (Pavlides, 1981; Coler et al., 2000; Horton et al., 2010). The crustal affinity of the Chopawamsic arc remains unclear, as evidence for its depositional basement is limited. However, isotopic and geochronological data of the arc exhibit evidence of formation above a basement with a component of Mesoproterozoic continental crust (Pavlides et al., 1982; Swinden et al., 1988; Coler et al., 2000). Mesoproterozoic basement is typical of eastern Laurentia, but it is also known to underlie some peri-Gondwanan terranes in the northern Appalachians (van Staal et al., 1996). Thus, the continental affinity of the Chopawamsic terrane remains ambiguous (Hibbard et al., 2013).

There are three successor basins in contact with the Chopawamsic arc in north-central Virginia. The largest is the Quantico successor basin which forms a narrow belt of mainly gray-black slate, phyllite, tuff, and quartzite, assigned to the Quantico Formation that unconformably overlies the Chopawamsic terrane (Pavlides, 1980, 1981) (Figure 1). The age of the Quantico rocks is constrained by both radiometric age dating and by fossils. A felsic tuff near the base of the Quantico Formation has yielded a U-Pb zircon age of 451+6 Ma (Horton et al., 1989). In addition, the formation nonconformably overlies the Dale City pluton, which has given a U-Pb zircon age of 459+4 Ma (Aleinikoff et al., 2002); these ages indicate that deposition of the formation started in the Late Ordovician and are consistent with reports of Late Ordovician fossils from the unit (Pavlides et al., 1980). Deposition could have continued well into the Devonian, based on unpublished detrital zircon data (Bailey et al., 2008). The two smaller successor basins, one in the Wilderness area and the other surrounding Storck, VA, have not been closely investigated in previous work; it is the one near Wilderness, VA (red box in Figure 1) that is examined in this study, while the basin near Storck, VA is being studied by another member of the study group in the broader, regional project. These basins were mapped as overlapping the Potomac and Chopawamsic terranes and overlying the Chopawamsic fault. A better understanding of these key features close to the Chopawamsic fault will help in delineating the tectonic history of the Western Piedmont of Virginia, the aim of the larger study group.

Previous Work

Based on relatively recent reconnaissance work, Wilderness rocks were interpreted to form a synclinal sedimentary basin that is in stratigraphic contact with both Mine Run I rocks and the Chopawamsic Formation, and that overlies the Chopawamsic fault (Pavlides, 1990). Prior to that study, the area was never closely investigated, and was either labeled as quartz-mica-schist (Neuschel, 1970), or Potomac terrane mélange rocks (Pavlides, 1989). Pavlides (1990) initially mapped the Wilderness rocks as Ordovician, undivided metasedimentary rocks that comprised mica-schist, metasiltstones, phyllite, greywacke and fine-grained quartzite layers. These "layers" were never described in further detail, but were later interpreted to form a basin, considered to be penecontemporaneous with the Quantico Formation (Pavlides, et al., 1995). The 'Wilderness basin' was interpreted to have developed after the Chopawamsic arc terrane had been deformed and when movement on the Chopawamsic fault had ceased. The latest document, in which this area is mapped, is the 1:100 000 open file report "Geologic map of the Fredericksburg 30'x60' Quadrangle, Virginia and Maryland" (Mixon, et al., 2000), which incorporates Pavlides'(1989, 1990, 1995) studies.

Interpretation of the Wilderness rocks as a successor basin (Pavlides, 1990; Mixon et al., 2000) appears to have relied heavily on airborne geophysical studies done in the 1960's because the present study demonstrates that few outcrops exist in the area of the purported contacts. This influence is evident in the magnetic contour map of Neuschel (1970), where the eastern boundary of the Wilderness rocks closely mimics the boundary between closely spaced magnetic contours to the east and widely spaced contours to the west (Figure 2). I.e. high magnetic signature to the east, which is characteristic of some lenses of Chopawamsic rocks (Pavlides, et al., 1982; personal field observations), and low magnetic signature to the west, generally characteristic of Mine Run I rocks. Thus, at the outset of this study, the most compelling evidence for a 'Wilderness basin' atop the Chopawamsic fault, appears to have been the interpretation of aeromagnetic data.

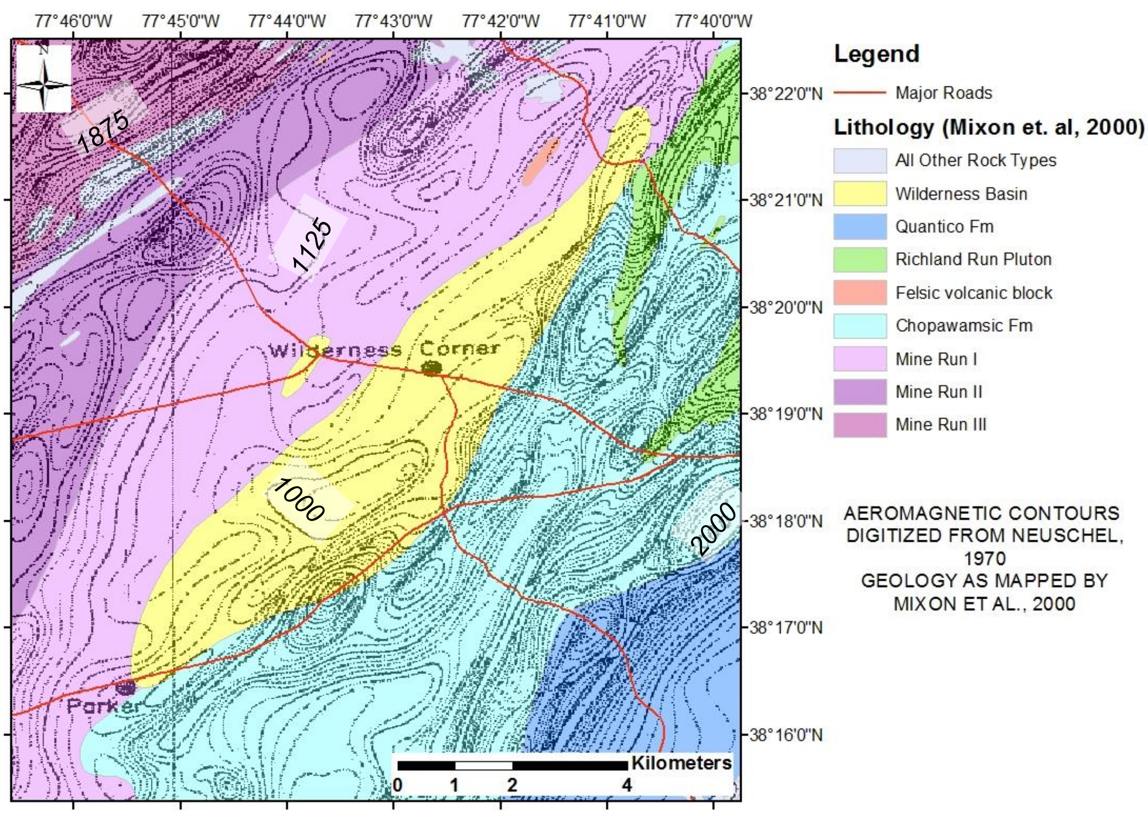

Figure 2: Aeromagnetic contours showing remnant intensity magnetic field of the earth in gammas, relative to arbitrary datum. Contour interval is 25 gammas, based on half-mile spaced; east-west flight lines 500ft above ground. Sources: Neuschel, 1970; Mixon et al., 2000.

Location and methods

The study area constitutes the Wilderness rocks and its peripheries, which includes the Mine Run I rocks to the west and rocks of the Chopawamsic Formation to the east. Bedrock outcrop was limited throughout the area and saprolite was studied where present. The study area is approximately 100km^2 in size in the vicinity of Wilderness, VA , 11km west of Fredericksburg, Virginia [77°40’ - 77°46’ West; 38°16’ - 38°22’ North]. The topography of the Wilderness area consists of rolling hills where the eastern edge of the area is on a ridge and the western extent lies in the valley of the Wilderness Run.

Geological Mapping:

Detailed bedrock geological mapping was completed at a scale of 1:24000. Traverses were mostly made along streams and creeks and a total of 60 field days were spent mapping in the summer of 2011. Approximately 140 hand samples were collected of which, thirty-five oriented samples were analyzed in thin section, and eleven for X-ray diffraction analysis.

Global Positioning System (GPS) and Geographical Information Systems (GIS):

Field stations were logged using a Magellan Triton recreational GPS (accuracy 5-10m) and maps were compiled by utilizing ArcGIS 10 and GRASS 6.4.2, with data obtained from the University of Virginia Library and the USGS Map Database. Extraction of watershed and stream development from digital elevation models (DEM) aided in the understanding of different weathering patterns in the Wilderness area. DEMs had a resolution of 10m. The horizontal datum is the North American Datum of 1983 (NAD83) and the vertical datum is National Geodetic Vertical Datum of 1929 (NGVD29). The land cover raster sets were obtained from the USGS Seamless server and was in Albers conformal conic projection, NAD83 with a 30m resolution. All vector data is in Geographic coordinate system, and NAD83.

X-Ray Diffraction:

A pilot X-ray diffraction (XRD) study was implemented with the aim of distinguishing between different sheet silicates, which were petrographically indistinguishable because of their fine grain size. This method was successfully employed by Milici, 1966 to distinguish between different phyllite units in the area of the Mountain Run fault system in central Virginia (Milici, et al., 1966).   Samples from the different units were carefully chosen and powdered with mortar and pestle and sifted to ensure majority of the sample contained phyllosilicates and less of the larger minerals, such as quartz and feldspar that were easily identifiable in thin section. Samples were placed on a 1 inch diameter glass platelet and flattened to 1mm in thickness. The range in diffraction angles peaked between 5-70° and the beam angle was adjusted to increments of 0.3° at one second intervals. X-ray powder diffraction was done on a Rigaku SmartLab, EGRC 303-C and analyzed using PDXL software.

Geophysical Studies:

As noted above, aeromagnetic data were apparently critical for previous workers in delineating the boundaries of the Wilderness rocks (Figure 2Figure 3). These data are old and required reprocessing. In Addition ancillary magnetometer traverses were undertaken in the area with the aim of shedding light on contacts where outcrop was not available and data from these traverses are included in the appendix.

Aeromagnetic data were downloaded from the USGS (Virginia Digitized Aeromagnetic Projects; Neuschel, 1970) in an ASCII format (lat/lon and magnetic anomaly in gammas) text file. Lines were flown at 0.5 mile East-West spacing between 1960 and 1964 (Neuschel, 1970)(Figure 3). New interpolation of the 1960's aeromagnetic data was done herein through exponential Kriging with 50 neighbors in order to create an image of continuous magnetic signature throughout the study area.

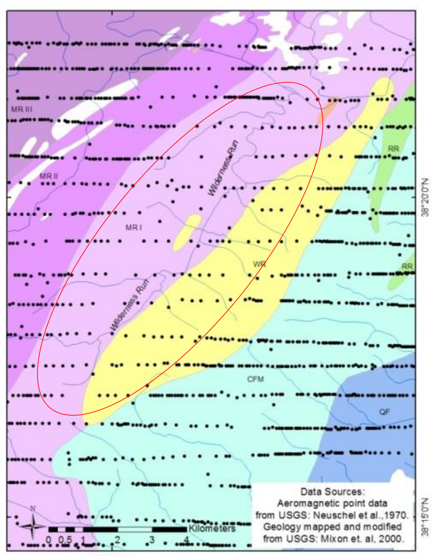

Figure 3: Raw point aeromagnetic data in the field area. The background colors represent geology as mapped by Pavlides in Mixon et al. in the 1990's with a lot of magnetic interpretations. The red ellipse shows the extent of the Wilderness Run watershed that is at a lower elevation than surrounding areas. Note the low point density across the watershed and the high point density on the edges of the watershed. Data sources: Neuschel, 1970 (Aeromagnetic data); Mixon, et al., 2000 (Geologic Data).

ORGANIZATION OF THIS REPORT

The goals of this study have been to assess the interpretation that the Wilderness rocks represent a successor basin atop the Chopawamsic fault and to learn more about these rocks in order to place constraints on the location, timing, and possibly kinematics of the fault. In this context, evaluation of the Wilderness rocks relies strongly upon bedrock exposure of the Wilderness rocks and bordering rock units. However, it was found that bedrock exposure was very poor, even by the notoriously low standard of the Appalachian Piedmont, such that the Wilderness rocks proved difficult to distinguish from bordering units and contact relationships were not exposed. Consequently, the main body of this report aims at outlining lithologic, metamorphic, structural, geophysical, and geomorphic characteristics of the rock units with the intention of providing circumstantial evidence with which to evaluate the interpretation of a Wilderness basin. This section will be followed by a summary of constraints on the age of rock units in the area and the report will be concluded with an interpretation of contact relationships between rock units.

LITHOSTRATIGRAPHIC UNITS

In assessing the nature of the Wilderness rocks, the definition of rock units is important and the contact relations between rock units are critical. As will become clear throughout this section, the rock units in the area are lithologically and visually similar making assignment of any one outcrop to a particular rock unit challenging, as one might expect in a basin with sedimentary sources in either one or both the Mine Run complex and the Chopawamsic Formation. In addition, contact relationships between the units are not exposed. However, circumstantial evidence accumulated during mapping allows for a geological reinterpretation of the area. This new interpretation is depicted on the maps included in this study, which also display the previously mapped geology. In this new interpretation, the Wilderness rocks are not viewed as a unique unit, but as a combination of Mine Run I and Chopawamsic Formation rocks.

In this section, the rock units designated by previous workers as Mine Run I and Chopawamsic Formation, as well as rocks here termed 'the Wilderness rocks', are described with respect to their distribution, lithologic characteristics, age and correlation, and interrelationships. In the study area, the Wilderness rocks are flanked to the west by rocks of the Mine Run Complex (specifically Mine Run I) and to the east by strata of the Chopawamsic Formation. This section starts with a description of these flanking units first, followed by a description of the Wilderness rocks. The interrelationships between units will be summarized following the descriptions.

