Detailed Bedrock Mapping in the Swift Run Gap 7.5' Quadrangle, Blue Ridge Province, Virginia

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INTRODUCTION

This proposal requests funding under EDMAP for geologic mapping of ~155 km^2 (~60 mi^2) in the Blue Ridge province in north-central Virginia by three undergraduate students and a faculty supervisor from the College of William & Mary during 2004. A bedrock geologic map of the Swift Run Gap 7.5' quadrangle will be completed, approximately 1/3 of the quadrangle occurs within Shenandoah National Park. The objectives for detailed mapping of this area include: 1) producing a publishable geologic map in a region lacking modern large-scale geologic maps and 2) understanding the stratigraphic, structural, and temporal relationships in the north-central Virginia Blue Ridge. The final products of this work will consist of digital and paper geologic maps at 1:24,000 scale with the appropriate explanations and figures.

LOCATION AND GEOLOGIC SETTING

The Blue Ridge province separates the fold and thrust belt of the Valley and Ridge from the Appalachian orogenic hinterland in the Piedmont (Figure 1). In central and northern Virginia, the Blue Ridge forms an anticlinorium with Mesoproterozoic basement rock in the core and Neoproterozoic to early Paleozoic cover rock on the flanks and in fault-bounded inliers (Figures 1 & 2). The present day structure of the Blue Ridge province is that of an imbricated stack of basement thrust sheets that experienced 40-60% shortening during Paleozoic deformation (Mitra, 1979; Evans, 1989; Bailey and Simpson, 1993).

The oldest rocks exposed in the core of the anticlinorium are gneisses (mostly orthogneisses) that were intruded by a series of 1180 to 1050 Ma charnockitic, leucogranitic, and anorthositic plutons during the Grenvillian event (Aleinikoff et al., 2000; Tollo et al., 2004). There appear to be two major magmatic episodes during the Grenvillian event, an early episode between 1180 and 1160 and a younger event between 1070 and 1050 Ma (Aleinikoff et al., 2000; Tollo et al., 2004). Grenvillian deformation occurred under upper amphibolite to granulite facies conditions and recent geochronology brackets the age of a major deformation event between 1060-1050 Ma (Tollo et al., 2004).

On the western limb of the Blue Ridge anticlinorium, the basement complex is unconformably overlain by metasedimentary and metavolcanic rocks of the Swift Run and Catoctin Formations (Figure 2). The Swift Run Formation was defined by Jonas and Stose (1938) for exposures in the Swift Run Gap quadrangle. This unit is of variable thickness and includes metaconglomerate, quartzite, phyllite, and metatuff (Jonas and Stose, 1938; King, 1950; Gathright, 1976; Dilliard and others, 1999). These arkosic rocks are interpreted to be rift-related deposits of fluvial and colluvial origin (Gathright, 1976; Dilliard et al., 1999). Tholeiitic metabasalts of the Catoctin Formation overlie the Swift Run Formation and were erupted approximately 570 Ma (Badger and Sinha, 1988; Aleinikoff et al., 1995). Catoctin volcanism was followed by deposition of the siliciclastic Chilhowee Group. In north-central Virginia the Chilhowee Group includes the Weverton, Harpers, and Antietam Formations (Figure 2). Chilhowee Group deposition records the transition from rift environment to subsequent development of a passive margin bordering the Iapetus Ocean (Wehr and Glover, 1985; Simpson and Erikkson, 1989).

Basement rocks in the Blue Ridge are cut by a series of anastomosing high-strain zones. Major high-strain zones are 0.5 to 3 km wide and extend 50-150 km parallel to the regional trend of the Blue Ridge (Figure 1). The temporal, kinematic and tectonic significance of these zones has been discussed by a number of workers (Mitra, 1979; Bartholomew et al., 1981; Conley, 1989; Bailey and Simpson, 1993; Bailey, 2003; Burton and Southworth, 2004). Different workers have variously interpreted these zones to be a reverse, normal, and strike-slip structures. Furthermore, the absolute age of Paleozoic deformation in the central Virginia Blue Ridge is not precisely known, however the available metamorphic cooling ages suggest some greenschist facies fabrics in both the basement and cover sequence developed prior to the Alleghanian Orogeny (~300 Ma) (Bartholomew et al., 1991; Evans, 1991). However, many Ar-Ar ages for deformation fabrics in the northern Virginia Blue Ridge are related to Late Paleozoic deformation (Burton et al., 1992; Kunk and Burton, 1999).

