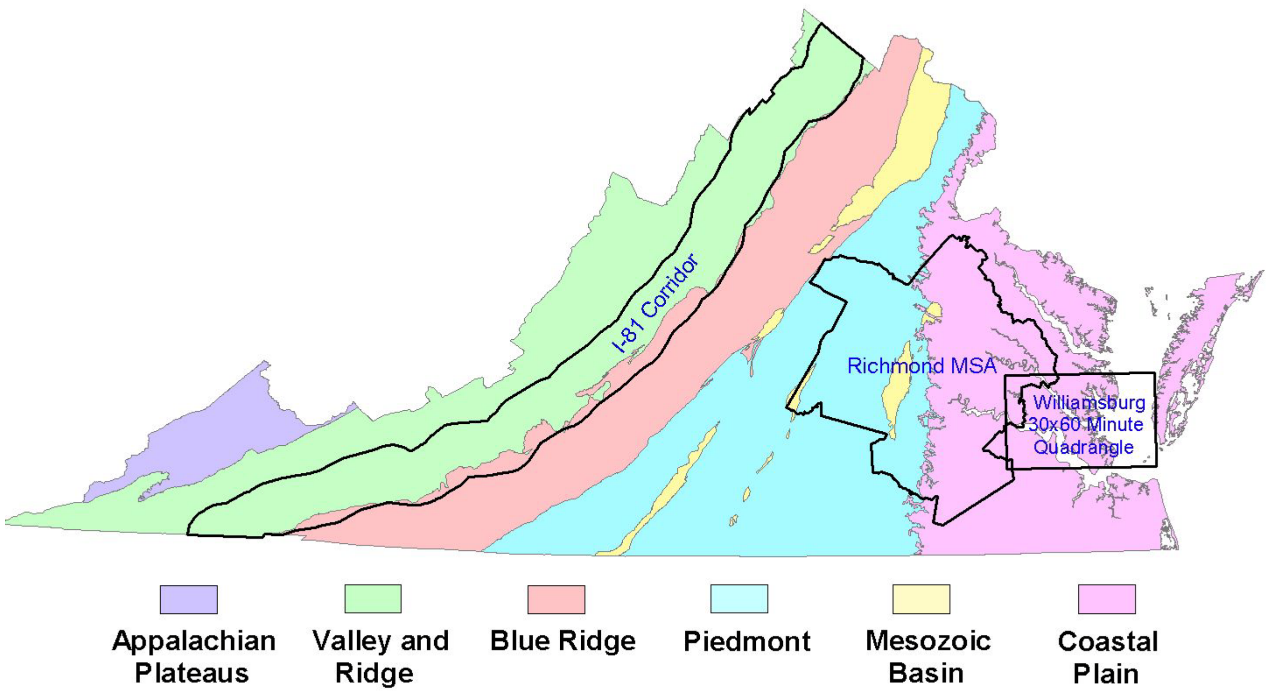
STATEMAP PROPOSAL - VIRGINIA

Submitted in response to USGS Program announcement
No. G12AS00007



Virginia Department of Mines Minerals and Energy

November 2, 2011

INTRODUCTION

The Virginia Department of Mines, Minerals and Energy, Division of Geology and Mineral Resources (DGMR) seeks continued funding for geologic mapping along the Interstate 81 corridor, in the Richmond Metropolitan Statistical Area, and in the Williamsburg 30- x 60-minute quadrangle. These long-term projects focus our efforts on three regions of Virginia that are in great need of new and accessible geologic information. The maps we produce will enhance Virginia's ability to develop and conserve natural resources in a safe and environmentally sound manner to support a more productive economy.

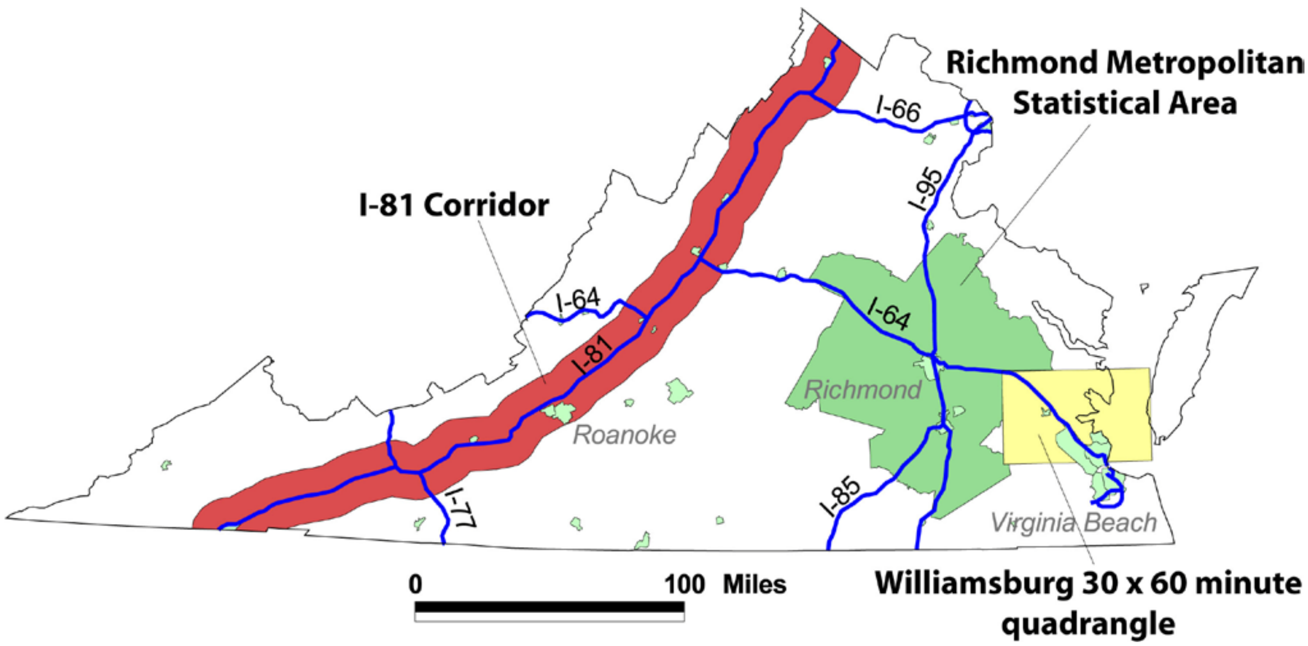


Figure 1. Locations of proposed project areas.

Long Range Plan

In October 2003, DGMR's Geologic Mapping Advisory Committee (GMAC) agreed that geologic mapping is needed in Virginia to locate water resources, develop economic products such as aggregate and sand, identify geologic hazards, protect natural resources, site waste disposal facilities, and develop roads and other infrastructure. The GMAC and DGMR staff evaluated areas in Virginia with respect to these needs and Virginia's diverse geology and natural resources (Figure 2). At the end of this process, three areas where mapping would provide the greatest benefit were identified: western Virginia, particularly along the I-81 corridor; the Richmond metropolitan area; and along the I-64 corridor between Richmond and Virginia Beach. The GMAC reconfirmed these priorities at its Septaember 2011 meeting. A long-term mapping strategy has been developed for each area. These strategies consider regional needs, development patterns, mineral resources, the location of existing mapping, and staff resources.