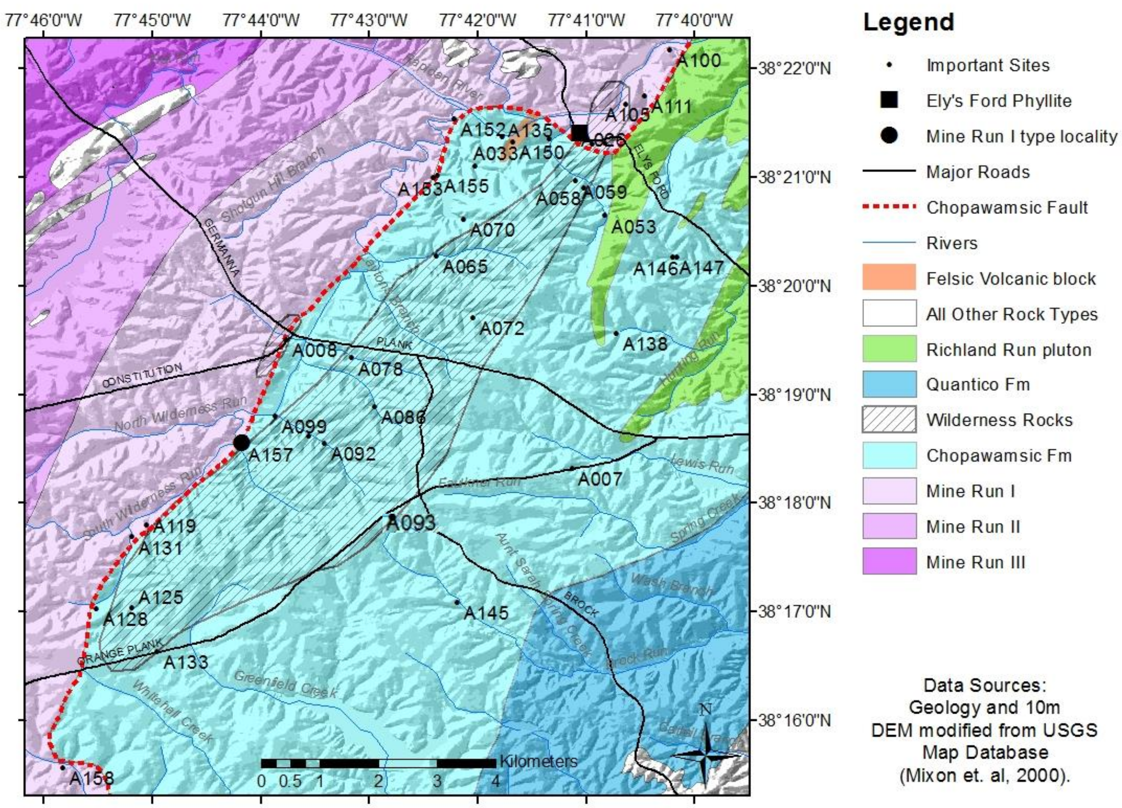

Figure 4: Important field station labels and names. Most of these sample sites will be referred to throughout the text.

Mine Run I

Distribution

The Mine Run I rocks make the eastern-most and structurally highest section of the Mine Run Complex (Pavlides, 1989). The Mine Run I sheet trends NNE-SSW and extends further to both the west and the north beyond the study area.

Rock Types

Mine I run rock types vary throughout the field area, from a medium- to coarse-grained metasandstone, locally with sparsely distributed pebbles and cobbles, to mainly phyllite at other localities.

The Mine Run I type locality is situated in the study area at the Wilderness Run Lake (Pavlides, 1989), indicated by the large black dot in Figure 4. There, the rock is a blue-grey chlorite-metasandstone that consists of mainly quartz, feldspar, and some myrmekite grains that are poorly sorted and poorly rounded (Figure 15).

. Bedding is not well exposed at outcrop scale, although locally it appears to trend NNE. The sandstone is rich in chlorite and biotite and contains inclusions of sparsely distributed lithic fragments that range in size from 2mm to 20cm in diameter. The grey to blue-grey rock fragments are typically subangular and poorly sorted and have both sedimentary and volcanic provenances. They are, in places difficult to distinguish from the dark green to blue-grey matrix sandstone. Rocks that are identical to the Mine Run I type locality rock are also found, from south to north, at locations A131, A119, A154 (at A155), and A152, on Figure 4.

Mine Run I rocks in the northeastern part of the study area (around location A111 in Figure 4) consist of gritty, muscovite rich phyllite (Figure 7) and also contains myrmekitic grains such as at the type locality. The gritty grains, up to 1.5mm in diameter, are mostly quartz and albite and the matrix consist of recrystallized quartz, albite, chlorite, and muscovite with accessory pyrite. Rocks in this section of the Mine Run I are well foliated with bedding parallel to foliation.

Figure 5: Mine Run I rock at type locality (black dot in Fig. 4). This is a chlorite-metasandstone consisting of mainly recrystallized quartz grains with chlorite and biotite. A weak foliation is present, indicated by the grey phyllosilicate mineral 'lines' in the center of the image.

Figure 6: Slightly magnetic Mine Run I rock at location A131. This is a chlorite-metasandstone containing recrystallized quartz, biotite, and accessory magnetite and showing only very weak foliation (not visible in the image). This rock is located close to the new interpreted contact with the Chopawamsic Formation.

Figure 7: Gritty phyllite at location A111 (a) and A100 (b) in the Mine Run I unit in the northernmost area of the study. This sample contains higher concentrations of plagioclase feldspar grains (up to 1mm in diameter) and muscovite than at the Mine Run I type locality. The foliation is also well defined here as opposed to weak foliation in

A small section of rocks in the northwestern part of the study area (locations A135 and A150) were previously mapped as a felsic volcanic block surrounded by Mine Run I rocks (locations A033, A152, A070, and A155). Rocks mapped as the felsic volcanic block are typically metafelsites containing albite grains up to 0.2mm in diameter (40%) surrounded by a fine-grained recrystallized quartz and chlorite matrix (60%). The rocks previously mapped as Mine Run I in this vicinity were very sparse in outcrop, but where visible in road gutters, revealed a mixture of saprolitic layers containing metamudstone and metasandstone.

In thin section, the mineral assemblage of the Mine Run I type locality metasandstone consists of roughly 53% quartz, 24% albite and roughly 15% biotite and 8% chlorite with accessory muscovite, pyrite, and other opaques. Quartz grains range from 0.5mm to 2mm in rough diameter. Volcanic clasts are dacitic and rounded, ranging from 1-2mm in diameter. Albite occurs as original clasts that have been altered at the rims and the majority of the quartz grains have been recrystallized. The matrix consists of fine-grained recrystallized quartz and phyllosilicates such as biotite and chlorite, with biotite being more abundant than chlorite. Myrmekite was found in Mine Run I rocks at location A119 and the type locality, in the central part of the map, and in rocks at location A111 in the northernmost part of the study (Figure 4). Myrmekite is a typical product of a felsic intrusive rock that could have formed during the crystallization of the igneous body or that has undergone either metasomatism or hydrothermal alteration.

X-Ray Diffraction analysis of 5 samples of Mine Run I rocks throughout the area has revealed compositions consisting of quartz (up to 60%), mica (up to 80%), and albite (up to 24%) with wollastonite, a calcium silicate (up to 14%). Out of the 5 samples 1 contains chamosite, the Fe end-member of chlorite, and 2 contain clinochlore, the Mg end-member of chlorite.

Chopawamsic Formation

Distribution

The Chopawamsic Formation was first introduced by Southwick et al. (1971), as a sequence of interbedded metavolcanic and metasedimentary rocks that conformably underlies the Quantico Slate (later given formation status). It is located in the eastern part of my study area and extends further to the east, northeast and south beyond my field area.

Rock Types

In my field area, the Chopawamsic Formation consists of alternating saprolitic metasedimentary and metavolcanic layers that mostly occur in sequences of up to 10m at outcrop (Figure 8). The metasedimentary layers range between metamudstone and metasandstone, some of which contain magnetite. About 60% of the metasedimentary rocks are mudstone, while roughly 40% are metasiltstone to metasandstone. Layers that are magnetic tend to be metasandstones that are quartz-rich with chlorite and magnetite, and are blue-grey in color. Volcaniclastics are tuff layers (Figures 8 & 9) that range in thickness between 20cm to 2m throughout the Chopawamsic Formation. The tuff (Figure 9 at location A145) contains coarse-grained, angular microcline clasts, surrounded by a fine-grained quartzofeldspathic and muscovite/chlorite matrix.

In thin section the tuffs contain variations of about 51% microcline and albite grains, 28% quartz, and 21% chlorite/muscovite with accessory pyrite. The metasiltstone and metasandstone layers in thin section showed variations of compositions with roughly 50% quartz, 40% albite, 10% biotite/chlorite and accessory magnetite.

One sample from the Chopawamsic Formation was analyzed using X-Ray diffraction, showing the presence of only 3 minerals. The chlorite end-member, chlinochlore (21%) is present in A138, where the most dominant minerals are albite (51%) and quartz (28%).

Figure 8: Sequence of saprolitic metasedimentary and metavolcanic Chopawamsic rocks at location A138 in the northeastern part of the Chopawamsic Formation. Dark-grey layers are biotite-metasandstone, brown layers are metamudstone with mostly chlorite and other clay minerals, and the white layer is a pyroclastic ash layer with mostly feldspar, quartz and muscovite. Photo shows a portion of an outcrop that is roughly 8m thick in cross section. Foliation is near-vertical and parallel to bedding.

Figure 9: Chopawamsic tuff containing microcline lapilli (circled in insert image), roughly 2mm in diameter, in a quartz and feldspar ash matrix with foliation aligned muscovite and clusters of biotite and chlorite at location A145 in the southeastern section of the field area.

Wilderness rocks

Distribution

The Wilderness rocks mentioned from here on out refer to the rocks previously assigned to the Wilderness basin (Pavlides, 1990), a purported successor basin. The Wilderness rocks define the study area and encompass about 80% of it. Fresh exposure of these rocks was limited to the outskirts of the northern area and studies were mainly based on saprolitic outcrops from the central area of the Wilderness rocks.

Rock Types

The Wilderness rocks encompass two major divisions of rock types. The first is the saprolitic layers of finer grained metasedimentary rocks and volcanic ash that occur throughout the majority of the Wilderness rocks (Lyon's farm location A093, Figure 4). The second type is the generally coarser grained, resistant, gritty metasandstone and phyllite in the northern part of the field area at the Ely's Ford location (black square in Figure 4).

Rock types range in grain size from metamudstone to metasandstone with some pyroclastic ash layers. An outcrop of diabase approximately $100m^2$ in size was discovered in the central area of the Wilderness rocks. The rock is dark blue to black in color and has not been metamorphosed and thus is not considered to be part of the Wilderness rocks.

At the Lyons farm, location A093 (Figure 4), one of the best exposures of the Wilderness rocks displays a sequence of roughly 8 saprolitic beds (Figure 10) ranging in thickness from about 20cm to 2m each. The different beds are parallel to foliation, and although saprolitic, distinguishable from each other by color and grain size. The compositions of the beds were roughly 45% siltstone, 30% sandstone, 15% mudstone, and 10% ash. Chlorite is altered to different clay minerals that were unidentifiable in either thin section or X-Ray Diffraction. X-Ray Diffraction analyses of these samples shed light on which end-members of chlorite were present, but not the type of weathered clay minerals present. Grains are well-rounded, blue-grey recrystallized quartz that range in size from

0.2mm up to 2mm. In most cases feldspar grains are thoroughly altered to sericite or muscovite, but show remnants of plagioclase feldspar. The volcanic ash layers, roughly 30cm thick, are white-grey in color and grains are fine-grained, making it difficult to identify the mineral content.

Figure 10: Sequence of Wilderness rocks at location A093. Saprolitic outcrop of mudstone to sandstone, showing multiple layers of bedding, Most of which are gritty to fine-grained sandstone with a couple thinner ash layers and quartz veins. Bedding is parallel to foliation. The Layers range between 20cm to 2m in thickness.

Wilderness rocks at the Lyon's farm typically consist of 50% quartz which is mostly recrystallized, 40% albite clasts that show significant alteration around rims, and 10% chlorite and/or muscovite. Three samples were analyzed using X-Ray Diffraction, with two of them containing large amounts of muscovite, 54%, and 11% respectively. Other minerals are quartz, albite, chlorite, and a small amount of Ilmenite. These compositional determinations are supported by thin section and hand specimen analyses.

Figure 11: Gritty phyllite at Ely's Ford (black square on location map), blue-grey in color. Grains are mostly quartz and feldspar with mineral lineations of mica and quartz clusters on bedding surface, visible here in the grey and white lines.

The second major rock type within the Wilderness rocks is found only in the northern portion of the outcrop area (Figure 11). The best examples are seen at Ely's Ford (black square, Figure 4) and the creek immediately to the southeast. Here, dark grey to black phyllite, gritty phyllite and sandstone constitutes the bulk of the unit. The gritty phyllite there contains large (0.5 - 2mm in diameter), rounded, blue-grey quartz and feldspar grains that are elongated parallel to foliation, and set in a matrix of fine-grained muscovite and chlorite. Some beds display graded bedding with a southeastward fining of grains.

My mapping has indicated identical rocks further north from this location, outside Pavlides' basin area and in the Mine Run I unit. Lithologically, the Ely's Ford phyllite is similar to the Mine Run I rocks in the northernmost section of the study area, with minor variations in the amounts of muscovite versus chlorite.

Figure 12: Wilderness rocks at location A065 showing a very fine-grained phyllite that is green-grey in color.

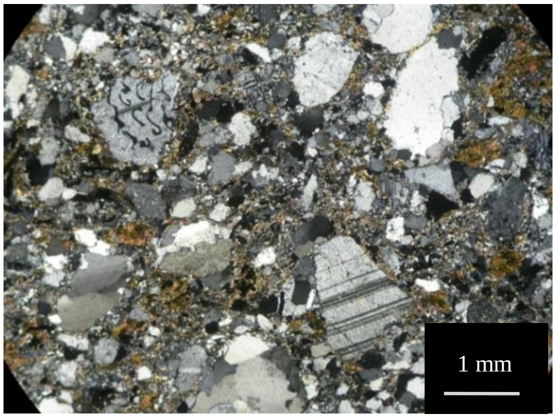

Figure 13: Mine Run I type locality sample under cross polars. Large angular minerals visible here are plagioclase and quartz, some with myrmekitic textures. Quartz show anastomosing exctinction, indicating slight deformation.

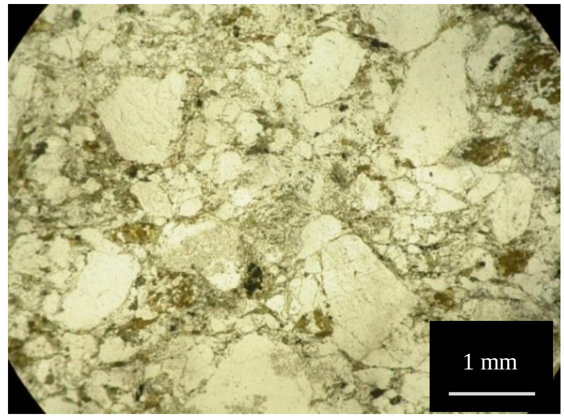

Figure 14: Mine Run I type locality in plain light. Brown minerals are biotite and light green minerals are chlorite.

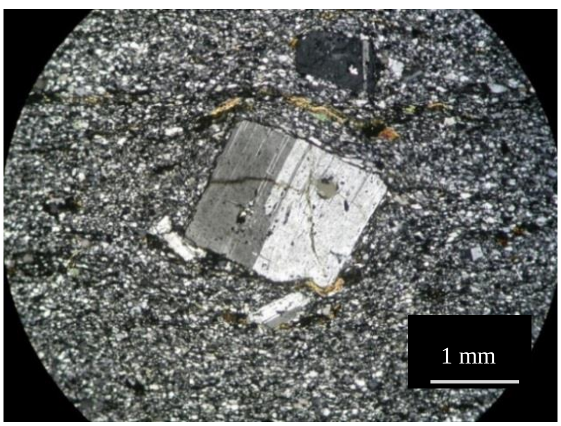

Figure 15: Chopawamsic rock (A138) under cross polars. Large angular grain is plagioclase porphyroclast, about 1.5mm in diameter, in a very fine-grained matrix of recrystallized foliation-aligned quartz, chlorite and biotite.