PURPOSE AND JUSTIFICATION

The primary goals of this study are:

•To produce publishable digital and paper bedrock geologic maps with geologic cross sections at 1:24,000-scale of the Swift Run Gap 7.5' quadrangle (Figure 3). Existing bedrock maps of the region are inadequate and at small scales.

•To provide rigorous training for undergraduate students in the area of geologic mapping, while conducting research that addresses specific geological questions concerning both regional and process-oriented topics.

• *Scientific Goals:*

1. Accurately map the distribution of Mesoproterozoic basement units. Recent work by Bailey et al., (2003) and Tollo and others (2004) to the northeast of the Swift Run Gap quadrangle has significantly revised the stratigraphy of the Blue Ridge basement complex.

2. Accurately map high-strain zones within the Blue Ridge basement complex and understand their kinematic significance. Burton and Southworth (2004) proposed a tectonic model linking the Rockfish Valley zone in central Virginia to the Short Hill fault in northern Virginia. Reconnaissance mapping suggests that individual high-strain zones tip out and cannot be linked from central to northern Virginia. Detailed mapping is needed to test existing tectonic models.

3. Understand the depositional and tectonic setting of the Swift Run Formation. The siliciclastic and volcanoclastic rocks of the Swift Run Formation are the first evidence of the rifting event that eventually led to the opening of the Iapetus Ocean and the development of a passive margin in eastern North America. We seek to better characterize the Swift Run Formation, determine if sedimentation was influenced by active normal faulting (e.g. Bailey et al., 2002), and determine the absolute age of the Swift Run Formation (U-Pb dating of felsic volcanics in collaboration with USGS personnel).

4. The contact between the Catoctin Formation and overlying Weverton Formation has been interpreted to be both conformable (Reed, 1955; Badger and Sinha, 1988) and unconformable (King, 1950; Gathright, 1976; Rader and Evans, 1993) (Figure 2). Some workers consider the Weverton to be equivalent to the upper Unicoi Formation in southern Virginia (Rader and Evans, 1993). Detailed stratigraphic analysis in the Swift Run Gap quadrangle will help to resolve these questions.

5. Quantitatively describe the geometry of brittle fractures in the Blue Ridge, providing baseline data for understanding groundwater occurrence and migration in this part of Virginia. Fracture data will be collected using the methods outlined by Davis and Reynolds (1996) and Mager and Bailey (2000). Mager and Bailey (2000) documented a complex fracture geometry in the Blue Ridge basement complex in the Madison area (20 km from

the Swift Run Gap quadrangle), it is unclear whether the complex fracture geometry is present in cover rocks on the west limb of the anticlinorium.

Justification for this study:

•Existing geologic maps of the area are at scales of 1:62,500 or smaller (Allen, 1963; Brent, 1960; Gathright, 1972; Virginia Division of Mineral Resources, 1993). Few detailed geologic maps have recently been completed in the Virginia Blue Ridge and most of the published maps are at least thirty years old. Recent geologic research by William & Mary geologists in the north-central Virginia Blue Ridge indicates that existing maps are inaccurate at 1:24,000 scale (Bailey et al., 2003). New geologic maps are needed that accurately show the distribution of rock types and delineate the orientation and density of fractures.

•The USGS is currently working to better understand the geologic evolution of Shenandoah National Park (FEDMAP Project titled "Appalachian Blue Ridge Landscapes"). New data and detailed geologic maps of the region are needed. We are working closely with USGS personnel to unravel the thermal history (with U-Pb, Ar-Ar, fission track dating) of the region.

•Greene County, Virginia is experiencing rapid population growth and development from the Charlottesville-Albemarle area (~25 km to the south). Many agricultural and forested tracts at the base of the Blue Ridge will be developed as home sites in the next decade. Accurate geologic maps are key to understanding hazards (debris flow and flood potential) and the existing groundwater resources.