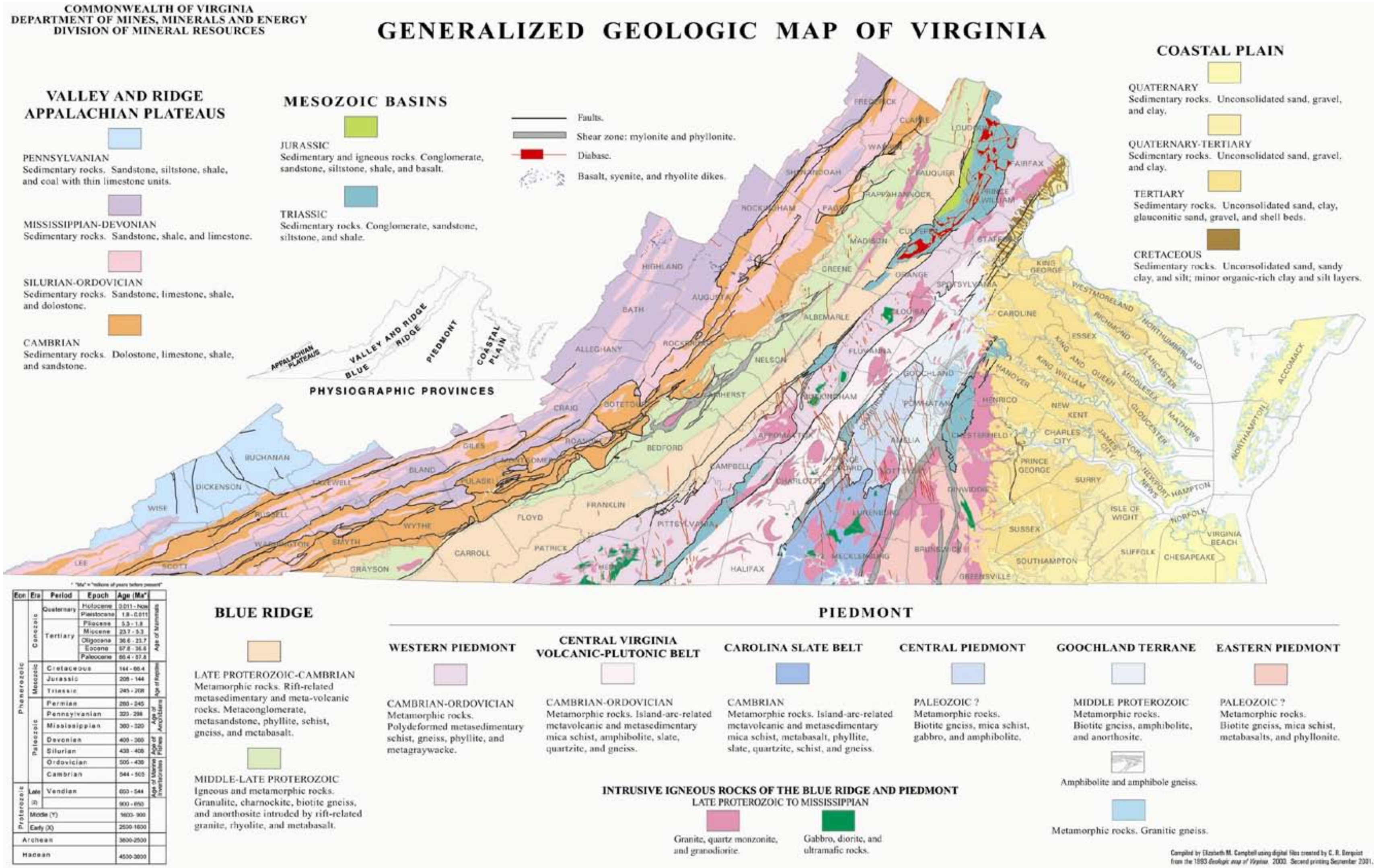


Figure 2. Generalized geologic map of Virginia.

Virginia Growth

Virginia is home to nearly eight million people (Weldon Cooper Center, 2009). The population of our state is expected to reach almost ten million people by 2030 (U.S. Census Data, 2005). Two thirds of this growth is expected in the Washington D.C., Richmond, and Virginia Beach–Norfolk–Newport News areas (Figure 3). Much of the remaining growth will occur near major highways such as Interstate 81.

Nearly one million people currently live within the twelve counties and ten cities that straddle I-81 (Weldon Cooper Center, 2009). The population in this region is expected to grow more than 15 percent between 2000 and 2030 (Virginia Employment Commission, 2003). Approximately 90 percent of this growth is expected to occur in areas that are currently unincorporated.

Approximately 1.2 million people live in sixteen counties designated as the Richmond Metropolitan Statistical Area (Weldon Cooper Center, 2009). Municipal centers include the cities of Richmond, Petersburg, Hopewell, and Colonial Heights. The population of this area is expected to grow approximately 35 percent by 2030 (Virginia Employment Commission, 2003). Almost all of this growth is expected to occur outside of existing city boundaries.

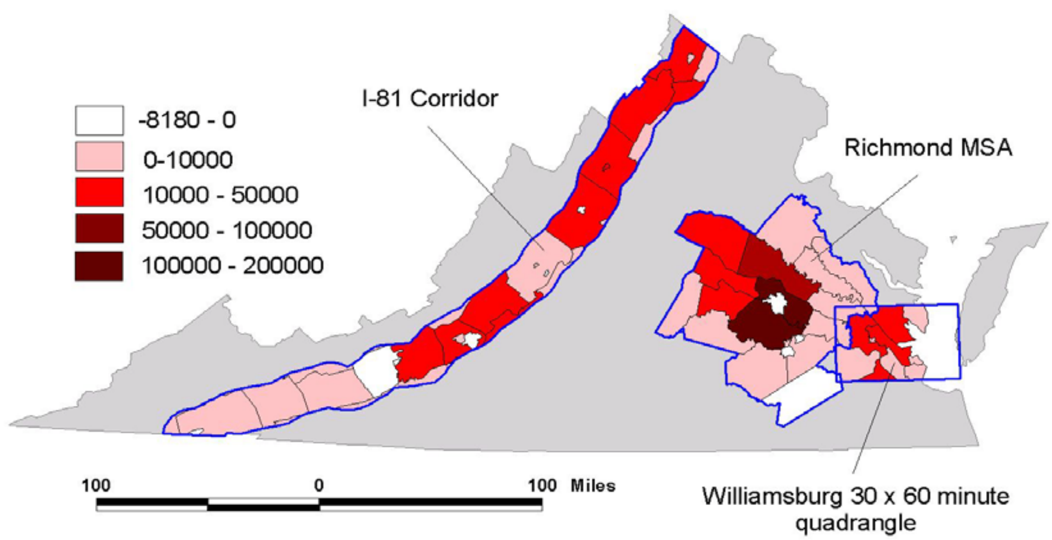


Figure 3. Projected population change, by county and municipality, in proposed project areas from 2000 to 2030 (Virginia Employment Commission, 2003).

Approximately 500,000 people live in the Williamsburg 30- x 60-minute quadrangle (Weldon Cooper Center, 2009). Municipal centers include Hampton, Newport News, Poquoson, and Williamsburg. The population of this area is expected to grow approximately 20 percent by 2030 (Virginia Employment Commission, 2003). Much of the growth will occur outside existing city boundaries.

INTERSTATE 81 CORRIDOR PROJECT

Introduction

DGMR proposes to continue a concentrated multi-year effort to complete new 1:24,000-scale geologic mapping and digitally compile existing geologic maps along the entire I-81 corridor in Virginia. This portion of the Appalachian Valley is where most of the population lives, works, and travels on a daily basis. It is home to a variety of farms, industries, and commercial enterprises. I-81 is also a nationally significant transportation corridor that connects manufacturers and markets from the southern and northeastern United States.

For the purpose of this study, the I-81 corridor is defined to extend for 10 miles (16.1 km) on either side of the highway (Figure 1). DGMR plans to complete 1:24,000-scale geologic mapping of all quadrangles that are wholly or substantially within this corridor. DGMR also plans to selectively map quadrangles that are adjacent to the I-81 corridor in areas of current or projected future growth.

Intermediate products for this study will be 1:24,000-scale geologic maps of single or multiple quadrangles, to be published in paper or digital form, and a series of open-file reports on CD and the internet that contain files for the current extent of the geologic compilation. The final product will be a 1:24,000-scale digital compilation of the entire corridor.

Location and Geologic Setting

I-81 extends for 325 miles in western Virginia, along the Appalachian Valley. It is the longest interstate in Virginia and has 90 interchanges, including intersections with Interstates I-66, I-64, and I-77. Two proposed Interstates, I-73 and I-74, will also intersect with I-81. Since its completion in the 1960s, I-81 has become the “main street” of western Virginia, serving as a corridor for travel, commerce, and development.

Industries and commercial businesses have located in the I-81 corridor to take advantage of the transportation system. Abundant high-quality ground-water supplies in some areas have also attracted industries. The Radford and Holston Army Ammunition plants are major facilities in the corridor. Away from municipal centers, agriculture is dominant. The twelve counties that I-81 passes through contain approximately 11,750 farms on approximately 1.66 million acres (U.S. Department of Agriculture, 2007). This includes nearly 10,000 livestock operations.

The Appalachian Valley contains headwater portions of five major watersheds. Three of these watersheds are located on the eastern side of the eastern continental divide. The Shenandoah-Potomac and James rivers begin in the north and north-central parts of the Valley. Water from these rivers eventually flows into the Chesapeake Bay. The Roanoke River begins in the central Valley and flows into North Carolina where it enters Albemarle Sound and eventually the Atlantic Ocean. The New and Tennessee rivers, in the southern part of the valley, flow northwest and southwest, respectively, and ultimately enter the Mississippi River system.