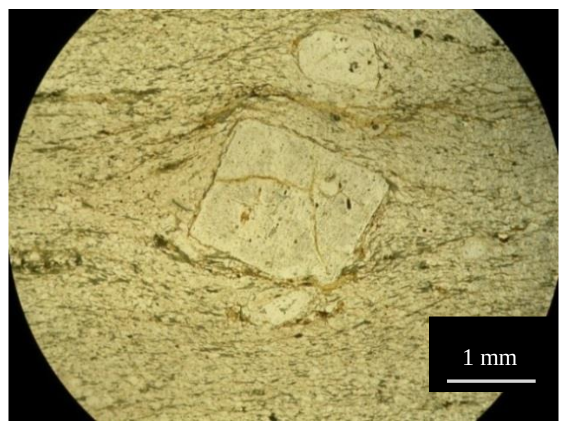

Figure 16: Chopawamsic rock in plain light. Large angular grain is plagioclase porphyroclast, about 1.5mm in diameter, in a fine-grained matrix of recrystallized foliation-aligned quartz, chlorite and biotite.

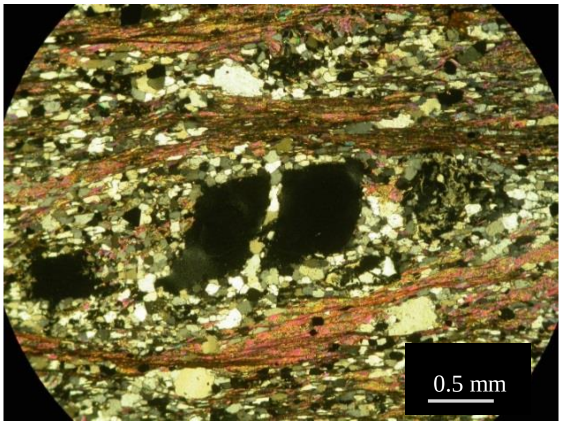

Figure 17: Wilderness rock (A058) under crossed polars. Angular grains are quartz porphyroclasts with fine-grained matrix of recrystallized quartz and micas (mostly muscovite).

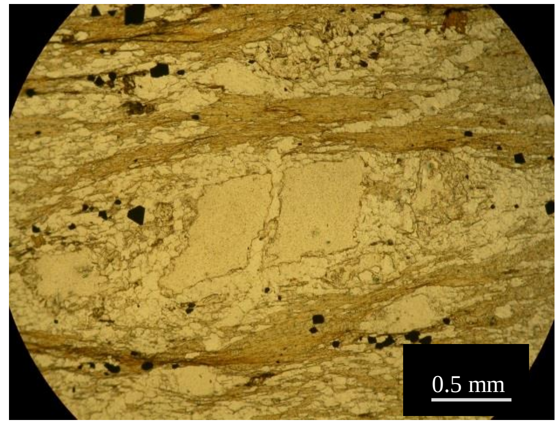

Figure 18: Wilderness rock (A058) in plain light. Angular grains are quartz porphyroclasts with fine-grained matrix of recrystallized quartz, muscovite, and chlorite with predominantly pyrite opaques.

Table 1: Table showing mineral compositions in percentages of all samples analyzed with X-Ray Diffraction. Sample locations are displayed in the Important Locations map (Figure 4), where samples A154 and A126 above can be seen at locations A155 and A125, respectively, on the map. Rock units are; MR = Mine Run I, WR = Wilderness rocks, CFM = Chopawamsic Formation. Chlorite end-members are Chamosite (Cham) and Clinochlore (Clino).

Sample	Unit	Quartz	Micas				Feldspar	Chlorite		Greenalite	Wollastonite	Ilmenite	Vermiculite
			Muscovite	Biotite	Phlogopite	Phengite	Albite	Cham (Fe)	Clino (Mg)				
MRI	**MR**	53					24		9		14		
A154	**MR**	39	9		38		14						
A111	**MR**	6		80			11		3				
A100	**MR**	24	39				15	12		10			
A153	**MR**					72	12		16				
A158	**MR**	60		38									2
A065	**WR**	29	54				7	10					
A126	**WR**	72	11				11					6	
A135	**WR**						2	98					
A138	**CFM**	28					51		21				

Summary

Rocks from the Mine Run I unit were found to be more resistant and fresh than the saprolitic outcrops of the Wilderness rocks and Chopawamsic Formation. The saprolitic Wilderness rocks (at Lyon's farm, location A093) are layered and compositionally similar to the Chopawamsic Formation in the area where both units contain fine-grained metasedimentary rocks and ash. X-Ray diffraction and thin section analyses also suggests a similarity between the Wilderness rocks and the Chopawamsic Formation, being higher in overall feldspar and muscovite content, where feldspar grains are surrounded by fine-grained quartz, chlorite, and muscovite matrices, unlike the Mine Run I rocks that contain angular, larger grains of feldspar and quartz surrounded by mostly chlorite and biotite matrices. The grains to matrix ratios in the Wilderness and Chopawamsic rocks are roughly 40% to 60%, whereas the ratio in Mine Run I rocks have roughly 75% grains to 25% matrix. The Mine Run I rocks can be subdivided in the study area between the type locality chlorite-metasandstone in the central area, the gritty phyllite in the northern area, and the saprolitic, scarce in outcrop, rocks in the northwestern area (locations A033, A070, and A155). It is clear after studying the gritty, resistant Wilderness rocks in the northern section (at Ely's Ford) that it is lithologically similar to the gritty, well foliated Mine Run I rocks at locations A111 and A100 in the far northern area. My mapping suggests that the felsic volcanic block and saprolitic Mine Run I in the northwestern field area consist of metasedimentary and volcaniclastic rocks, mostly metasiltstone and felsite that is consistent with Wilderness rocks and the Chopawamsic Formation.

AGE & CORRELATION

Constraining the age of the Wilderness rocks is one of the goals of this study. If the Wilderness rocks are indeed a basin, one should expect it to be younger than the underlying Mine Run I and Chopawamsic rocks, exposed on either side.

Mine Run I:

There are no direct age constraints on the depositional age of the Mine Run I rocks in the region. However, detrital zircon studies (Hughes, et al., 2012a) provide a maximum age of deposition of rocks at the type locality (large black dot in main map); the youngest zircon dated is c. 500 Ma, indicating that Mine Run I rocks are younger than Furongian (Late Cambrian)(Figure 19).

Further age constraints on the Mine Run I are provided by a dated pluton that cross-cuts the unit. The terrane has been intruded by the Goldvein pluton that has been dated and therefore give us the minimum final age of deposition at c. 456Ma (Aleinikoff et al., 2002). Thus Mine Run I deposition must have taken place between c. 500 Ma and 456 Ma, or Late Cambrian to Late Ordovician.

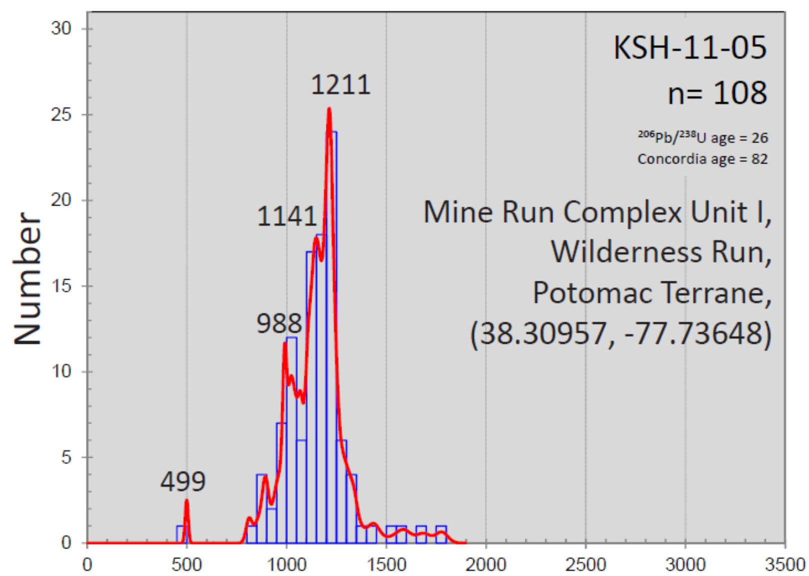

Figure 19: Detrital zircon ages of the Mine Run I type locality in Millions of years before present (Hughes, et al., 2012a).

Chopawamsic Formation:

Recent published studies have shown ages of the formation to both the north and south of the field area as ranging from approximately 472 Ma to 449 Ma (Coler et al., 2000; Horton et al., 2010). The latest dating on the formation is by LA-ICPMS analysis of detrital zircons that yield U/Pb dates between 470 - 457 Ma (Hughes, et al., 2012a). In addition, the Chopawamsic Formation is overlain by the Quantico Formation, which contains Late Ordovician fossils; thus the Chopawamsic Formation is Middle to Late Ordovician in age.

Wilderness rocks:

It has been suggested by Pavlides (1995) that the basin may have been deposited penecontemporaneous with the Storck, and Quantico basins and that they are of Late

Ordovician age (Pavlides, 1995). The Ely's Ford phyllite (large black square in Figure 4) which was originally mapped as part of the Wilderness rocks (Pavlides, 1990), has been analyzed for detrital zircon ages by Jeff Pollock from Mt. Royal University in Calgary, Alberta (Figure 20). These dates range from roughly 1.6 Ga to 760 Ma, therefore the Ely's Ford phyllite is younger than 760 Ma. Clearly there is roughly a 260 million years discrepancy between rocks of Late Ordovician age (Quantico and Storck basins) and 760Ma and younger (Ely's Ford phyllite). As will be discussed below in the text, these dates suggest that the Ely's Ford phyllite might be equivalent to rocks in the Mine Run Complex.

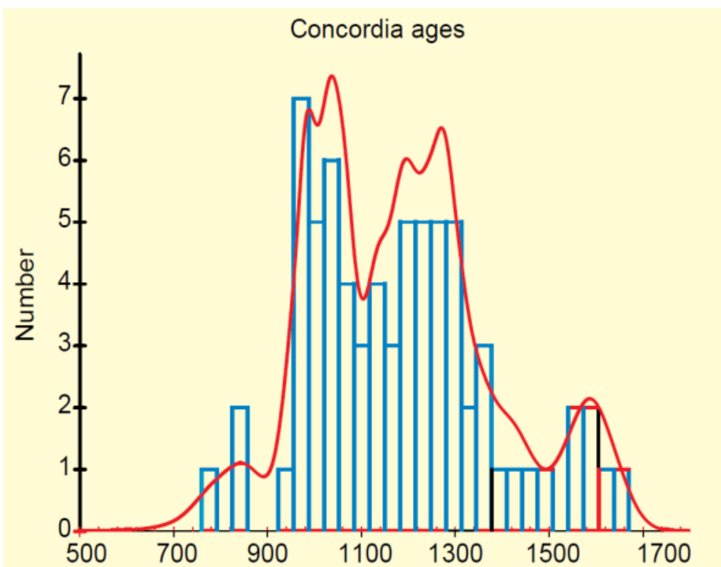

Figure 20: Detrital zircon ages of the Ely's Ford phyllite in millions of years before present. Sampled and analyzed by Jeff Pollock, Mount Royal University, Calgary, Alberta (unpublished data).

Summary:

The Mine Run I rocks have broader age constraints (c. 500 – 456Ma), from Late Cambrian to Late Ordovician, than the Middle to Late Ordovician Chopawamsic Formation (c. 472 – 449Ma). The detrital zircon age distribution from the Wilderness rocks at Ely's Ford is similar to that of the Mine Run I rocks, showing the oldest possible time that deposition could have started is at c. 760 Ma, suggesting that it is older than the Chopawamsic Formation. Significantly, Mine Run I detrital zircon ages show no evidence of a Chopawamsic source, suggesting that the two were not in 'depositional communication' at the times of their deposition. However, with the Chopawamsic Formation constrained to the Middle to Late Ordovician, any basin atop it must be Late Ordovician or younger, of which there is no evidence in the Wilderness rocks at Ely's Ford.

STRUCTURE & METAMORPHISM

Pavlides previously interpreted the Wilderness rocks as a synclinal successor basin that formed in a depositional trough unconformably on top of collapsed Mine Run I and Chopawamsic Formation rocks that have undergone significant thrusting (Mixon et. al, 2000). If this is the case, then certain observations in the structure and metamorphism are to be expected within the Wilderness rocks. A basin as described by Pavlides should show minor folding locally as well as large scale folding where the beds on either sides of the basin are facing upwards towards the center of the basin and the basin should be less intensely deformed than the underlying, older rocks which should display more complex structure, having undergone thrusting. Should the age of metamorphism coincide with the time of thrusting the underlying rocks would show higher metamorphic grade as well as more complex structure than the basin.

The high content of chlorite, muscovite, and biotite within all of the rocks in the study area, along with minor alteration of albite into micas and the recrystallization of quartz, is indicative of low grade greenschist facies metamorphism. Primary features have largely been overprinted by the low grade metamorphism in rocks from all three units. These observations are consistent in rocks throughout the area, suggesting that metamorphism post-dates thrusting. Consequently, metamorphic grade is not a useful measure by which to test the validity of a ‘Wilderness basin.’

Foliations

Phyllitic cleavage is the most prominent structure in rocks of all units in the field area. Foliations trend consistently NNE-SSW, with steep dips. In thin section, the quartz-feldspar domains are separate from the phyllosilicate domains, with spacing of about 0.2 - 1.0 mm between domains. Mine Run I rocks are coarse-grained and show only a weak, single foliation defined by a recrystallized quartz and phyllosilicate matrix with some volcanic grains indicating slight flattening parallel to foliation. Crenulation cleavage was observed in a few Wilderness rocks samples, e.g. A099 and A105, both of which are located along the Mine Run I – Wilderness rocks contact in the central and northern edge of the study area. Another location showing weak crenulation, is A065 within the central part of the Wilderness rocks. The crenulation cleavage is roughly perpendicular to the original cleavage in all above-mentioned samples.