• William & Mary undergraduates have made good use of previous EDMAP support. In 1999 three William & Mary undergraduates mapped in the Madison, Virginia area of the Blue Ridge province with EDMAP support. The resulting geologic map (with associated cross sections structural data, and write-up) was published by the Virginia Division of Mineral Resources (Bailey et al., 2003). These same students also presented posters on their Blue Ridge research at the Southeastern meeting of the Geological Society of America (Berquist and Bailey, 2000; Mager and Bailey, 2000; Shotwell and Bailey, 2000). In 2001 three William & Mary undergraduates mapped in the Columbia, Virginia area of the Piedmont province with EDMAP support. This map is currently being finished for submission to the Virginia Division of Mineral Resources. Support from the 2001 EDMAP project led to a student presented poster at the Southeastern meeting of the Geological Society of America (Koteas et al.,, 2002) and a Virginia Geological Field Conference (Spears and Bailey, 2002). EDMAP funding has been used not only to provide William & Mary students with mapping experience, but the results of that research are meaningful and are being communicated to a larger scientific audience. Of the six William & Mary undergraduates supported by the 1999 and 2001 EDMAP projects; three are currently pursuing advanced degrees in tectonics, two are employed as consulting geologists, and the other is a high school earth science teacher.

STRATEGY FOR PERFORMING THE GEOLOGIC MAPPING

Our strategy for achieving our scientific objectives will start with traditional fieldwork. All stations will be precisely located with GPS receivers and plotted on field sheets. All data (rock type, structures, etc.) will be compiled as metadata files and information on field sheets will be transferred to digital base maps on labtop computers in base camp at the end of each day in the field. The geologic maps and cross sections will be constructed in an iterative fashion using GIS and Adobe Illustrator software. Samples will be collected from key exposures for petrographic, geochemical, kinematic, and strain analyses in the laboratory. Stratigraphic sections will be measured at a number of locations. We anticipate collecting between 500 and 1,000 structural measurements for the entire quadrangle.

TIMETABLE AND MENTORING STRATEGY

The 2004 William & Mary Geologic Field Methods class (~15 undergraduates) will map approximately 30 km^2 in Shenandoah National Park during Spring Break (March). Most of the mapping by Bailey, Forte, Hasty, and Wooton in 2004 will occur during an eight-week field season (June-August). Completion of the mapping will occur during a week long field excursion in January 2005. We plan to work closely with Dr. L. S. Eaton (James Madison University) who is submitting an EDMAP proposal to map surficial deposits in the McGaheysville quadrangle (immediately west of the Swift Run Gap quadrangle, Figure 1). Over the next few years we plan to collaborate on a variety of bedrock and surficial projects across the Blue Ridge. James Madison University undergraduates with an interest in structure and petrology will be involved in our work and William & Mary undergraduates with an interest in surficial processes will work with Dr. Eaton.

Professor Bailey will spend the majority of the summer in the field with three rising-senior geology students. Each student will have a particular problem and a region that they are responsible for mapping. All geology majors at William & Mary are required to complete a year-long senior research project, thus mapping completed during the summer will be followed up with detailed laboratory analysis during the school year and a reviewed thesis before graduation in May 2005. In the last six years, 25 William & Mary undergraduates have presented the results of their research at Geological Society of America meetings. We plan to lead a field trip for VDMR and USGS personnel in the Swift Run quadrangle this coming summer.

DELIVERABLES

Copies of paper and digital geologic maps and cross sections, with appropriate descriptions and illustrations will be provided for review to EDMAP and VDMR for either open file or publication. The bedrock geology of the Swift Run Gap 7.5' quadrangle will be completely mapped at 1:24,000 scale.

PROJECT PERSONNEL

1. Professor Christopher M. Bailey has been conducting geologic research in the Blue Ridge province of Virginia since he was an undergraduate in the late 1980's. Over the last ten years he has mapped at a variety of scales in the Virginia and North Carolina Blue Ridge and Piedmont, Basin & Range, and Coast Mountains of British Columbia. Since 1996 he has advised 41 undergraduates conducting field research, co-authored seven peer reviewed papers with undergraduate co-authors and seventeen abstracts with undergraduate co-authors.

2. Adam Forte will be a rising-senior at the College of William & Mary. Some of his undergraduate course experience includes Structural Geology, Sedimentology and Stratigraphy, and Geological Field Methods. His will focus on fracture geometry characterization across the west limb of the Blue Ridge anticlinorium. He will map the western third of the Swift Run quadrangle.

3. Brian Hasty will be a rising-senior at the College of William & Mary. Some of his undergraduate course experience includes Petrology, Sedimentology and Stratigraphy, Geological Field Methods, and Regional Field Geology. His thesis topic will involve trying to better understand the stratigraphy and deformation history of the Swift Run Formation. He will map much of the area within Shenandoah National Park.