The I-81 corridor is predominately underlain by clastic and carbonate sedimentary rocks of the Valley and Ridge geologic province. Metamorphic and igneous rocks of the Blue Ridge geologic province underlie a portion of the eastern edge of the corridor. Early to late Paleozoic-age limestone, dolostone, sandstone, and shale comprise much of the Valley and Ridge province. These rocks formed from sediments that were deposited in a variety of terrestrial and marine settings. Folding and faulting of these rocks, predominantly during the Alleghanian Orogeny, has produced complex geologic structures. Subsequent erosion has resulted in a distinctive topography that is dominated by alternating linear ridges and valleys. The stratigraphic sequence in the Valley and Ridge geologic province was mapped at a scale of 1:250,000 by Butts (1933; 1940). Subsequent 7.5-minute quadrangle, county, and 30- x 60-minute quadrangle mapping in portions of the project area has identified additional evidence for faulting and folding and refined the stratigraphy. STATEMAP mapping and compilation projects continue to identify map-scale structures, harmonize the portrayal of regional tectonic features, and establish consistent nomenclature in this portion of western Virginia.

Rocks of the Blue Ridge geologic province are Middle to Late Proterozoic and early Paleozoic in age. The older rocks exist as basement and are nonconformably overlain by the younger rocks. Both groups of rocks may overlie a major decollement and sit atop rocks that are thought to be correlative to those exposed in the Appalachian Valley. Contacts between Blue Ridge rocks are commonly sheared, making original relationships difficult to determine.

Purpose and Justification

Water resource location, economic product development, geologic hazard identification, natural resource protection, and infrastructure development are important issues along the I-81 corridor. Some of these issues are at a critical stage. Locating aggregate sources and identifying geologic hazards is very important as Virginia considers capacity improvements for I-81 that include lane additions and an adjacent long-haul rail system. The need to locate additional water resources continues as development expands. The need to protect natural resources including river systems, forests, ground-water supplies, mineral resources, cave systems, and open space is also increasing in response to development pressures. This project will provide useful information at an appropriate scale to address the issues identified by the GMAC in the following ways:

Water Resource Location

Cities and towns in western Virginia obtain their water supplies from ground-water aquifers, surface reservoirs, or a combination of the two. Away from municipal centers, drilled wells are the primary water sources for residents, businesses, and industry. Well yields vary depending upon rock type, location, and depth. In karst and fractured rock aquifers, well yields are unpredictable. Supplies are typically adequate for residential use, but higher yield supplies for industries and municipalities are more difficult to locate. Some surficial deposits in the Appalachian Valley are significant reservoirs for ground water. Ground water residing in alluvial fan deposits supplies many businesses in the Valley, including those that require a high quality water source such as MillerCoors Shenandoah Brewery, Merck Chemical, Hershey's Chocolate, Invista, and McKee Foods. Detailed geologic mapping will provide useful information to municipalities, businesses, and industries when situating future wells.

Economic Product Development

There are 79 active mine and quarry operations in the twelve counties along I-81. These businesses produce significant quantities of crushed stone, clay, sand, gravel, dimension stone, and industrial minerals. Aggregate resources provide local sources for high-demand construction materials. Industrial minerals including iron oxides, high-calcium limestone, salt, and silica are exported, providing business income and local jobs. The potential for additional aggregate and high-calcium resources exists along the I-81 corridor. The identification of these resources for quarrying will support continued economic development in the region.

Geologic Hazard Identification

Sinkholes are significant hazards along large parts of the I-81 corridor. Many sinkhole collapses result from changes in water use, drainage, or recharge due to changes in land use and construction-related disruption of natural drainages. Landslides, debris flows, and unstable slopes are also hazards. These types of problems are common in the northern half of the corridor where the Blue Ridge Mountains meet the Appalachian Valley and in the southern half of the corridor where the hill slopes are steep. Landslides, debris flows, and extensive reworking of alluvial boulder deposits can occur during periods of heavy rainfall, such as those experienced during Hurricane Isabel in 2003 and Hurricane Ivan in 2004 (Wieczorek and others, 2009). Even on moderate slopes, some rock types and geologic structures create stability problems for structures and roads.

Natural Resource Protection

Development pressures within the I-81 corridor are resulting in changes in land use. Open space is being converted to industrial, commercial, and residential use. These changes have both positive and negative effects on the region's natural resources. In many cases, the geology can play an important role in the nature, type, and extent of these impacts. Detailed geologic maps will provide useful information to land use planners, natural resource caretakers, and environmental consultants who work in the corridor.

Water quality is a significant problem in the region and ultimately impacts water quality in the Chesapeake Bay. Although significant pollutant reduction strategies are currently underway, point and non-point pollution sources, including agricultural runoff, outdated water treatment facilities, failing septic systems, and excessive sedimentation continue to degrade ground- and surface-water quality. One third of monitored streams and rivers in the Shenandoah-Potomac basin are not supporting designated uses that include providing aquatic or wildlife habitat, fish for consumption, public water supply, or outdoor recreation (Virginia Department of Environmental Quality, 2008).

Roads and other Infrastructure Development

A statewide expansion of I-81 continues to be considered; major widening has already begun in the Lexington and Christiansburg areas. This expansion project would likely include the widening of the interstate, and possibly the installation of rail along the corridor and other improvements. Additional projects include the construction of I-73 and I-74 in the vicinity of Roanoke. Commercial, industrial, and residential development and associated utilities will likely follow road construction and expansion projects. Detailed geologic maps will provide useful information to the Virginia Department of Transportation, municipal and private utilities, and private and public land developers during this process.

Science Issues

The geology of the Valley and Ridge Province in Virginia has been studied for nearly 200 years. It is a classic area of research in carbonate stratigraphy, invertebrate paleontology, and thin-skinned tectonics. Major research activities include relating lateral and temporal changes in depositional environments to orogenic activity and climate change, and unraveling the nature and timing of deformation during the Alleghenian Orogeny. More recent research has focused on the modeling of ground water flow in faulted and folded clastic-carbonate bedrock terrain, documenting the extent of karst systems and their role in ground water transport, and understanding the geomorphic evolution of the Shenandoah River Valley. Our mapping program directly supports all of these areas of research by providing basic geologic information and regularly consulting with researchers. In addition, our employees and contractors are regular contributors at Geological Society of America and other professional meetings.

Strategy for Performing Geologic Mapping

Most 7.5-minute quadrangles in the I-81 corridor have geologic map coverage that falls into one of the following categories: published mapping at 1:24,000 scale; unpublished or published mapping at a scale between 1:50,000 and 1:100,000; unpublished or published mapping at a scale of 1:125,000 or 1:250,000; and mapping at a scale smaller than 1:250,000 (Figure 4). Our strategy is to compile existing blocks of published 1:24,000-scale maps and bring the level of mapping in other quadrangles up to 1:24,000-scale resolution. Geologic and digital compilation will be continually expanded as new quadrangles are mapped.

Quadrangles will be prioritized to include areas:

- where new geologic mapping is needed to address an important environmental, development or natural resource issue;
- adjacent to previously compiled geologic maps;
- where existing geologic mapping is nearly 1:24,000 resolution;
- where existing geologic mapping has been completed at 1:100,000-scale.

This project requires mapping approximately 70 7.5-minute quadrangles. Half of these quadrangles have not previously been mapped at a scale of greater than 1:250,000. The final product will be a digital compilation of these maps and approximately 60 additional quadrangles. It is anticipated that the I-81 corridor geologic mapping project can be completed in approximately 9 years with full funding and continued collaboration with the USGS and state universities through the FEDMAP and EDMAP programs. For 2011-2012, we propose the following activities:

1. New Geologic Mapping (2 quadrangles)

This project will build upon our 2004 - 2011 STATEMAP geologic mapping effort, consisting of 24 quadrangles. This year, we will map the Glenvar (½), Rileyville (½), and Timberville quadrangles (Figure 5). These quadrangles are entirely or substantially within the I-81 corridor.