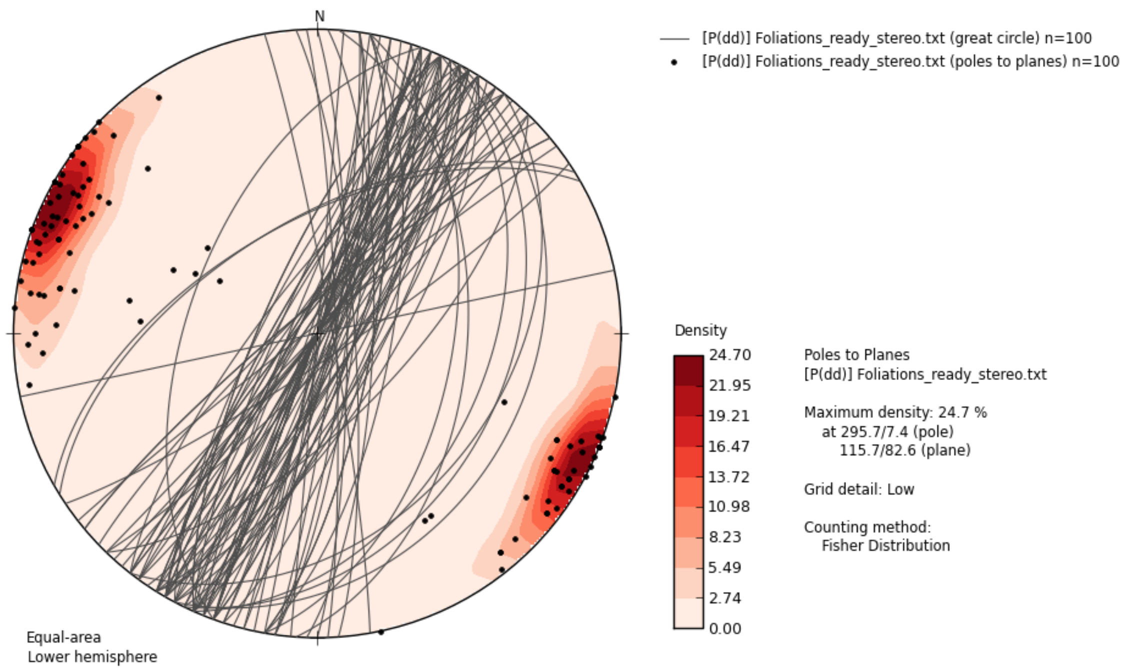

Figure 21: Stereogram of foliation measurements in the Wilderness area. Software used: GEOrient version 9.5 (Holcombe, 2011).

Folding

No minor folds were observed in outcrop. However, where evident in outcrop, primary bedding is parallel to sub-parallel to the foliation, suggesting the possible presence of tight to isoclinal folding. The dip of the foliation is generally steep and dip direction varies randomly, being either WNW or ESE. Graded bedding was visible at three locations in the Wilderness rocks, A093, A105, and A026 (Figure 4, 22). All locations display fining upwards of the grains to the southeast, thus stratigraphic top of the beds are facing southeast. Given these observations, no pattern indicative of a synform or basinal structure was found.

Figure 22: Gritty metasandstone at Ely's Ford. Graded bedding is visible in this rock, where beds are facing upward towards the southeast (image courtesy of Dr. J. Hibbard).

Lineations (L_m)

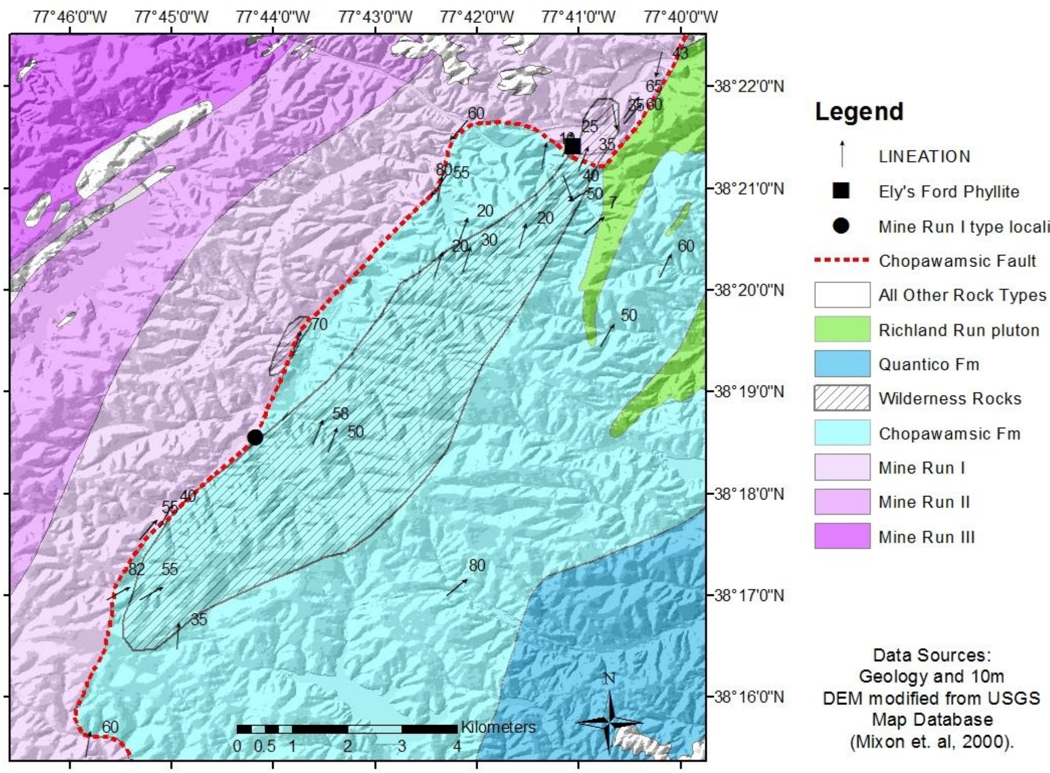

Figure 23: Map of lineation measurements with numbers indicating plunge values and arrows indicating the trend.

Lineations are weakly preserved in rocks throughout the study area. However, where visible, a mineral lineation (L_M) occurs predominantly in the form of elongate clusters of mica smears. These lineations, which are roughly mutually parallel, are plotted in Figure 24. Lineation within the Chopawamsic Formation and Wilderness rocks consistently trend NNE and plunge between 50° and 80°, but plunge less steeply (20°) in the northwestern area of the Wilderness rocks, which includes the Ely’s Ford location. Lineation within the Mine Run I rocks vary throughout the area between NNE and SSW with plunges ranging between 35°

and 60°. The rocks at one location within the Wilderness rocks (A105) show two lineations. The most prominent lineation, of mica smears, is 35/170, and the other, crenulation lineation, is 25/220 (Figure 25). This indicates a more complex deformation history within the northern extent of the Wilderness rocks, bordering the Ely's Ford phyllite.

Overall the lineations are constant throughout the different units in the area, with minor variations in plunge values, suggesting the deformation had to take place after the juxtaposition of the three units.

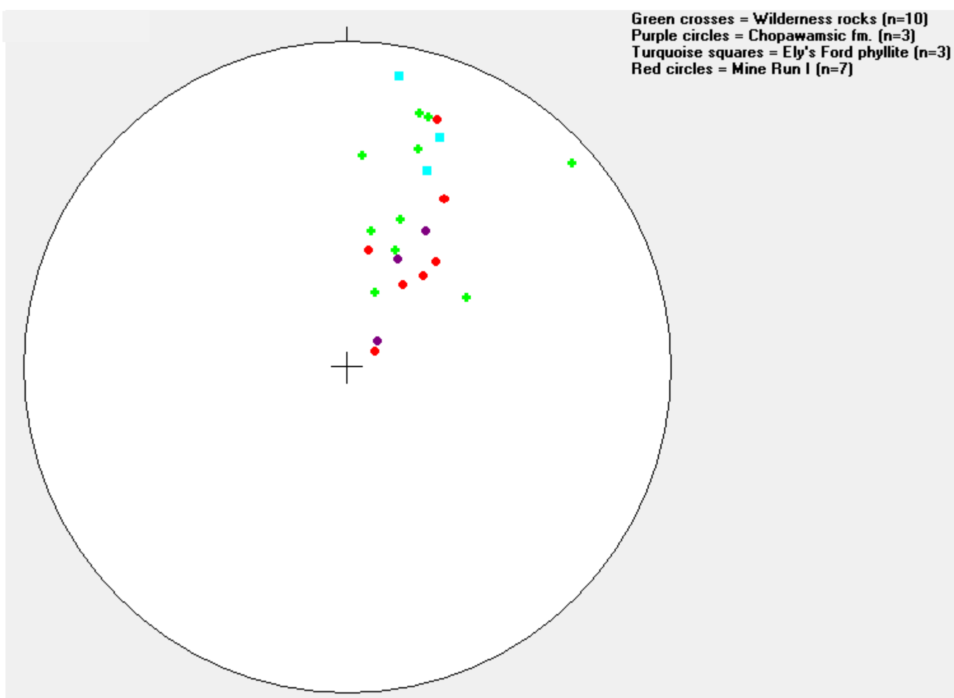

Figure 24: Stereogram of mineral lineations in the form of mica smears in all units. Symbols: green = Wilderness rocks, purple = Chopawamsic fm., turquoise = Ely's Ford phyllite, red = Mine Run I. Lower hemisphere, equal area. Software used: GEOrient version 9.5 (Holcombe, 2011).

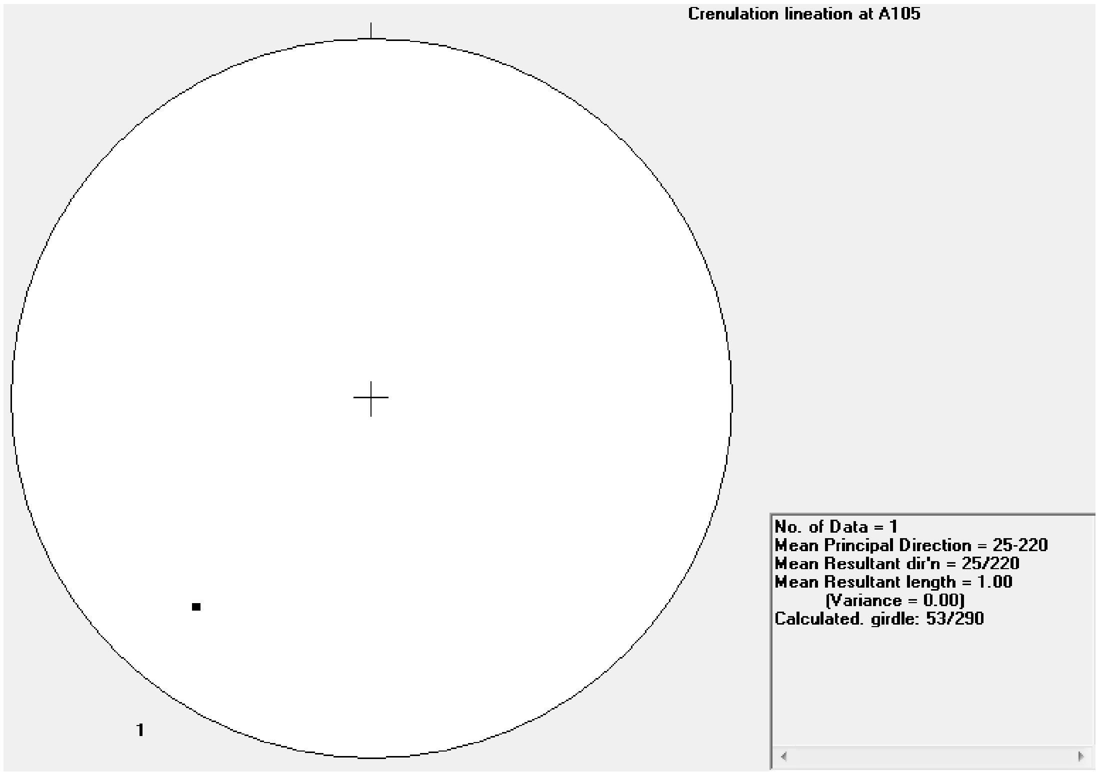

Figure 25: Stereogram of crenulation cleavage lineation at location A105 in the Wilderness rocks at Ely's Ford. Lower hemisphere, equal area. Software used: GEOrient version 9.5 (Holcombe, 2011).

Summary

With constant metamorphic grade, foliation and lineation throughout the area, it is evident that the rocks underwent similar deformation conditions and that the Wilderness rocks are not distinctly less deformed nor have less complex structure than the underlying units. In fact, the only few locations that show crenulation cleavage, and thus slightly more complex structure, is within the Wilderness rocks, which is counter-intuitive to what might be expected within a successor basin.

GIS ANALYSIS AND PROCESSING OF GEOPHYSICAL DATA

After spending a few days in the study area around Wilderness, Virginia, it became evident that good out crop was sparse. Soil can be up to 2m thick at places, and finding even saprolitic outcrops is a challenge. In recent years GIS (geographic information systems) analysis has aided the way scientists interpret landforms, e.g. geomorphology. It was implemented in this study to extract all possible information from the topography that might give insight to the underlying bedrock. The three ways in which watershed analysis was implemented, was in the studies of streams, slope, and erosion. Because erosion studies did not add to the main interpretations in my mapping it is included in the appendix.

Typically the best outcrops are found along streams in the Virginia Piedmont where majority of soil has been eroded away. Therefore delineating the stream network in the area, utilizing stream extraction methods in GIS, can help identify important locations which to investigate. Steep slopes are where rock outcrops are more common due high run-off rates and are also closely connected to erosion potential of an area. The following section outlines the analysis of information from Digital Elevation Models (DEMs) to understand the terrain better.

Streams

Stream extraction was performed by using the 10m DEM, the best quality raster data that was available for the area. In this DEM the elevation is represented in digital format through 10 x 10 meter pixels by interpolating elevations obtained from topographic contours.

The result for the stream extraction is shown in Figure 26 where streams are represented by blue lines. The amount of detail obtained in the stream network is manipulated by selecting the minimum size of the watershed in cells or pixels. The stream network below represents watersheds containing a minimum of 5000 cells. This size of watershed sufficiently displayed the stream network necessary for my study in order to target the major streams in the area. In the extraction process artifacts of straight, parallel lines appeared where lakes occur and can be overlain or extracted by a map layer that represents only lakes. The Wilderness Run watershed, in which most of the Wilderness rocks occur, is highlighted in magenta in (Figure 27).

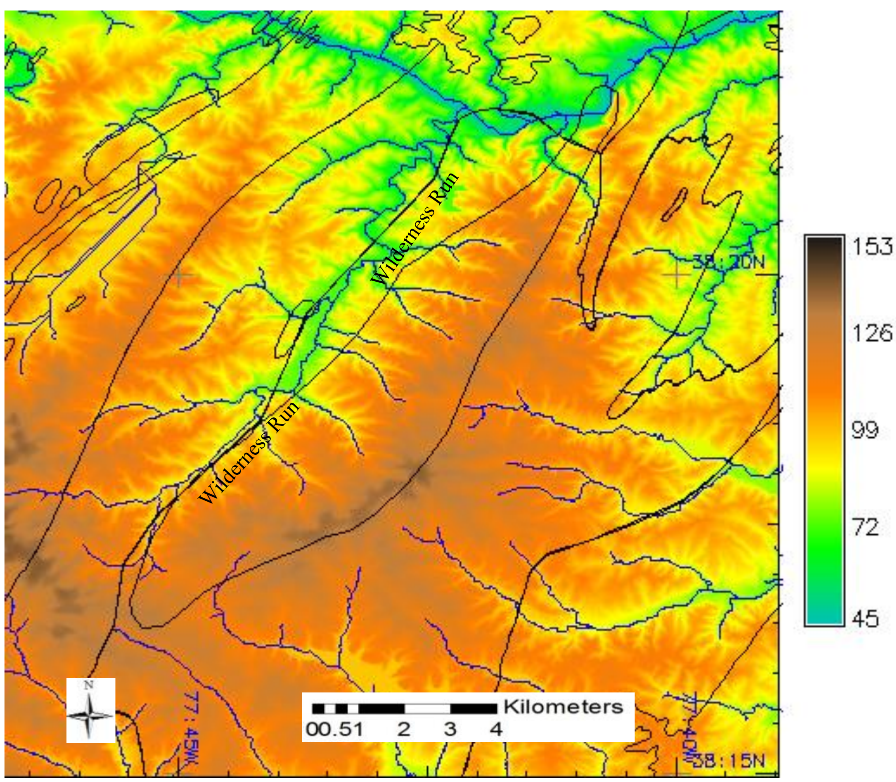

Figure 26: Elevation in meters with outline geology in black and extrapolated streams in blue.