4. Kathleen Wooton will be a rising-senior at the College of William & Mary. Some of her undergraduate courses include Petrology, Structural Geology, and Regional Field Geology. She plans to focus on understanding the petrology and structural geometry of the Blue Ridge basement complex. She will map the southeastern part of the Swift Run Gap quadrangle.

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ABBREVIATED C.V.

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Professional Preparation
1994 Ph.D. (structural geology) Johns Hopkins University
1991 M.A. (structural geology) Johns Hopkins University
1989 B.S. (with Highest Honors) College of William & Mary

Appointments
2003: Visiting Scholar, Department of Geosciences, University of Arizona, Tucson, AZ
2001-: Associate Professor of Geology, College of William & Mary, Williamsburg VA
1996-2001: Assistant Professor of Geology, College of William & Mary, Williamsburg VA
1994-1996: Assistant Professor of Geology, Denison University, Granville OH

Recent Publications

Bailey, C. M., Mager, S. M.*, Gilmer, A. G.*, and Marquis, M. N.* *in press*. Monoclinic and triclinic high-strain zones: examples from the Blue Ridge province, central Appalachians. *Journal of Structural Geology. 2004*

Bailey, C. M., Francis, B. E., and Farhney, E. E.* *in press*. Strain and vorticity analysis of transpressional high-strain zones from the Virginia Piedmont, USA. Transport and flow processes in shear zones: *Special Publication, Geological Society of London. 2004*

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Davidson, C. M., Davis, K. J*, **Bailey, C. M.**, Tape, C. H.*, Singleton, J.*, and Singer, B. 2003. The age, origin, and significance of brittle faulting and pseudotachylyte along the Coast shear zone, Prince Rupert, British Columbia. *Geology*, v. 31, p. 43-46.

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* undergraduate co-author

Synergistic Activities

Co-convener of topical session 'Geometry, Kinematics, & Vorticity of High-strain Zones' at GSA annual meeting, October 2002

Co-convener of GSA Field Forum 'Kinematics and Vorticity of High-strain Zones', April 2002

Co-leader Virginia Geological Field Conference, October 2002

Creator of 'Geology of Virginia Website' 1997-present (http://www.wm.edu/CAS/GEOLOGY/virginia/index.html)

Awards

Thomas Jefferson Teaching Award, College of William & Mary, 2002

Geological Society of America Biggs Award for Excellence in Geoscience Education, 1999

Undergraduate Thesis Advisees in last 5 years (with graduate institution attended/attending)

Lorrie Coiner '99 (Vanderbilt)
Amy Gilmer '99 (UT-Austin)
Ashley Griffith '99 (U-Mass, Stanford)
Sara James '99 (Northern Arizona)
Brian Knight '99 (UT-Austin)
Peter Berquist '00 (Vanderbilt)
Stephanie Mager '00 (Auburn)
Rich Santoro '00
Nate Shotwell '00
Jonathan Weiss '00 (U-Hawaii)
Ken Davis '01 (UC-Santa Barbara)
Lisa Coughlin '01 (W&M, educ)
John Dubose '01 (USC, law)
Eleanor Eyster '01
Barbara Francis '01 (U-Minnesota)
Matt Goodman '01
Chris Koteas '02 (Vanderbilt)
Jon Relyea '02
Ethan Weikel '02
Jay Chapman '03
Lina Polvi '03
Caroline Webber '03 (U-Wisconsin)