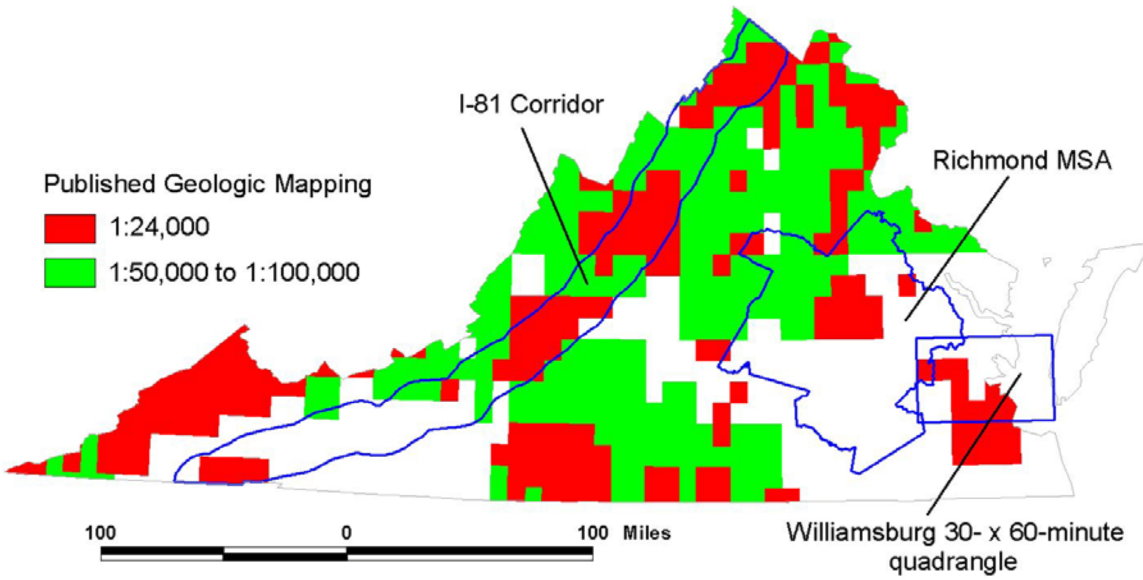


Figure 4. Published geologic map coverage in Virginia prior to the initiation of long-term mapping projects in 2003. Best geologic coverage for unshaded areas are 1:125,000- and 1:250,000-scale maps of the Coastal Plain and Appalachian Valley or the 1:500,000-scale state geologic map.

Lorrie Coiner will be mapping half of the Glenvar quadrangle. **Steve Whitmeyer** will be mapping half of the Rileyville quadrangle; the remaining half of the quadrangle will be mapped by James Madison University students through the EDMAP program. **Matt Heller**, in cooperation with **Randy Orndorff** through the FEDMAP program, will be mapping the Timberville quadrangle. **Hannah Shepherd** will assist with field work on the Glenvar and Timberville quadrangles.

The Glenvar quadrangle has only been mapped at a scale of 1:250,000 (Butts, 1933). The Timberville and Rileyville quadrangles have been mapped at 1:100,000-scale (Rader and Gathright, 2001). Work in all three areas will include collecting additional data to bring the maps up to 1:24,000-scale, updating stratigraphy as needed, and modifying contacts and map-scale structures to match recent mapping in adjacent areas.

As part of the mapping program, samples that are representative of significant map units will be collected. One portion of these samples will be submitted for whole rock chemical analysis. A second portion will be used to make thin sections. A third portion will be placed into our rock repository. Whole rock analyses will include major, minor, trace and rare earth elements. The analytical results will be used to correlate rock types and identify potential mineral resources, including high-calcium limestone. The results will be compiled into a database that is available to the public. One anticipated use is to identify the background concentrations of metals such as arsenic, barium, cadmium, chromium, lead, and mercury that are routinely detected in soil and ground water during environmental investigations. Physical testing of potential aggregate resources may also be completed.

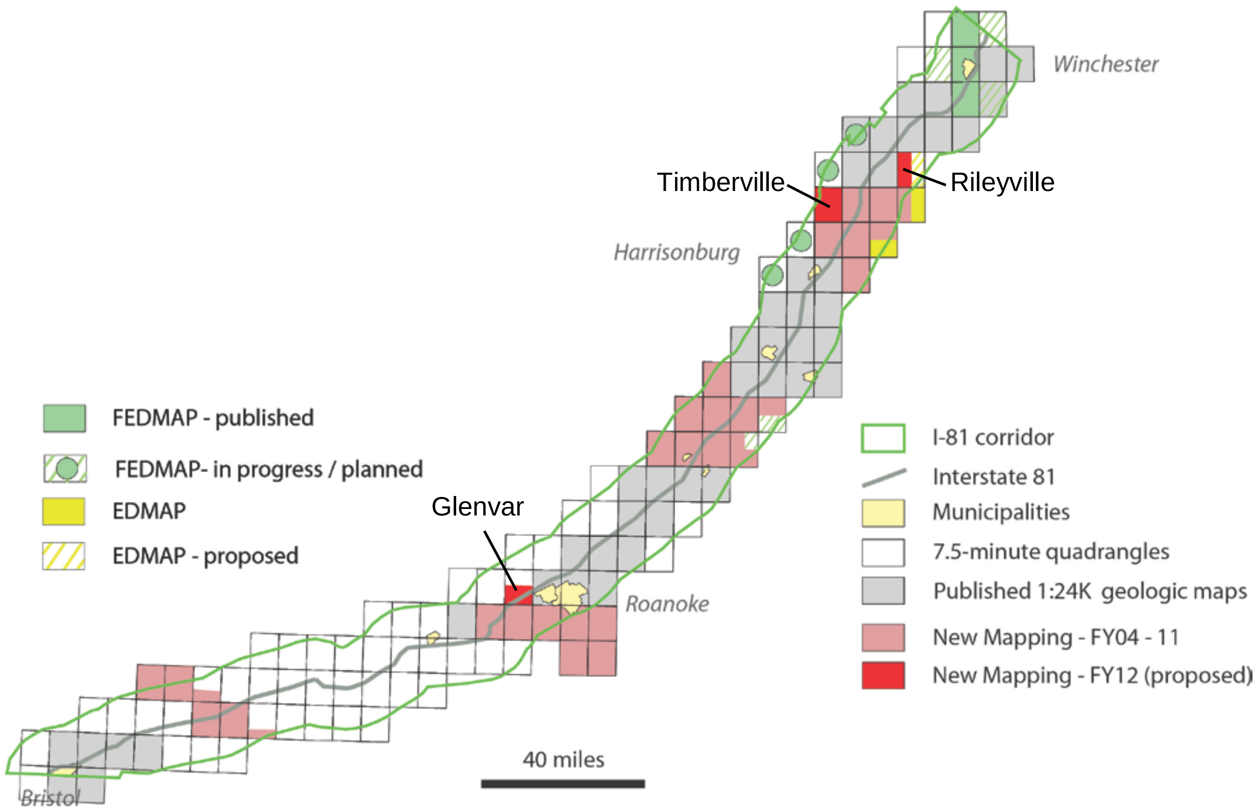


Figure 5. 7.5-minute quadrangles proposed for new geologic mapping within the I-81 corridor project. FY = Federal fiscal year.

2. Geologic Compilation of Existing Maps (4 quadrangles)

This project will build upon our 2003 through 2011 STATEMAP geologic compilation, consisting of 39 7.5-minute quadrangles. This year we will add the Pulaski, Riner, Toms Brook, and Woodstock quadrangles (Figure 6). These quadrangles are wholly or substantially within the I-81 Corridor.

The Toms Brook quadrangle was mapped by Rader and Biggs (1976). The Woodstock quadrangle was mapped by Young and Rader (1974). The Pulaski and Riner quadrangles were mapped by Mervin Bartholomew and his students at Virginia Tech in the 1980s, but were never published. For this project, data will be collected at new exposures and in other area to improve data density and resolve stratigraphic and structural inconsistencies. In addition, digital terrain models will be created and used to improve the resolution and accuracy of mapped surficial deposits. **Bill Henika** will complete field checking of the Pulaski and Riner quadrangles. **Lorrie Coiner** will complete field checking and GIS compilation of the Woodstock quadrangle. **Aaron Cross** will complete field checking and GIS compilation of the Toms Brook quadrangle. **Hannah Shepherd** will assist with the digital compilation of the four quadrangles.

The digital compilation of these quadrangles will utilize the standard format for geologic map publications developed by the National Cooperative Geologic Mapping Program of the USGS (NCGMP09 standard database schema). This compilation will be an ESRI geodatabase that will include the principal map view, cross-sections, FGDC Digital Cartographic Standard symbology, feature-level metadata, standard lithology descriptions, geochemistry data, reference glossary, and data sources. We also intend to use these updated files to make publishable maps of all three quadrangles.