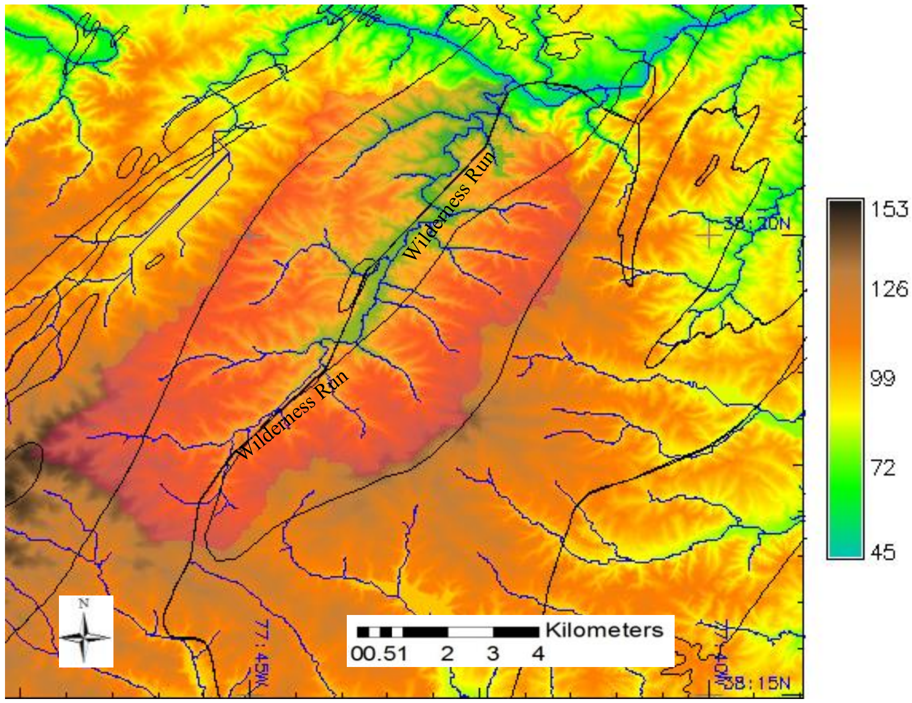

Figure 27: 10m DEM representing elevation in meters, overlain by geology in black, streams in blue, and the Wilderness Run watershed in magenta with 70% transparency.

Slope

The general slope of the area is relatively flat, which is common in the piedmont of Virginia. Steep cliffs occur at the incising bends of the large Rapidan River and at some north-facing slopes on smaller streams. Steeper slopes on north-facing hills may be due to less vegetation as a result of less direct solar irradiation than on south-facing hill slopes. It is useful to locate these steep slopes for geological mapping, as the likelihood of bedrock outcrop is very good, because erosion of topsoil increases at steeper slopes. The slope map shows very interesting features with respect to the outline of geology, which correlates to the aeromagnetic map (Figure 30). The eastern boundary of the Wilderness rocks almost exactly mimics the slope pattern along a very flat surface, i.e. low slope values of around 2 degrees (yellow), and the edge of the watershed where a ridge occurs along higher elevation (Figure 26). These observations will further be discussed in the next section.

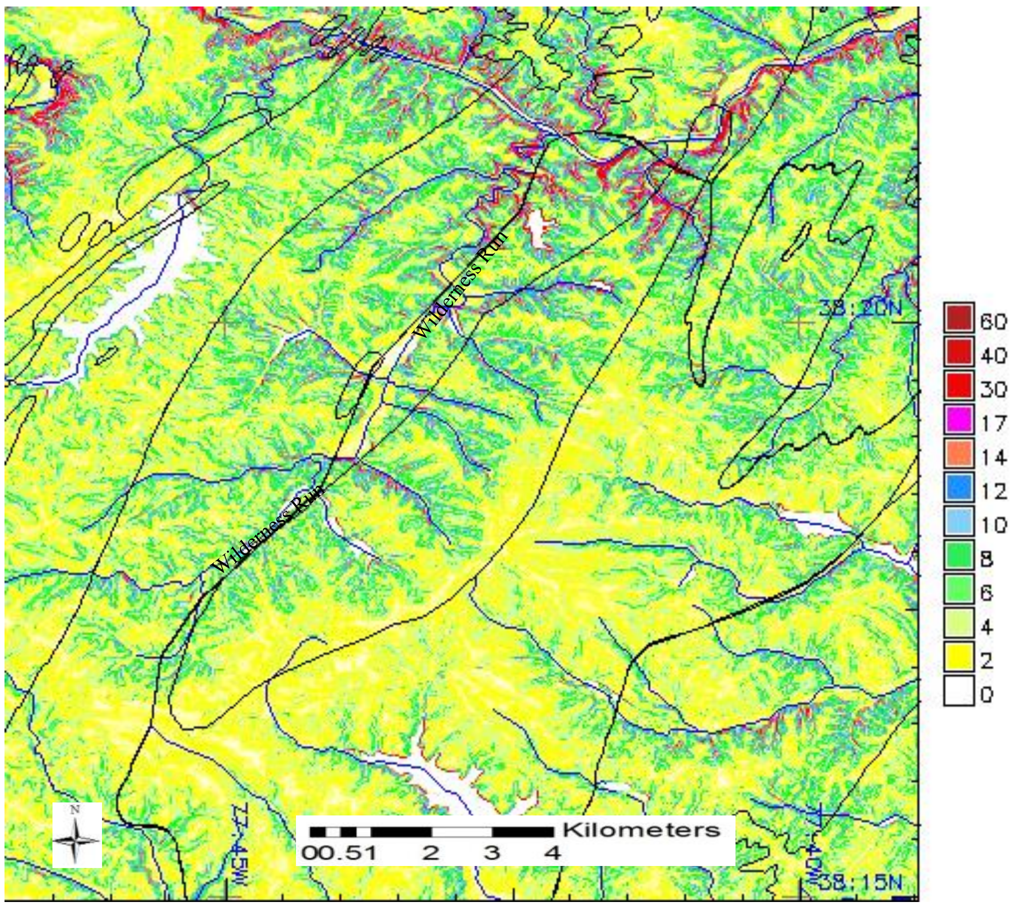

Figure 28: Slope map (in degrees) with geology outline. Note the eastern edge of the Wilderness rocks that mimic the flat, high elevation area.

Reprocesssing of Airborne Geophysical studies

The aeromagnetic data available for this area is very old and was collected between 1960 and 1964 (Neuschel, 1970). The positioning of the readings was performed by locating the airplane's current position on topographic maps and then manually assigning the magnetic reading to a specific spot on the map. This method is barely comparable to the accuracy of aeromagnetic surveys done today, where the highly accurate GPS is used in coordination with the magnetometer and therefore recording the exact position of each reading. The 1960's raw point data (Figure 3) was reprocessed and interpolated with GIS methods to show a continuous magnetic anomaly map (Figure 30). Previous aeromagnetic maps of the area were presented by a contour map which is harder to interpret due to lack of resolution and clarity of image (Figure 2)(Neuschel, 1970). The contour map was made from the scattered data points displayed in Figure 3 where it is very clear that the point density is the lowest across the Wilderness Run watershed which is at a lower elevation than the surrounding ridges with higher point density and higher magnetic anomalies.

Although the existing aeromagnetic data was old, irregularly spaced, and surveyed over a period of 4 years, it was very useful seeing exactly what geologists in the past were working with and how they might have come to certain conclusions in their mapping. It is also useful to me now, having the latest geostatistical technology in GIS where I can better represent such data on a continuous color map.

Interpolation Method:

Many methods exist in which one can interpolate point data. Methods investigated were Inverse Distance Weighted, Regularized Spline with Tension, and Kriging. Kriging is the most commonly used interpolation method for natural features such as soil and geology that are spatially correlated within certain distances (Billings, et al., 2002) and it is used here. Kriging was invented by a South African geologist and used for the prediction of gold distribution in the Witwatersrand reef (Krige, 1951). It makes use of data points with known values and a chosen model to interpolate values, in this case magnetic, for locations where data is not available. The model is chosen by plotting the data points on a semivariogram, which reveals the relationship between the distance of two or more points from each other and the variability of magnetic values, and then fitting it with a trend line. Based on this set of data, the best fit for this relationship was exponential (Figure 29).

In reprocessing the data (Figure 30) there remains a higher anomaly on the eastern border between the Wilderness rocks and the Chopawamsic Formation, but it is not as distinct as it appears in the Neuschel (1970) contoured aeromagnetic map (Figure 2). This case emphasizes that interpretations from the original magnetic contour maps do not hold great substance where they cannot be supported by bedrock outcrop. The slope map (Figure 28) also indicates that the higher, flat lying ridges (0-2°) correlate with the higher magnetic anomaly on the eastern edge of the Wilderness rocks. This observation suggests that the magnetic susceptibility increased here, where the ground is flat and closer to the aircraft. Since the aeromagnetic data are old and collected with old techniques, it could be possible that the magnetic signature at flat slopes were stronger than in the valleys even though the relief in this terrain is not that high.

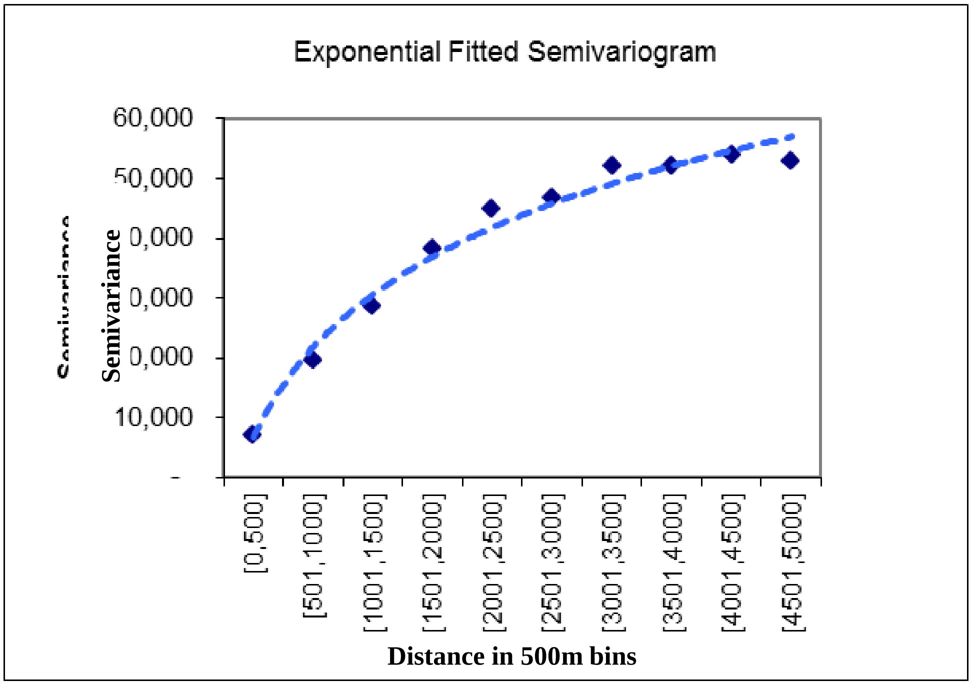

Figure 29: Semivariance of magnetic point data fitted to an exponential trend of an increase in variance of magnetic value as distance increases between points.

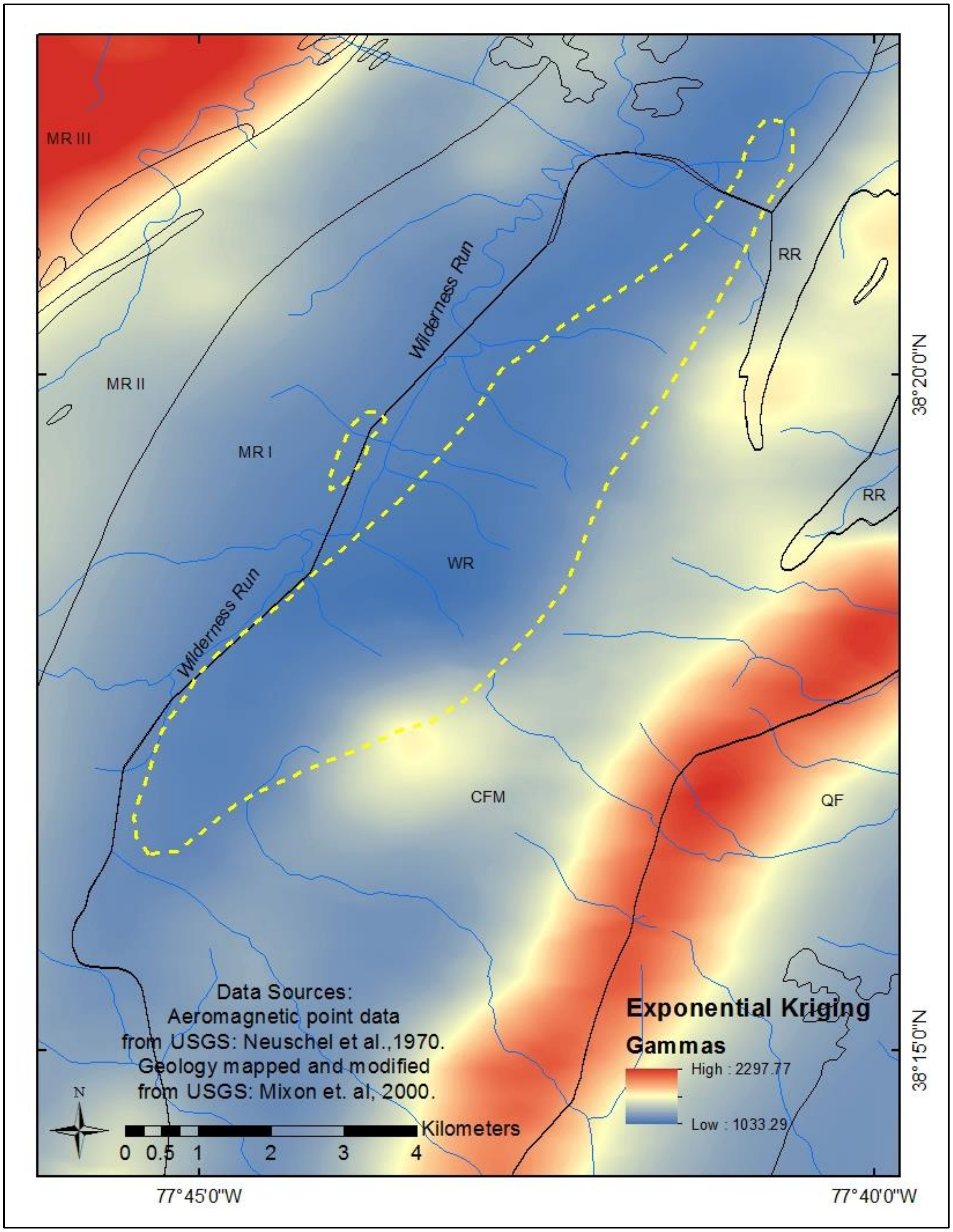

Figure 30: New aeromagnetic map of the wilderness area with overlying geology outline. Interpolation was done through Exponential Kriging. Black labels indicate geologic units: Mine Run I (MR I), Chopawamsic Formation (CFM), Wilderness rocks (WR), Richland Run (RR), Quantico Formation (QF).