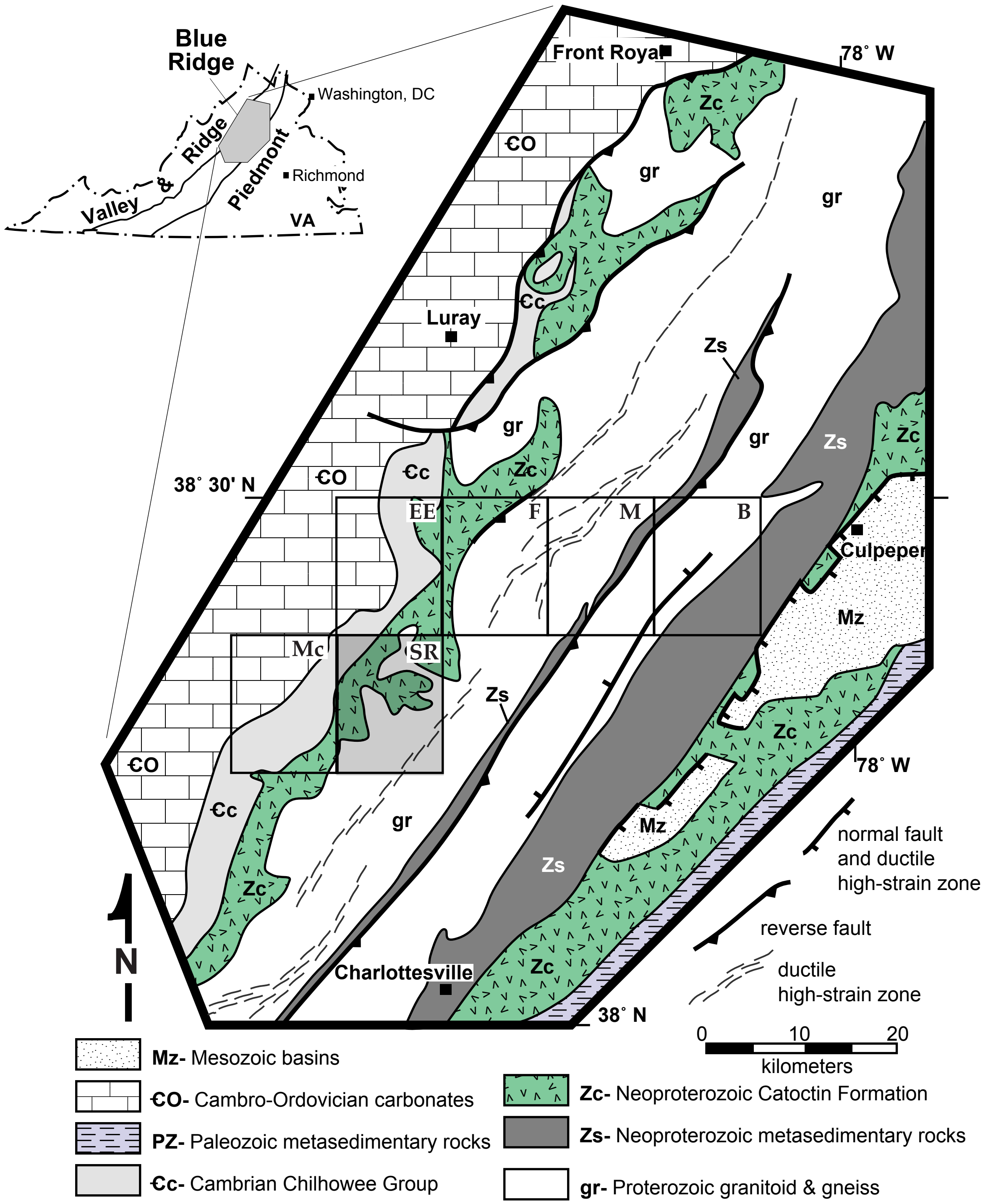

Figure 1. Generalized geologic map of the north-central Virginia Blue Ridge. Modified from Virginia Division of Mineral Resources (1993) and more recent 1:24,000 scale mapping. Rectangles are 7.5' quadrangles. B- Brightwood (Bailey and others, in prep.), EE- Elkton East (Bailey, future mapping), F- Fletcher (Tollo and others, in prep.), M- Madison (Bailey and others, 2003), Mc- McGaheysville (Eaton and others, EDMAP 2004), SR- Swift Run Gap (Bailey and others, EDMAP 2004).

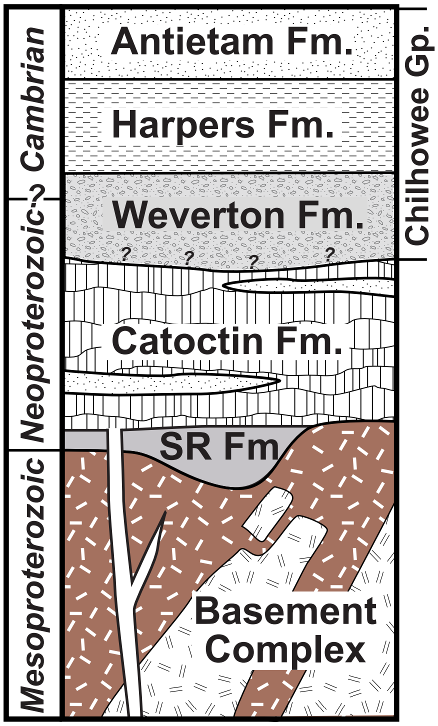

Figure 2. Generalized stratigraphy of the western Blue Ridge in the vicinity of the Swift Run Gap 7.5' quadrangle. Basement Complex includes at least two generations of Grenville-age plutons. The contact between the Catoctin Formation and Weverton Formation has been interpreted as both conformable and unconformable by previous workers.