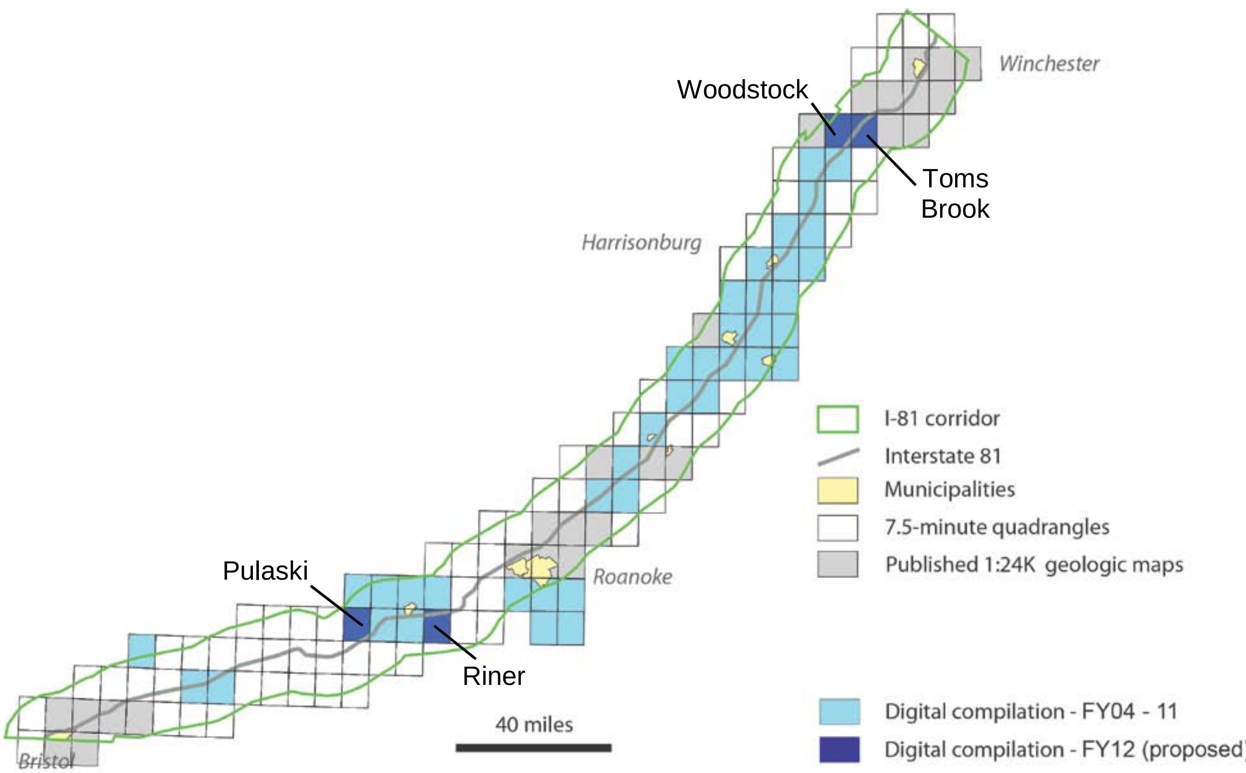


Figure 6. 7.5-minute quadrangle proposed for new digital compilation within the I-81 corridor project. FY = Federal fiscal year.

Preliminary Results and Previous Work

Between 2004 and 2011 new geologic mapping of approximately 31 7.5-minute quadrangles has been completed within the I-81 Corridor, including six quadrangles mapped through FEDMAP and one quadrangle mapped through EDMAP. Our current STATEMAP project involves mapping the Big Levels (½), Collierstown, and Ironto (¼) quadrangles.

Our 2003-2011 digital compilation projects include a total of 40 1:24,000 geologic maps along the Interstate 81 corridor (Figure 6). Newly acquired and original field data have also been incorporated into the compilation. Approximately 40 months of fieldwork have been completed to resolve map boundary discrepancies, structural complexities, and to provide new data upon which to base cross-sections. Our current STATEMAP digital compilation for the I-81 Corridor project includes the revision and compilation of the Blacksburg and White Gate quadrangles (Figure 6).

New mapping and targeted remapping for this project is helping to refine the stratigraphy and structure of the Valley and Ridge and adjacent Blue Ridge provinces. Field checking along the Blue Ridge front in the Crimora, Waynesboro East, and Waynesboro West quadrangles in 2004-2005, supported by seismic profiles, provided evidence for the existence of the Blue Ridge Fault separating Chilhowie Group rocks from those of the Rome Formation (Williams and others, 2006). Mapping in the Boones Mill, Garden City, and Hardy quadrangles in 2004-2005, supported by geochemical analyses, established genetic relationships among deformed plutonic and volcanic rocks of the Blue Ridge and inner Piedmont (Henika, 2006). Mapping in the Marion and Atkins Quadrangles in 2005-2007 redefined the Hungry Mother Creek and Greenwood faults as remnants of a thrust that overlies the Saltville sheet. Mapping in the Augusta Springs quadrangle in 2006-2007 confirmed the existence of a significant structure, the Little North Mountain Fault (Coiner and Wilkes, 2010). Mapping in the Elkton West and Stanley quadrangles confirmed the presence of east-directed thrusts within and to the east of the Massanutten Synclinorium and has redefined the nature of the Stanley Fault (Heller and others, 2007; Kirby and others, 2008; Whitmeyer and others, 2009). Geochemical analyses completed to support the project provide data on natural concentrations of potentially hazardous metals in bedrock and information about the acid-forming potential of shales in the Shenandoah Valley (Coiner and others, 2007). Mapping of surficial deposits in the Elkton West and Tenth Legion quadrangles has led to an improved understanding of debris-flow occurrence along the Massanutten Range (Heller and Eaton, 2010). Recent mapping in the Broadway and New Market quadrangles has increased the known length of the Saumsville Fault by 25 km; this structure may link the North Mountain and Pulaski fault systems. Recent mapping in the Edinburg Quadrangle has revealed multiple generations of terrace deposits.

Deliverable Geologic Maps

The deliverables for this project will be:

1. Geologic map and cross-section of ½ of the Glenvar quadrangle;
2. Geologic map and cross-section of ½ of the Rileyville quadrangle;
3. Geologic map and cross-section of the Timberville quadrangle;
4. Digitally compiled geology as GIS files for the Pulaski, Riner, Toms Brook, and Woodstock quadrangles (paper copies of each quadrangle that is part of the compilation will also be provided).

RICHMOND METROPOLITAN STATISTICAL AREA PROJECT

Introduction

DGMR proposes to continue a multi-year effort to complete 1:24,000-scale geologic mapping and digital compilation of existing geologic maps in a portion of a 16-county area that has been designated by the U.S. Office of Management and Budget as the Richmond Metropolitan Statistical Area (MSA). According to the U.S. Census Bureau website, "the general concept of a metropolitan or micropolitan statistical area is that of a core area containing a substantial population nucleus, together with adjacent communities having a high degree of social and economic integration with that core." DGMR and the GMAC have targeted the Richmond MSA for investigation because it is a recognized jurisdiction that encompasses the area of future growth around Virginia's capital, the City of Richmond.

The Richmond MSA straddles the Piedmont and Coastal Plain provinces. It is situated at the intersection of three major interstates: I-95, I-64, and I-85 (Figure 1). This area is home to approximately one in seven of Virginia's citizens, contains nearly every type of business and industry, and is home major military installations, including Fort Lee. Outside of developing areas, agriculture is a stable part of the economy, with approximately 4,300 farms on nearly 900,000 acres (U.S. Department of Agriculture, 2007). This area encompasses all or a portion of six regional planning districts.

DGMR has ranked the 95 unpublished 7.5-minute quadrangles that are substantially within the Richmond MSA either a high or low priority. This ranking is based upon societal needs identified by the planning districts or other government agencies and the potential for mineral resources or geologic hazards. Quadrangles that are assigned a high priority ranking meet one or more of the following criteria:

- Significant change in land use anticipated;
- High potential for mineral resources;
- Known geologic hazards exist;
- Population center or highly developed area;
- Situated along an Interstate;
- Within the epicentral area for the August 23, 2011 magnitude 5.8 earthquake centered in Louisa County (added at the 9/28/2011 GMAC meeting)

The goal of this project is to complete 1:24,000-scale geologic mapping of all quadrangles in the MSA that are identified as high priority (Figure 7). An ultimate goal is to use this data in combination with existing data on the low-priority quadrangles to create a 1:100,000-scale geologic map of the entire MSA. Intermediate products for this study will be 1:24,000-scale geologic maps of single or multiple quadrangles, to be published in paper or digital form, and a series of open-file reports on CD and the internet that contain GIS files for the current extent of the geologic compilation.