Summary

GIS can be a helpful tool when trying to find patterns within the topography of an area. In this study GIS also aided in the reprocessing of old aeromagnetic data to better understand interpretations of previous workers. Utilizing GIS here with elevation, stream extraction, and slope has helped to elucidate features that otherwise would not have been obvious. The most prominent features are the higher elevation and flat slope along the eastern edge of the Wilderness rocks, i.e. the previously mapped contact between the Wilderness rocks and the Chopawamsic Formation. This old contact mimics the flat ridge that coincides with the change in magnetic signature that is displayed more drastically in the old maps (Figure 2) than the new reprocessed map (Figure 30). This observation poses doubt as to how reliable the interpretation of a contact can be if only based on aeromagnetic maps that could have been highly influenced by topography and irregularly spaced data readings.

CONTACTS & RELATIONSHIPS BETWEEN UNITS

Contacts as mapped by previous workers (Figure 31) were not exposed throughout the field area which made it difficult to identify the basin and to differentiate between units. The existence of a basin can however be assessed through circumstantial evidence, such as rock type, age, structure, metamorphism, GIS, and aeromagnetic analysis.

The Wilderness rocks of the Lyon's farm type and Chopawamsic Formation consist of saprolitic sequences both having pyroclastic influences, while the Mine Run I type locality rocks are more resistant to weathering and contains a higher ratio of grains to matrix as well as higher overall quartz grain content than both Wilderness rocks and Chopawamsic Formation. The felsic volcanic block that was shown within the northern part of Mine Run I (Pavlides, 1990) as well as the Mine Run I rocks directly south of that show similar characteristics to the Wilderness rocks and Chopawamsic Formation, with the volcanic block containing pyroclastic rocks that show bedding facing upward to the southeast and the Mine Run I rocks in the small area south of the volcanic block being very saprolitic and indicating alternating layers of metamudstone and metasandstone having been altered to muscovite and various clay minerals. The second type of Wilderness rocks, of Ely's Ford type, are nearly identical to the Mine Run I rocks in the northernmost part of the area in that both are gritty phyllites rich in biotite and chlorite.

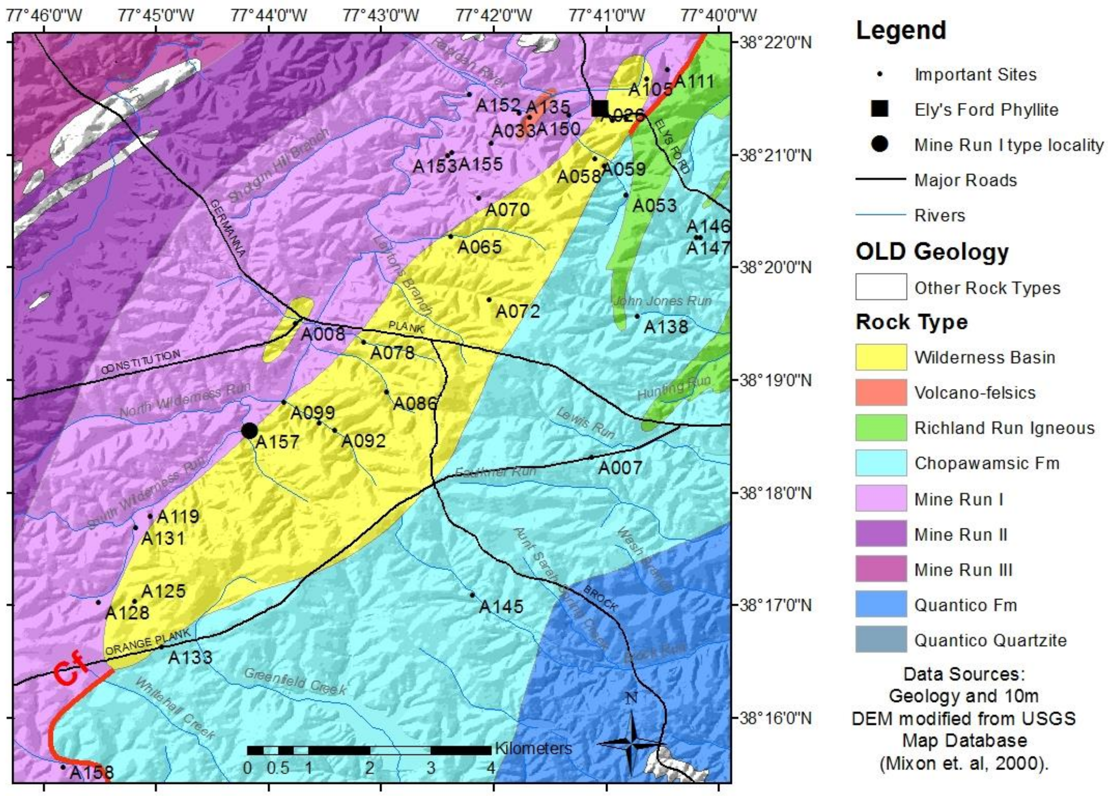

Figure 31: Geology as mapped by Pavlides in Mixon et al., 2000. The yellow represents the Wilderness basin atop the Chopawamsic fault with Mine Run I rocks and a felsic volcanic block to the west and Chopawamsic Formation to the east.

The age on the Ely's Ford phyllite indicate a possible earliest age of deposition at c. 760 Ma which is much older than the age of the Chopawamsic Formation. Should the Wilderness rocks represent a basin it should contain rocks from both the underlying units and is expected to be younger than them as well, for which there is no evidence for here.

Concerning structure in the Wilderness rocks, there are about 3 locales that show crenulation cleavage indicating a more complex structure than the typical Chopawamsic

Formation rocks found in my field area. This challenges the idea of the Wilderness rocks being a basin, as it should show less complex structure and deformation. Structurally, the Wilderness rocks and the Chopawamsic Formation contain graded bedding that consistently indicate top of the beds to the southeast, where foliation is well defined by a phyllitic cleavage and where foliation is parallel to bedding. In addition, the Wilderness rocks do not show structures, e.g. folded bedding, typical of a syncline.

GIS analysis indicates a unique topographic pattern (flat slope, high elevation) where a positive magnetic anomaly is shown on old maps, as well as point density of magnetic data, decreasing from east to west on the eastern edge of the wilderness run watershed. With the reprocessing of the data, the decrease in magnetic signature is more subtle than portrayed on the old contour map, on which previous workers based a lot of mapping decisions.

It is based on this circumstantial evidence that I interpret the geology of the Wilderness area through remapping and regrouping the units. Wilderness rocks of the Lyon's farm type and the Mine Run I volcanic block area are grouped as part of the Chopawamsic Formation. The Ely's Ford phyllite has been remapped as part of the Mine Run I unit and the fresh outcrops of rocks identical to the Mine Run I type locality delineate the new interpreted contact between the Mine Run I and newly mapped Chopawamsic Formation. Although this contact is not exposed, it represents the Chopawamsic fault in my field area.

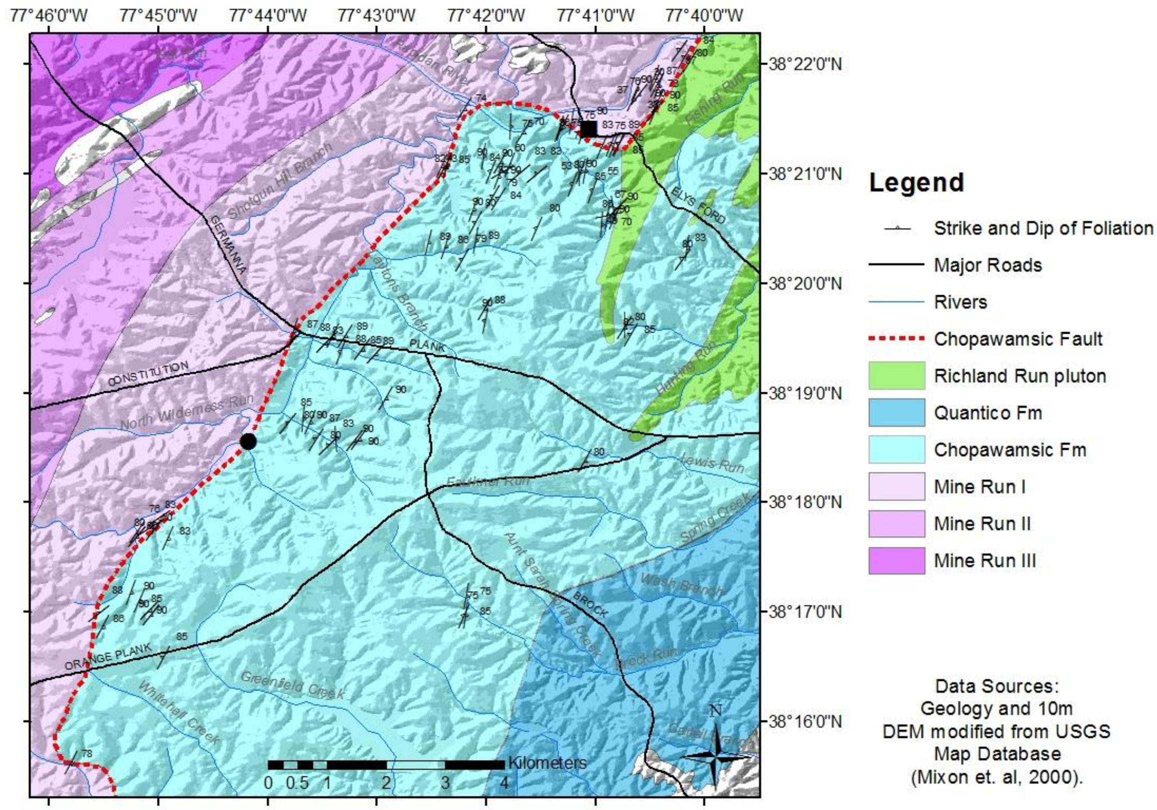

Figure 32: Final geologic interpretation of the Wilderness area, Virginia.

IMPLICATIONS & CONCLUSIONS

Originally, the primary focus of this study was to evaluate the interpretation of a successor basin in an attempt to support the broader study of the timing, kinematics, and significance of the Chopawamsic fault. However, detailed mapping and multiple analytical methods lead to the conclusion that a 'Wilderness Basin' does not exist in this area; instead rocks previously designated as forming the basin are herein assigned to the flanking units, Mine Run I and Chopawamsic Formation. The bulk of the Wilderness rocks are interpreted to be part of the Chopawamsic Formation, whereas the northern section of Wilderness rocks are remapped as Mine Run I rocks. The contact between the newly mapped Chopawamsic Formation and Mine Run I unit now represents the Chopawamsic fault, although unexposed in the area and is remapped along the eastern side of fresh outcrops of Mine Run I rocks that are evenly distributed from south to north throughout the field area. This interpretation has resulted in the fault trace trending east-west in the northern part of the field area at the Ely's Ford location, giving it the appearance of a tear fault, which is consistent with the interpretation that the Chopawamsic fault is a thrust (Pavlides, 1989, 1995).

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APPENDICES

The following two appendices; Erosion, and Ground Geophysical studies, are analyses that were undertaken, yet did not add to the main conclusions in my mapping interpretation of the area. However, they were useful in the sense that they did not reveal anything contradictory to my findings. By not revealing much, they still add to the broader scheme of methods utilized in order to obtain as much information from the area as possible.

Appendix A

Erosion

The study of erosion in the Wilderness area was implemented with the hope of distinguishing between underlying bedrock patterns and possibly delineating boundaries between the Wilderness rocks and both Mine Run I and Chopawamsic Formation units. The initial thought of doing erosion studies was to combine the field information with erosion patterns so that it might give further insight to the bedrock distribution and contacts where surface outcrop was not found. This, however, was not successful due to the large influence that land cover plays in the outcome of soil loss, opposed to the impact of underlying lithology. For that reason it is included in the appendix as work that was done that did not aid in the final interpretation of the geology of the area.

The major factors that influence soil erosion are rainfall intensity (R), soil erodibility (K), human impact (C), length and steepness of slopes (LS), and dimentionless prevention practices (P) mostly used in large scale farming. These factors were used in the empirical universal soil loss equation (USLE) to create a map of most likely soil loss in the area (Figure 33) (Institute of Water Research).

Universal Soil Loss Equation (USLE)

The equation states: E = R K L S C P (Institute of Water Research), where *E [ton/(acre.year)]* is the average soil loss, *R [hundreds of ft.tonsf.in/acre.hr.year]* (in SI: *[MJ.mm/ha.hr.year], R[SI]=17.02R[EU]* or [N/h=kg m/s^3]) is the rainfall intensity factor, *K [tons per acre per unit R] = [tons.acre.hr/hundreds.acre.ft.tonsf.in]* is the soil factor, *LS [dimensionless]* is the topographic (length-slope) factor, *C [dimensionless]* is the cover factor and *P[dimensionless]* is the prevention practices factor. *R, K, C* and *P* factors are usually derived from land use and soil maps (digitized or derived from imagery), and slope and slope length for the LS-factor are derived from a DEM. (Mitasova, et al., 1999).

R factor:

The rainfall intensity factor for this area is 200. It is a measure of the height of water layer covering the ground in a period of time (hundreds of ft.tonsf.in/acre.hr.year). Average R values exist for areas throughout the USA.

K and C factors:

K factor is the soil erodibility factor which represents both susceptibility of soil to erosion and the runoff rate. Soil is given low K values when it is resistant to detachment. These soils are high in clay and sand content. Coarse-grained soils, such as sand has a medium K value, due to its low runoff rates, although they can be detached easily. Medium-grained silt and loam soils have higher K values because of moderate runoff rates and higher susceptibility to detachment. High silt content soils have the most susceptibility of detachment and high runoff rates (Institute of Water Research). C factor is used to determine the impact (land cover management) humans have on the erosion rates. To implement these values in the erosion map, each class of the land cover map obtained from the USGS land cover database (Land Cover Data, 2012) has to be updated with K and C values (Hill, 2002). This process is called reclassification.