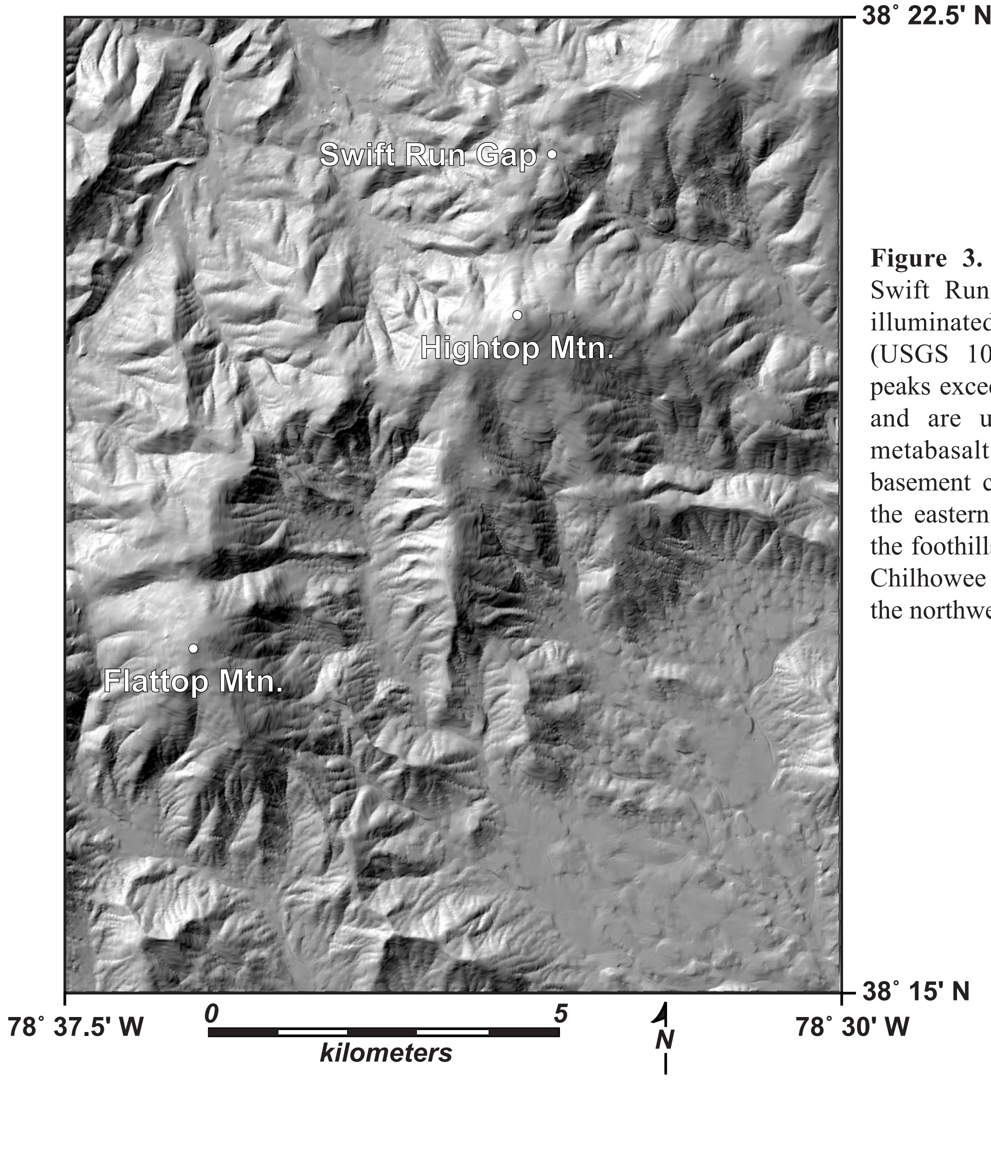

Figure 3. Shaded DEM of the Swift Run Gap 7.5' quadrangle illuminated from the northwest (USGS 10 meter data). High peaks exceed 1000 m in elevation and are underlain by Catoctin metabasalts. Mesoproterozoic basement complex is exposed on the eastern flank of range and in the foothills to the southeast. The Chilhowee Group is exposed on the northwest flank of the range.