Location and Geologic Setting

The Richmond MSA encompasses 16 counties in the Piedmont and Coastal Plain of Southeast Virginia. The cities of Richmond, Petersburg, Colonial Heights, and Hopewell are located along interstates I-95, I-64, I-85, and I-295. Several major U.S. Highways connect these cities with smaller communities both inside and outside of the MSA. The region contains significant portions of three river basins; from north to south they are the York, James, and Chowan. The lower portions of the York and James rivers flow through the area and into the Chesapeake Bay. Several smaller rivers form the headwaters of the Chowan River and become part of the Albemarle-Pamlico watershed. The Chesapeake Bay and the lower reaches of the Albemarle-Pamlico watershed represent the largest and second largest estuarine systems in the United States, respectively.

The western half of the Richmond MSA is located in the Piedmont physiographic province. Crystalline rocks in the Piedmont portion of the MSA may be assigned to three separate tectonic terranes. From west to east they are the Chopawamsic terrane, the Goochland terrane, and the Southeastern Piedmont terrane. The Chopawamsic terrane contains metavolcanic, metaplutonic and metasedimentary rocks of similar age that are believed to have formed in an early to middle Paleozoic-age volcanic arc (Coler and others, 2000). The Goochland terrane is composed of multiply-deformed igneous rocks and metamorphic rocks of uncertain affinity. At least a portion of the Goochland terrane is Mesoproterozoic in age. The Goochland terrane is separated from the Chopawamsic terrane by the Spotsylvania fault and is separated from the Southeastern Piedmont terrane by the Hylas fault (Spears and others, 2004). The Southeastern Piedmont terrane contains a variety of metamorphic rocks, some of which appear to have volcanic protoliths. The late Paleozoic-age Petersburg Granite intrudes a substantial portion of the Southeastern Piedmont terrane in the project area. Another portion is unconformably overlain by Mesozoic-age sedimentary rocks of the Richmond and Taylorsville basins, which were deposited in a series of half-grabens. All three of these basins have had historic coal production and oil and gas exploration.

The central part of the Richmond MSA lies within the Fall Zone. In this complex zone, Coastal Plain sediments overlie rocks of the eastern Piedmont, and both sediment and bedrock are exposed and mappable. Much of the eastern part of the Richmond MSA is within the Coastal Plain. Cretaceous through Holocene sediments in the Coastal Plain form an eastward-thickening wedge as much as 1,000 feet thick. These sediments overlie Precambrian to Mesozoic rocks. Estuarine and fluvial sediments of Miocene-Pliocene age cap the higher elevations and become thicker to the east.

Purpose and Justification

Water Resource Location

The City of Richmond and nearby counties of Henrico and Chesterfield in the Richmond MSA obtain their water supplies from surface sources, including the James River. Most other public and private water supplies in the MSA are groundwater-based. Recharge areas for major Coastal Plain aquifers are present in the area. Mapping in the areas where these units crop out is providing an opportunity to better understand the characteristics of these important units.

Shallow wells in the Coastal Plain may be vulnerable to surface contamination. In fractured crystalline rock aquifers, well yields are unpredictable, although supplies are typically adequate for residential use. Higher yield supplies for industries and municipalities are more difficult to locate. Detailed geologic mapping will also provide useful information to municipalities, businesses, and industries when siting reservoirs and wells.

Economic Product Development

The Richmond Metropolitan Statistical Area (MSA) currently contains 89 active mine and quarry operations that produce economically significant quantities of crushed stone, clay, sand, gravel, and industrial minerals. Crushed stone, clay, sand, and gravel resources provide local sources for high-demand construction materials. Industrial minerals including feldspar, vermiculite, and fuller's earth are exported from the Richmond area, providing business income and local jobs. Titanium and zircon are currently being produced from a nationally significant heavy mineral mine in the southern part of the MSA.

Past mineral production in the Richmond MSA includes many commodities not currently being produced, but which may have potential for redevelopment in the future. Coal from the Mesozoic Richmond Basin was produced locally for over two hundred years; while it's not likely that coal mining will return to Richmond, deep coal deposits have been explored in recent years for coal bed methane. Building and dimension stone played a significant role in the growth and development of the City of Richmond until the 1940s. Gold, sulfide minerals, and mica were produced in the past and may still be present in significant quantities. Improvements in technology or changes in demand may make some of these commodities economically viable in the future. Detailed geologic maps will be critical for the evaluation and development of these resources.

Geologic Hazard Identification

Known geologic hazards in the Richmond MSA include earthquakes, acidic soils, shrink-swell soils, subsidence in the vicinity of abandoned underground mines, flooding, slope stability, and unsafe levels of radon and other potentially hazardous naturally occurring elements in soil and ground water. The western part of the Richmond MSA is within the Central Virginia Seismic Zone. Small magnitude earthquakes within this area are common, occurring every year or two. The frequency of larger earthquakes such as the August 23, 2011 magnitude 5.8 earthquake centered in Louisa County is entirely unknown.

In light of the recent earthquake, a better understanding of the location and attitude of faults in the western part of the Richmond MSA is clearly needed. A lack of detailed geologic mapping and sparse seismic monitoring in the epicentral region delayed the identification of damaged areas and made it impossible for local emergency workers to proactively check on citizens at greatest risk for injury. In the initial phases of response, geologists and geophysicists documenting property damage, looking for evidence of surface rupture, and installing seismic stations to monitor aftershocks were reduced largely to guesswork. Critical infrastructure within the Central Virginia Seismic Zone includes a nuclear power plant, a coal-fired power plant, two natural gas-fired power plants, and eight state prisons. Understanding the relationship of these facilities to potentially active faults will enable better emergency response in the future.

Surface collapses in the vicinity of historic coal mines in the Richmond basin have been a significant problem in recent years because of residential and commercial development in former coal mining areas. Since most of these mines were abandoned in the 1800s, their exact locations and extents are often unknown. Acidic soils associated with the Eastover Formation (Miocene lower Chesapeake Group) are widespread in the eastern portion of the Richmond MSA. Water discharging from these soils can have a pH as low as 2 or 3, contributing to habitat degradation in streams and the premature failure of concrete and metal structures. The remnants of tropical depression Gaston in 2004 caused severe flooding and numerous landslides in downtown Richmond and vicinity.

Natural Resource Protection

Developmental pressures within the Richmond MSA are causing changes in land use. During development, open space is converted to industrial, commercial, and residential use. These changes have both positive and negative effects on the region's natural resources. In many cases, the geology can play an important role in the nature and extent of these impacts. Detailed geologic maps will provide useful information to land-use planners, natural resource caretakers, and environmental consultants who work in the MSA. The Petersburg and Richmond National Battlefields are located in the Richmond MSA and the National Park Service has expressed interest in geologic mapping of these properties and surrounding areas to support park management.

Water contamination is a significant problem in many parts of Richmond MSA. Water quality in the region is impacted by a number of pollution sources, including contaminated water runoff and excessive sedimentation. Non-point and point source pollution in developing areas also contributes fertilizers, pesticides, petroleum products, solvents, and other chemicals to streams and aquifers. Development often results in greater areas of impervious surfaces, resulting in increased surface overland flow into streams. Approximately 36 percent of monitored streams and rivers in the York River Basin and 23 percent in the James River Basin are not supporting designated uses that include providing aquatic or wildlife habitat, fish or shellfish for consumption, public water supply, or outdoor recreation (Virginia Department of Environmental Quality, 2008). These rivers affect water quality in the Chesapeake Bay. Monitoring suggests that 50 percent of the Chesapeake Bay is not supporting its designated use (Virginia Department of Environmental Quality, 2008).

Facility Siting

As development in the region continues, additional major facilities such as solid and liquid waste disposal facilities will need to be constructed. These include municipal landfills, wastewater treatment plants, and land application sites. In addition, the North Anna Nuclear power station is seeking to expand its power generation capacity. Geologic conditions such as the thickness and texture of regolith, the spacing and orientation of fractures and planar fabrics, the location and character of fault surfaces, and the susceptibility to earthquakes can be important to consider when situating, designing, and monitoring these types of facilities. Detailed geologic maps will provide useful information to the decision makers.

Roads and Infrastructure Development

Several major highway construction projects are underway or are being planned in the region, including the expansion and realignment of U.S. Highway 460 and the widening of I-64 east of Richmond. Detailed geologic maps will provide useful information to the

Virginia Department of Transportation, municipal and private utilities, and private and public land developers.