Reclassification in ArcGIS did not allow for the input of floating point numbers and K and C values were therefore multiplied by 100 and 10000 respectively to convert the values to integers. Once the resampling was completed, the erosion rate was divided by 1000000 to correct for the multiplication of C and K factors.

Table 2: K-Factor values for each soil type.

High clay	0.05-0.15
Sandy	0.05-0.2
Silt and Loam	0.25-0.4
High silt	>0.4

Table 3: Land Cover map Classes and corresponding C values. The colors and class numbers correspond to the official Land Cover maps used by the USGS.

Class	Color	Land Use	C-value
11	blue	Open water	0
21	grey	Developed, open space	0.8
22	mauve	Developed, low intensity	0.6
23	red	Developed, medium intensity	0.7
24	wine	Developed, high intensity	0.8
31	grey	Barren land	0.3
41	m_green	Deciduous forest	0.0005
42	d_green	Evergreen forest	0.0005
43	l_green	Mixed forest	0.005
52	beige	Shrub/scrub	0.1
71	o_white	Grassland/herbaceous	0.1
81	yellow	Hay/pasture	0.5
82	brown	Cultivated crops	0.5
90	l_blue	Woody wetlands	0
95	m_blue	Herbaceous wetlands	0

P factor:

P factors could not be found for this area in Virginia, most probably because of its use in large scale farming in the Midwest, which contrasts the small farming practices in the study area. Due to the fact that P is a measure of land use and soil maps (which has already been incorporated in the K and C values) it is not that imperative that it be included for the purpose of this study.

LS Factor Equation

In order to calculate the erosion rates, the LS factor needs to be obtained first. There are two ways to calculate the LS factor; using the slope length, or the upslope contributing area (flow accumulation). For this study I used the upslope contributing area. Below is the typical equation for calculating the LS factor:

LS_factor = 1.6 * (Power("flow_acc" * 10 / 22.13 , 0.6) * Power((Sin("slope_rad") / 0.089) , 1.6))

Where “flow_acc” represents the upslope contributing area and “slope_rad” is the slope values in radians.

Final Soil Loss (Erosion)

Soil_loss_C = (200 * "cfac_10000" * "LS_factor" * "kfac_100") / 1000000

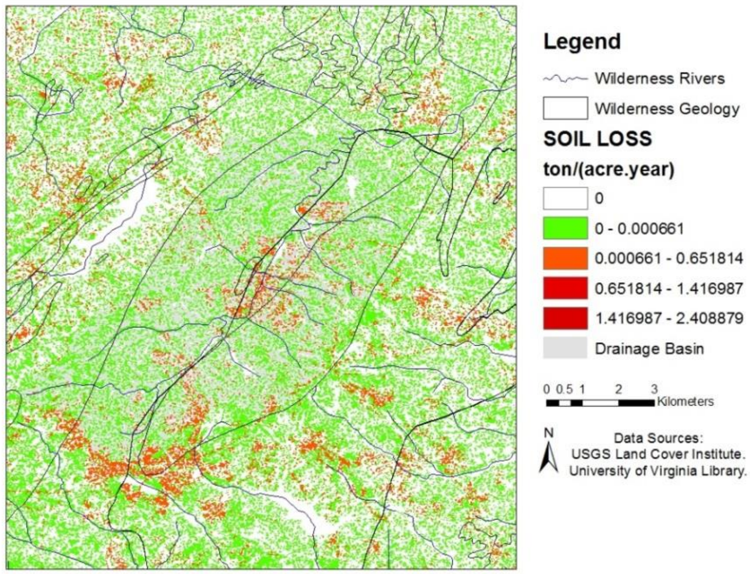


Figure 33: Map indicating the erosion potential of the Wilderness area. Wilderness Run drainage basin highlighted in grey.geology outline overlaying in black.

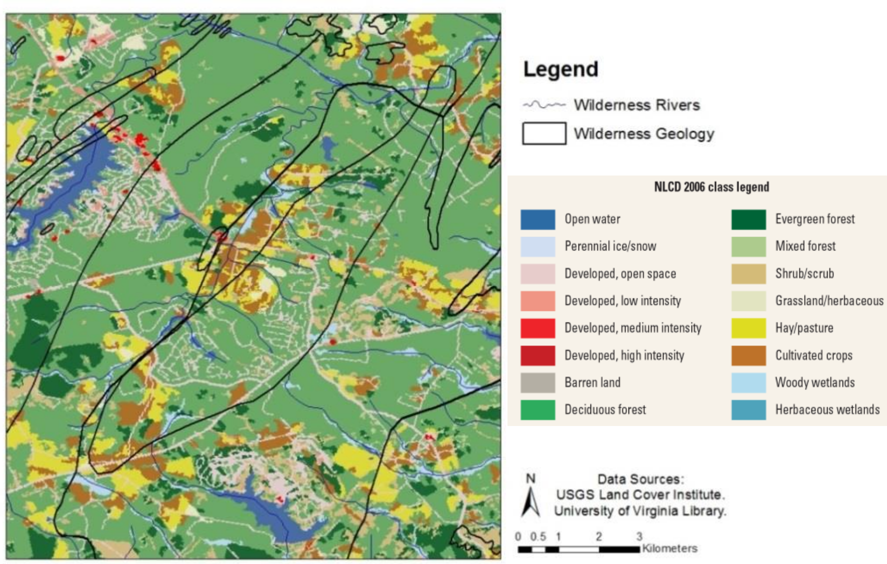


Figure 34: Land use map of the Wilderness area. Data obtained from the usgs Land Cover Institute (LCI, 2012). Geology outline in black.

Erosion Summary

The majority of erosion taking place throughout the area ranges from 0 to 0.000661 ton/(acre.year) and is indicated in green on the map. Areas in red have higher erosion potential with the majority of these values averaging around 0.65 ton/(acre.year). Due to the fact that the land cover map (Figure 34) plays such a big role in computing the K and C factors, the farming areas show the most erosion. Cultivated crops, pastures and barren land are given the highest erosion potential and therefore those areas within the study area will ultimately be affected the most by erosion. Farms are concentrated on the eastern side of the watershed, the area where Wilderness rocks occur. I feel that even though I would have liked to prove that erosion on the eastern side of the watershed is more severe due to softer rock type, I cannot ignore the large impact that the land cover plays and how little impact the soil type, and thus bedrock indirectly, has.

Appendix B

Ground Geophysical studies

Method:

High-precision magnetometry was done in order to highlight differences in lithology and/or structure where outcrop was scarce or saprolitic. Three locations were chosen where artificial magnetic interference was minimal and profiles were walked each section about 1 mile long.

The instrument used in the survey is a Scintrex SM-5 NAVMAG cesium magnetometer, known for its high sensitivity, continuous output, high cycling rates, and low susceptibility to electromagnetic interference. The system has a resolution of 0.001 nT that takes ten readings per second which was later averaged when analyzing the data using Matlab software. In the field, the position of the magnetometer at each second was determined using WAAS-enabled (Wide Area Augmentation System) GPS, providing an accuracy of 1-3 m.

Ground Geophysical Study Results:

This study was employed with the hope of finding different magnetic patterns between different rock units and possibly delineating contacts where surface outcrop was not found. For accurate measurements, the paths had to be unpaved with as little metal interference as possible. Due to the nature of the magnetometer, being very bulky, heavy, and ±3m tall, it was very difficult to traverse the sections in the field area that are covered in woods, which is the majority of the area that has unpaved roads/paths. Many areas where contacts were previously mapped were impossible to reach extensively on both sides of the contacts with the magnetometer and therefore this study is included in the appendix for it does not bear a lot of weight in the final interpretation of my mapping of the area. It would have been ideal to cover the same surface area on both sides of the contacts instead of stopping right by the contacts due to impassable terrain.

The three trails that were walked were sections of woods that had cleared paths. The results indicate the distribution of rocks with different magnetic content (Figure 35Figure

38). The change in magnetic signature is the most evident in the northern two trails where there are sections up to 600m of similar magnetic signature with surroundings free of metal interference. The trail in the south shows a lot of change in magnetic signature indicating either many thin alternating rock layers or man-made metal interference in the surroundings. Even though this surface on the farm was unpaved, the probability of metal features, from farming, underneath the ground is very likely. Historically this was also a battlefield in the Civil War. Therefore a lot of weight cannot be placed on the majority of magnetic signatures of the southernmost trail.

Summary

Even though no significant results were obtained through the ground geophysical study, it is good to see that no contradicting results to my final mapping interpretation were found. Profiles that crossed the previously mapped Chopawamsic Formation – Wilderness rocks contact (Figure 38) did not show a distinct change in signature, while the newly mapped Wilderness rocks-Mine Run I contact (Figure 36Figure 37) showed a slight change in magnetic signature. However, these changes are subtle and are not significant enough to support the final mapping interpretation.

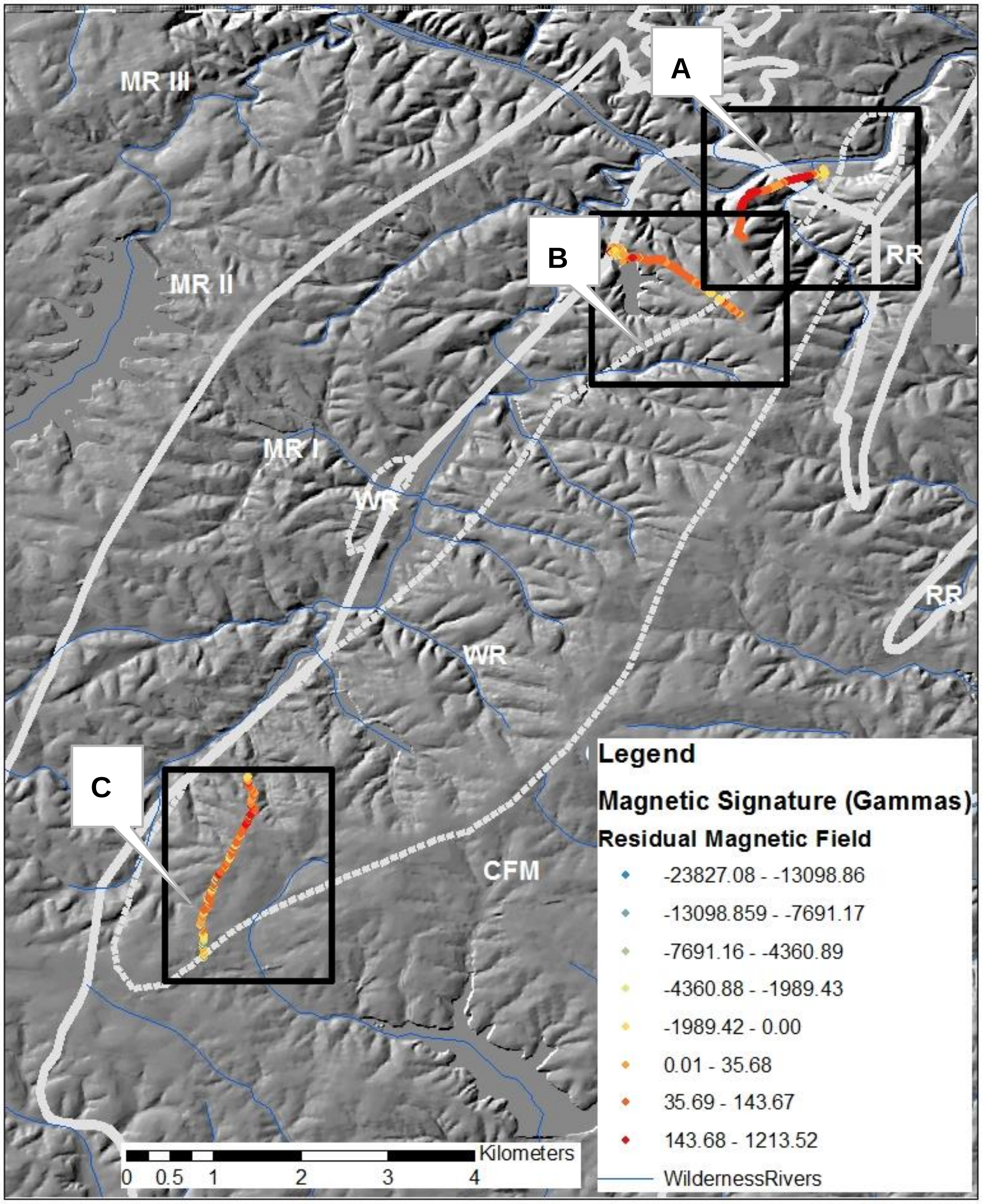


Figure 35: map showing magnetic signatures of 3 trails walked with a magnetometer. The earth's magnetic field (51480 Gammas) has been subtracted from the original values. The geology is outlined in white on the larger map. MRI = Mine Run I, WR = Wilderness rocks, CFM = Chopawamsic Formation.

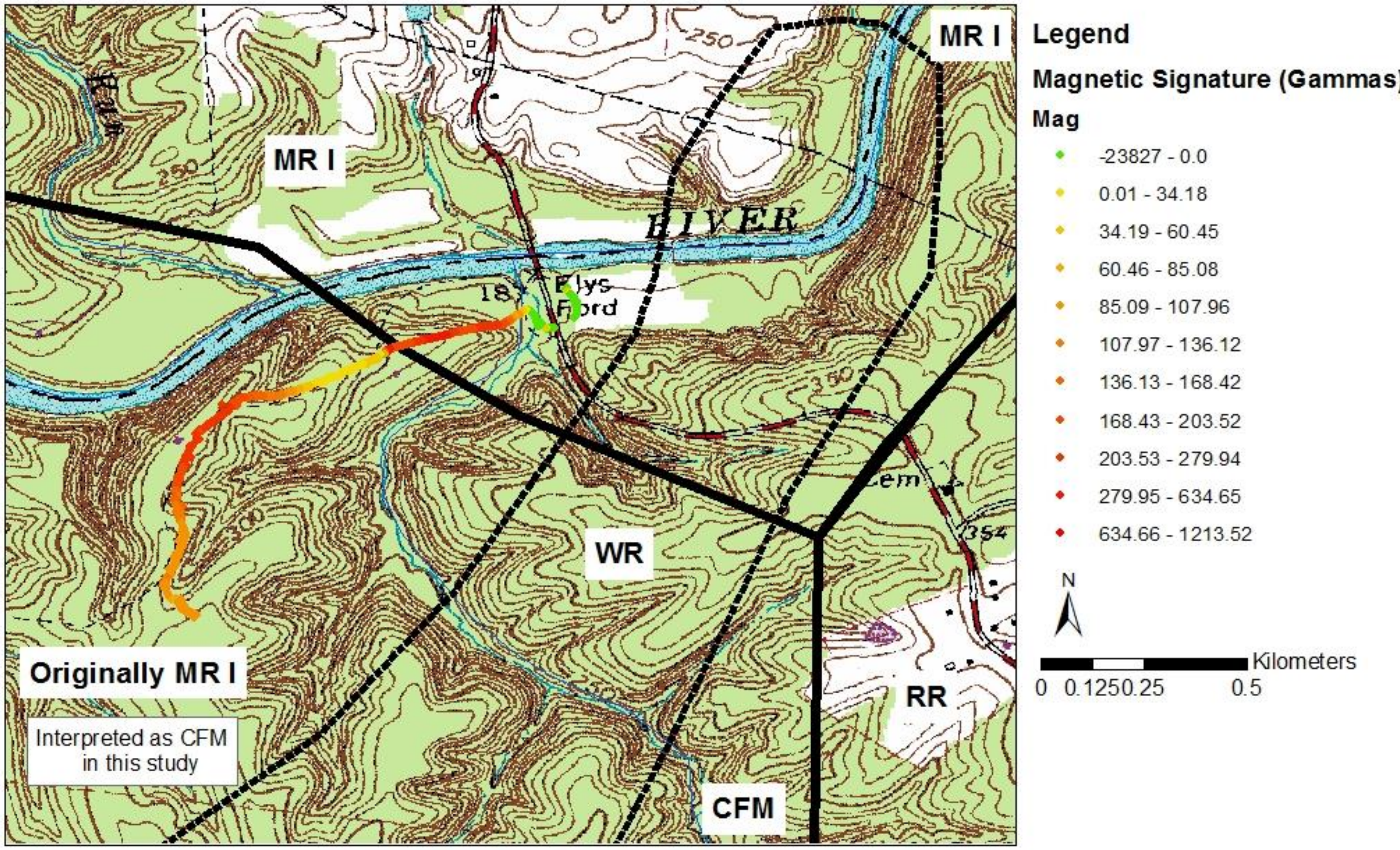


Figure 36: Section A of the magnetic signatures in Figure 35. This trail indicates a change in magnetic signature where I have mapped the Chopawamsic – Mine run I contact. It does not cross any other, previously mapped contacts and therefore mostly indicates a change in signature within the CFM.