Science Issues

One research goal of this project is deciphering the potentially complex metamorphic history of the Petersburg Granite. Although traditionally portrayed as a single, homogenous pluton (e.g., Calver and others, 1963), detailed mapping in the Richmond area demonstrates that the granite can be subdivided into four phases, following the earlier work of Bobyarchick (1978), and challenges the relevance of a single geochronometric date for the entire outcrop belt (i.e., Wright and others, 1975).

In the Coastal Plain, we have been able to extend the Bacons Castle Formation (Coch, 1965) and Chesapeake Group (Ward and Blackwelder, 1980) from the outer Coastal Plain subprovince, following Mixon and others (1989), to the Inner Coastal Plain in the Richmond area at 1:24,000-scale. Researchers can now begin to expand the Chesapeake Group into recognized formal lithostratigraphic units, based primarily on detailed paleontologic and stratigraphic studies. In addition, our detailed maps and borehole database in the Coastal Plain are allowing us to construct derivative isopach maps, which will enable paleogeographic interpretations of sea level fluctuations and syndepositional tectonics from the Cretaceous to the Holocene in the Richmond area. We are also identifying younger structures that offset Coastal Plain units. These faults may play a significant role in ground water transport, and are described in more detail in the Preliminary Results section.

Strategy for Performing Geologic Mapping

Most 7.5-minute quadrangles in the Richmond MSA have geologic coverage that falls into one of three categories: published mapping at 1:24,000 scale; unpublished or published mapping at a scale between 1:24,000 and 1:250,000; and mapping at a scale of less than 1:250,000 (Figure 4). Our strategy is to compile existing blocks of published 1:24,000-scale maps and bring the level of mapping in high priority quadrangles up to 1:24,000-scale quality. Geologic compilation will be continually expanded as new quadrangles are mapped.

Quadrangles will be prioritized to include areas:

- where new geologic mapping is needed to address an important natural hazard, environmental, development, or natural resource issue;
- adjacent to previously compiled geologic maps;
- where existing geologic mapping is nearly 1:24,000-scale quality.

This project requires mapping approximately 45 7.5-minute quadrangles (Figure 7). Unpublished data exist for many of these quadrangles, but only seven are covered by published mapping at a scale of greater than 1:250,000. The final product will involve the compilation of these maps and 13 previously published quadrangles. It is anticipated that the Richmond MSA geologic mapping project could be completed in approximately ten years with adequate staff and funding. For 2011-2012, we propose the following projects:

1. New Geologic Mapping (3 quadrangles)

Detailed 1:24,000-scale mapping of the Caledonia (½), Ferncliff (½), Pendleton, and Quinton quadrangles is proposed (Figure 7). The Caledonia, Ferncliff, and Pendleton quadrangles are ranked as high priority because they are within the epicentral region for the August 23, 2011 earthquake and along I-64. The Caledonia quadrangle contains the highest concentration of historic gold deposits in Virginia (Spears and Upchurch, 1997). The Quinton quadrangle is situated along I-64 and is in a rapidly developing area.

As part of the mapping program, samples that are typical of significant map units will be collected. A portion of these samples will be submitted for whole rock chemical analysis. A second portion of consolidated rocks will be used to make thin sections. A third portion of consolidated rocks will be placed into our rock repository. Whole rock analyses will include major, minor, trace, and rare earth elements. The analytical results will be used to correlate rock types and identify potential mineral resources. The results will be compiled into a database that is available to the public. This database can be used to identify the background concentrations of metals such as arsenic, barium, cadmium, chromium, lead, and mercury that are routinely detected in soil and ground water during environmental investigations. Samples may also be collected and analyzed for heavy minerals.

Rick Berquist will map the Quinton quadrangle. **David Spears** will map the Caledonia quadrangle. A **geologist-to-be-hired** will map the Ferncliff quadrangle. **Amy Gilmer** will map the Pendleton quadrangle. A **geologic technician-to-be-hired** and **students** will assist with drilling, other field work, and map production.

2. Geologic Compilation of Existing Maps (1 quadrangle)

This project will build upon our 2005 - 2011 STATEMAP geologic compilation, consisting of eight 7.5-minute quadrangles. This year we will add the Yellow Tavern quadrangle (Figure 7). The Yellow Tavern quadrangle was mapped by Daniels and Onuschak (1974). The stratigraphy of the remainder of the quadrangle will need to be updated to match more recent work. In addition, field checking is needed in areas of new exposure, areas where stratigraphic and structural inconsistencies exist, and along quadrangle boundaries. **Aaron Cross** will complete field checking and digital compilation of the Yellow Tavern quadrangle.

The digital compilation of this quadrangle will utilize the new standard format for geologic map publications developed by the National Cooperative Geologic Mapping Program of the USGS (NCGMP09 standard database schema). This compilation will be an ESRI geodatabase that will include the principal map view, cross-sections, FGDC Digital Cartographic Standard symbology, feature-level metadata, standard lithology descriptions, geochemistry data, reference glossary, and data sources. We also intend to use these updated files to make publishable maps of all three quadrangles.

Preliminary Results and Previous Work

Preliminary Results

We are in our seventh year of compiling new and existing geologic maps in the Richmond MSA. In our first two years, we significantly updated and re-mapped previously published geologic maps of the Richmond, Bon Air, and Seven Pines 7.5-minute quadrangles and began new mapping on the Chesterfield and Drewry's Bluff 7.5-minute quadrangles. We subsequently completed mapping the Chesterfield, Drewry's Bluff, Dutch Gap, Glen Allen, Providence Forge, and Roxbury quadrangles. We are currently mapping

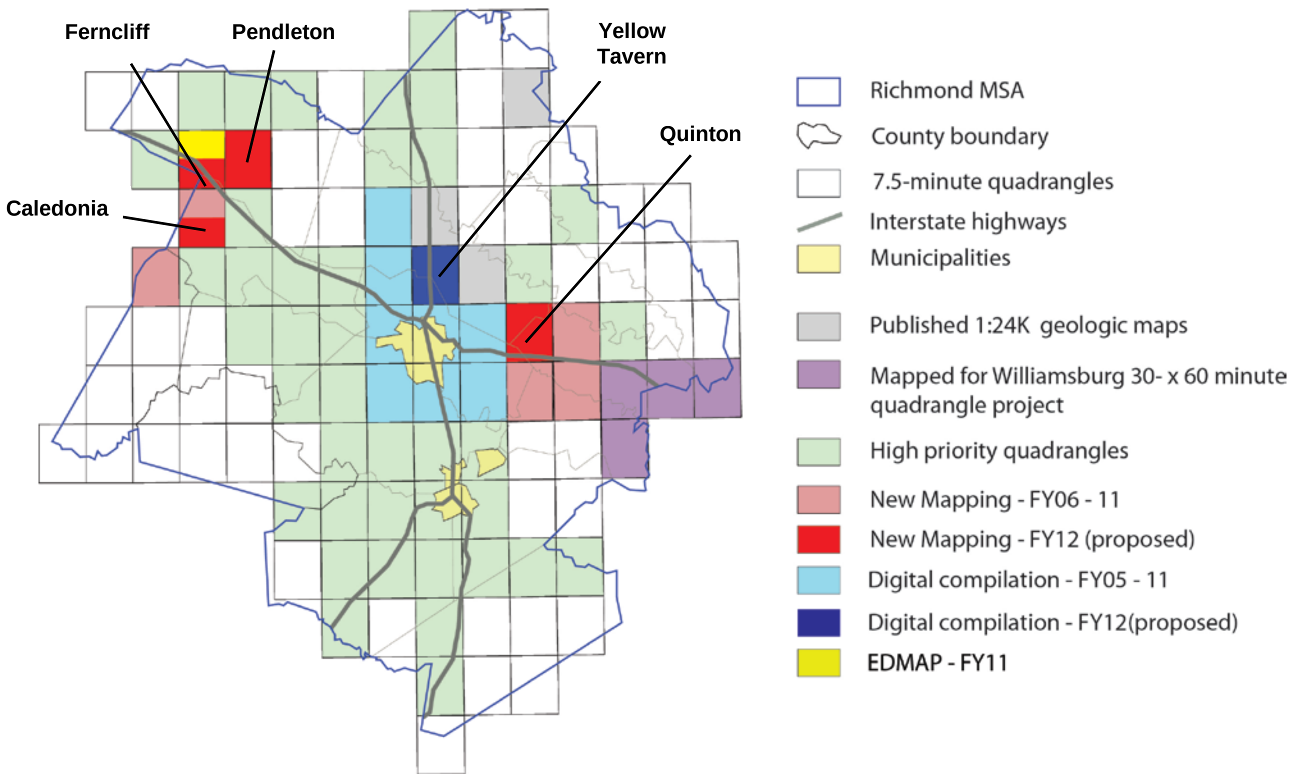


Figure 7. 7.5-minute quadrangles proposed for new mapping and digital compilation within the Richmond MSA project area. FY = Federal fiscal year.

the Tunstall quadrangle. This work has significantly increased our understanding of inner Coastal Plain and Southeastern Piedmont stratigraphy, structure, and geomorphic evolution in several areas:

Characterization of the Petersburg granite

Previous geologic maps (Daniels and others, 1974; Goodwin, 1980, 1981) grossly subdivided the Mississippian Petersburg Granite into two units in this area: uniform textured granite, and porphyritic granodiorite. We have more recently been able to delineate four phases of Petersburg Granite intrusion: early phases consisting of layered granite gneiss and well-foliated granite, a fine- to coarse-grained subidiomorphic middle phase, and a late phase of coarse porphyritic granite in map-scale screens and discrete zones. Within these phases, we are also recognizing map-scale xenoliths of biotite gneiss and schist, and mafic and altered ultramafic rocks.