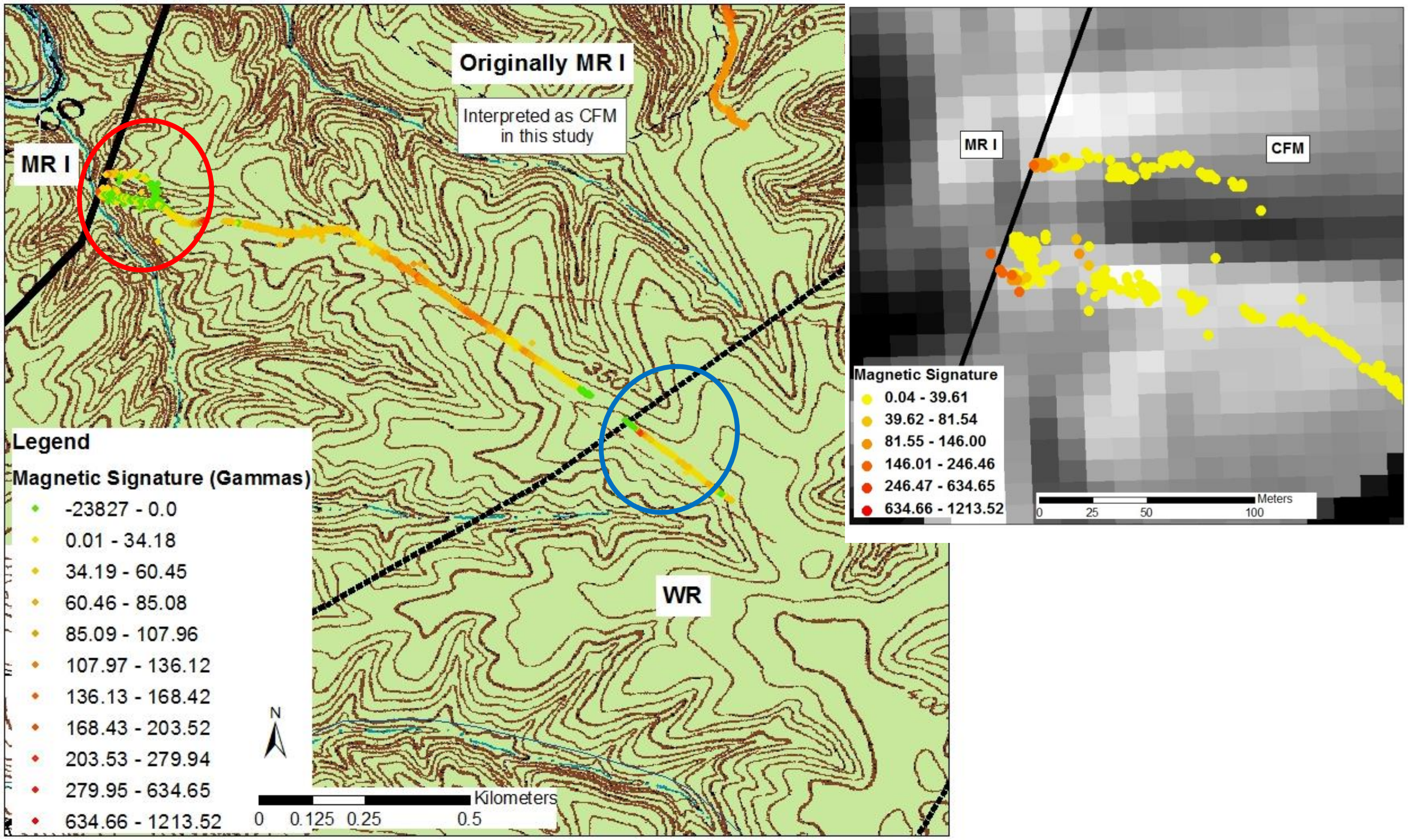


Figure 37: This trail is Section B in Figure 35. The trail crosses the previously mapped Wilderness rocks (WR) - Mine Run I (MR I) contact (blue circle). The negative values, in green, were obtained due to metal interference of large farming equipment, which is why the signature was interrupted there for a few meters. The red circle indicates the newly mapped Chopawamsic Formation (CFM) – MR I contact.

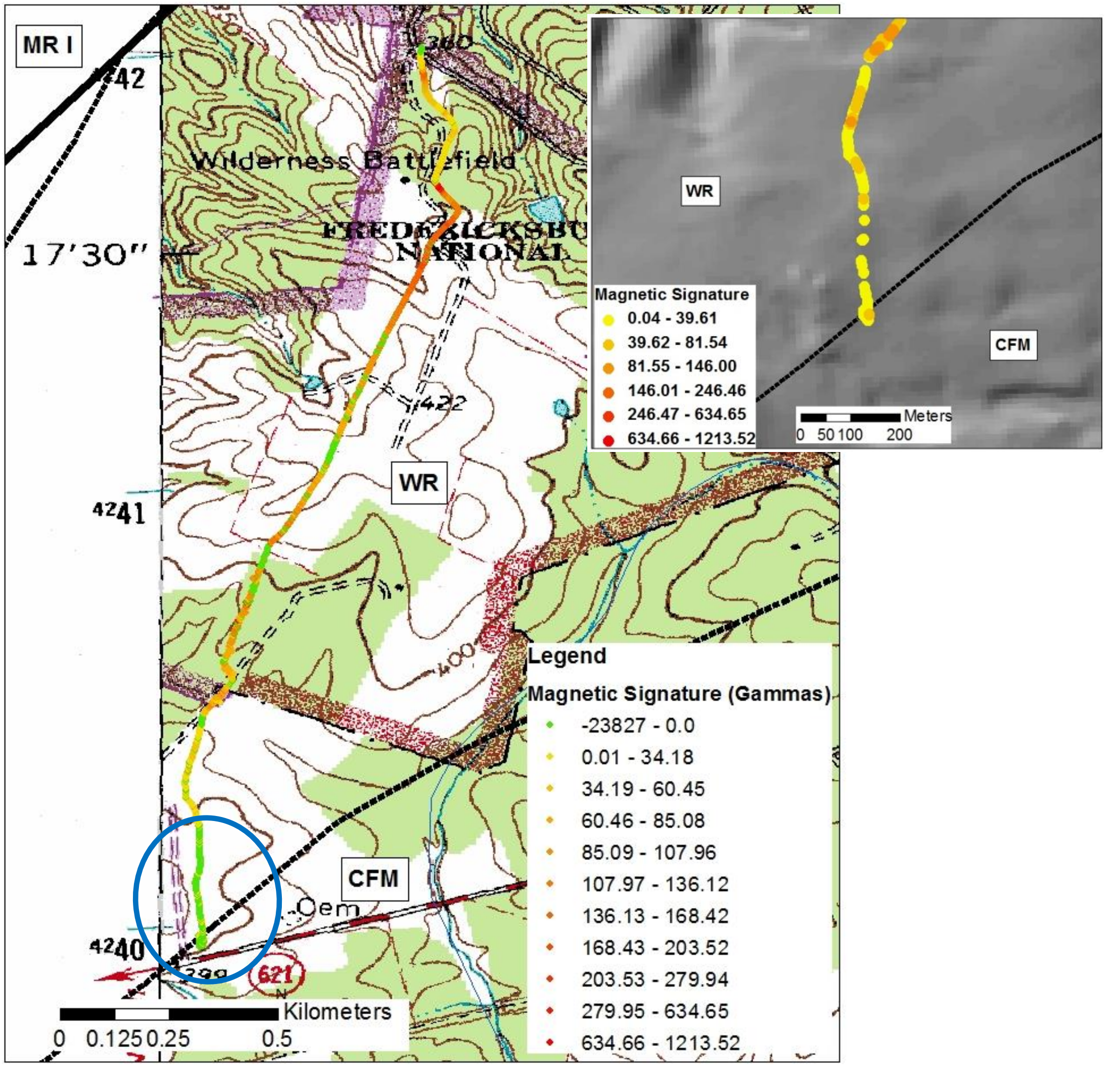
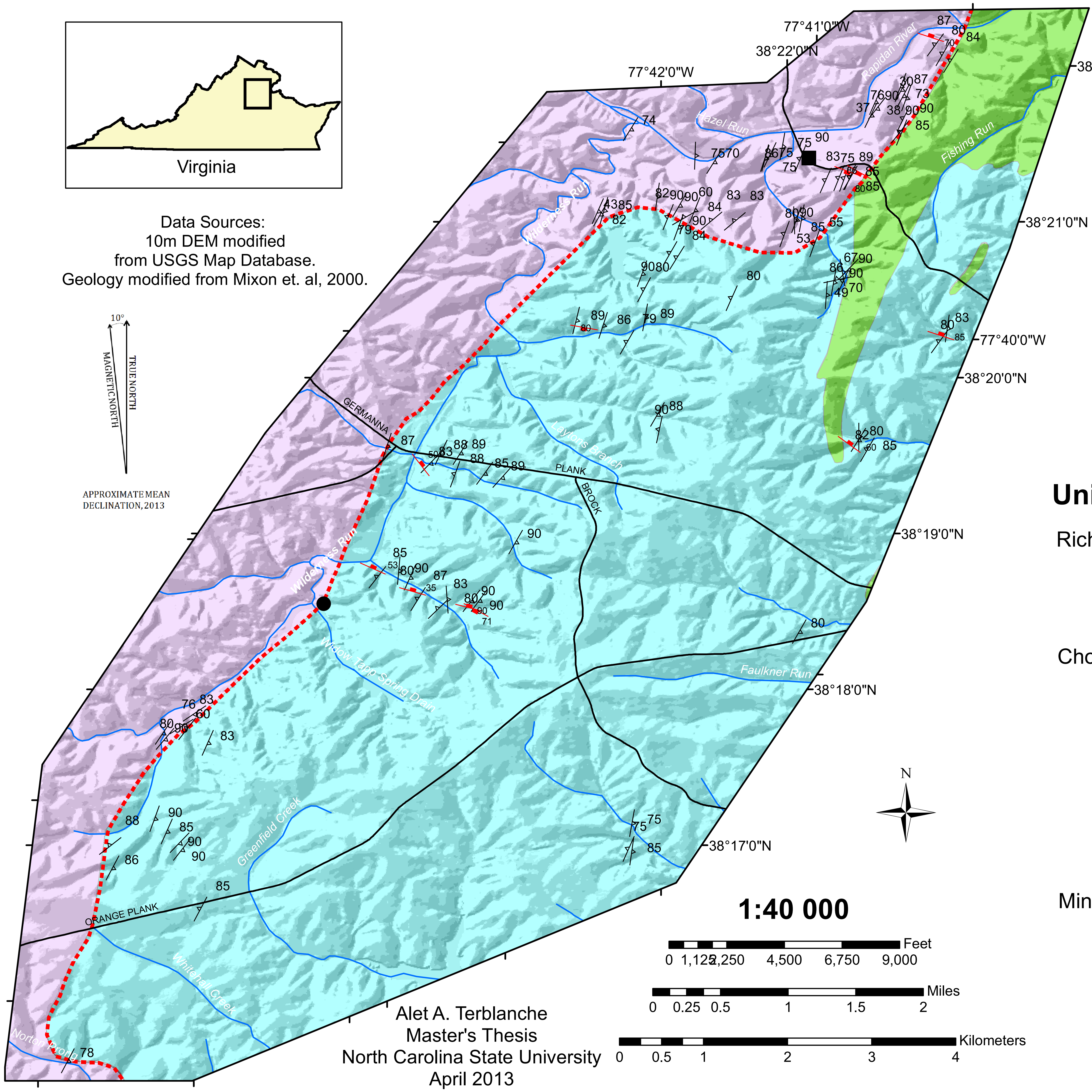


Figure 38: Magnetic trail from section C in Figure 35. This profile indicates lots of magnetic interference within the Wilderness rocks. The southernmost point of the trail (blue circle and insert map) somewhat crossed the previously mapped CFM – WR contact.

Geologic Map of the Wilderness Area, VA



Alet A. Terblanche
Master's Thesis
North Carolina State University
April 2013

Legend and Lithostratigraphy

- ■ Ely's Ford Phyllite
- ● Mine Run I type locality
- Strike and Dip of Joints
- Strike and Dip of Foliation
- Major Roads
- Chopawamsic Fault
- Rivers
- Richland Run pluton
- Chopawamsic Fm
- Mine Run I

Unit Descriptions

Richland Run pluton:

Medium- to coarse-grained blue-grey to light-grey tonalite slightly metamorphosed. Minerals include quartz, plagioclase, amphibole and pyroxene,

Chopawamsic Formation:

Sequence of felsic to intermediate ash layers, and metamudstones to metasandstones. Layers vary in color with ash layers mostly white to light grey, metamudstones light brown, and metasandstones dark grey. Layers vary in thickness between 20cm to 2m. Some layers contain magnetite, while most others are abundant in albite, quartz, chlorite, and phyllosilicates. Majority of outcrop is saprolitic.

Mine Run I:

Chlorite and biotite metasandstone mixture of fine- to coarse-grained quartz and feldspar grains, some with myrmekitic texture. Rocks are generally blue-grey in color. Grains are angular and range in size from 0.1 - 2mm, while larger, sparsely distributed rock fragments of the same rock type can range between 5cm - 20cm. Rocks are poorly sorted and poorly rounded with a 3:2 grains to matrix ratio.