Mineral resources

Coastal Plain stratigraphy has been significantly refined in the years since publication of the original quadrangles in this area. For instance, we now recognize that Pliocene Yorktown Formation (upper Chesapeake Group) and Pliocene-Pleistocene Bacons Castle Formation lithologies extend westward into the inner Coastal Plain (e.g., Mixon and others, 1989). Our new mapping demonstrates that sand and gravel of the Bacons Castle Formation underlies vast areas of the Richmond and Seven Pines quadrangles between the Chickahominy and James rivers, and is a virtually untouched source of aggregate in this increasingly urbanized region. Additionally, we have recognized internal stratigraphy within the near-shore facies of the Yorktown Formation in the Richmond area. South of Petersburg, similar Yorktown lithofacies hold the largest deposits of heavy minerals in the eastern U.S. Continued detailed mapping in the Richmond area has shown high abundance of heavy minerals in places, and may reveal additional resources such as phosphate.

Cenozoic faulting

Mapping in the Dutch Gap and Providence Forge quadrangles has identified two previously unknown, regionally significant structures, the Dutch Gap and Providence Forge faults. The Dutch Gap fault is located beneath Bacons Castle sediments. Exposure of the fault is concealed by colluvium and alluvium. This down-to-the-west fault likely affects recharge and transmission of ground water in the Cretaceous Potomac Formation, an important regional aquifer. The fault was traced into the Drewry's Bluff quadrangle and extends into the Richmond quadrangle. The Providence Forge fault is a north- to south-trending structure that exhibits down-to-the-east movement with approximately 125 feet of throw. Based on stratigraphic relationships, movement on the fault appears to be syndepositional with the Yorktown Formation. The fault overlies strong gravity and magnetic gradients suggesting a buried Mesozoic basin may lie to the east. While mapping the Roxbury quadrangle this past year, we discovered another fault, the Malvern Hill Fault. It is also northerly trending with down-to-the-east movement, but the throw ranges from 20 to 40 feet.

River Channel sediment mapping

A recent addition to the Richmond MSA and the Williamsburg projects includes mapping the sediments in the bottom of the James, Chickahominy, and other rivers within project quadrangles. Sidescan sonar is being used in conjunction with bottom sampling to identify scoured, muddy, and sandy to cobbly river bottoms. This mapping has benefited habitat studies (sturgeon habitat restoration, for example) and located potential sand and gravel deposits.

Previous Work

David Spears collected limited data on the Caledonia quadrangle during field work related to mapping of the adjacent Lakeside Village quadrangle from 1998 to 2003. He is mapping the north half of the quadrangle this year through the STATEMAP program. The Pendleton quadrangle was previously mapped at 1:100,000-scale (Marr, 2002). The northern half of the Ferncliff quadrangle was mapped recently through the EDMAP Program (Hughes, 2011); we anticipate some field work in this half of the quadrangle to increase data density. The south half of the Ferncliff quadangle has not previously been mapped. No published mapping beyond the 1:250,000-scale geologic map of the Virginia Coastal

Plain (Mixon and others, 1989) is available for the Quinton quadrangle. The Yellow Tavern quadrangle was originally mapped by Daniels and Onuschak (1974); Mark Carter remapped the southwest quarter of the Quadrangle in 2008-2009 through the STATEMAP program.

Deliverable Geologic Maps

The deliverables for this project will be:

1. Geologic map and cross-section of half of the Caledonia (½) quadrangle;
2. Geologic map and cross-section of the Ferncliff (½) quadrangle;
3. Geologic map and cross-section of the Pendleton quadrangle;
4. Geologic map and cross-section of the Quinton quadrangle;
5. Digitally compiled geology as GIS files for the Yellow Tavern quadrangle (a paper copy of the quadrangle will also be provided).

WILLIAMSBURG 30 x 60-MINUTE QUADRANGLE PROJECT

Introduction

DGMR proposes to complete the compilation of the Williamsburg 30- x 60-minute quadrangle during the 2012-2013 STATEMAP project year (Figure 1). At the end of the 2011-2012 project year all mapping will be complete and the westernmost 12 quadrangles will be compiled (Figure 8). Our plan is to compile the remaining 20 quadrangles this year. This work will include field checking in selected locations to resolve quadrangle boundary and stratigraphic discrepancies. The final product for this project will be a 1:100,000-scale digital compilation of the entire Williamsburg sheet.

Location and Geological Setting

The Williamsburg 30- x 60-minute quadrangle lies completely within the Tidewater region of Virginia (Figure 1). I-64 passes diagonally through the map area and is the major corridor for travel, commerce, and development between Richmond and the Virginia Beach–Norfolk–Newport News area. The interstate here defines the southern part of the "Golden Crescent" (an area of high population and development) that extends from Richmond to Washington D.C. Other prominent geographic features are the York and James rivers — two major estuaries that are tributaries to the Chesapeake Bay. The eastern third of the Williamsburg sheet encompasses both shorelines of the lower Chesapeake Bay.

The region is home to major tourist attractions such as Colonial Williamsburg, Busch Gardens, Colonial National Historical Park, and Jamestown Settlement. It also contains industries such as Newport News Shipyard, and coal and shipping terminals. Military bases include Fort Monroe, Fort Eustis, Yorktown Coast Guard Center, Langley Air Force Base, Yorktown Naval Weapons Station, and Camp Peary. A well-established seafood industry is centered in the lower bay and tributary estuaries. One of Virginia's two nuclear power stations is also located in the quadrangle.

The Williamsburg map area is entirely within the Coastal Plain province. Map units exposed above sea level consist predominately of estuarine, nearshore marine, and marine unconsolidated sediments of Pliocene and Pleistocene age. There is limited exposure of Miocene marine sediments in the project area. There is a substantial link between the morphology (scarps and flats) and Pleistocene stratigraphy resulting from world-wide sea-level changes during repeated glacial activity.

Below sea level, early Tertiary and Cretaceous sediments overlie basement rocks. Strata dip seaward as a thickening wedge. Depth to basement ranges from approximately 800 feet in the west part of the map area, to 2,100 feet at Newport News, to possibly 7,000 feet in the east at Cape Charles. However, the center of the Chesapeake Bay impact crater (33 Ma) is located below Cape Charles, with a zone of fractured and faulted basement rocks extending more than 25,000 feet below sea level. The crater has affected basement and overlying Cretaceous- through Eocene-age sediments out to a diameter of 56 miles from its center (Powars, 2000). Faults believed to be as young as Pliocene that are associated with the outer rim of the crater pass through the study area in the Gloucester, Mathews, Newport News, and Hampton quadrangles.

Purpose and Justification

Water Resource Location

Water supply in the project area comes from surface impoundments and wells. A desalinization plant is providing some water supply for James City County. The City of Newport News has developed several reservoirs in the map area. Newport News and Gloucester have recently begun pumping and desalinizing brackish ground water to increase their water supply.

Economic Product Development

Sand and gravel resources in the Williamsburg area are currently being lost to housing developments. Most of the richest deposits in the Coastal Plain are found in the fluvial parts of the Pleistocene terraces, adjacent to major rivers (estuaries). Fossil shell beds have been used as a source of lime (calcium carbonate) and may have a future use as a substrate for reseeding oyster beds. Using DGMR's auger drill rig greatly enhances the capability of locating potential aggregate resources. Our mapping has also suggested the presence of heavy mineral deposits in this region.

Geologic Hazard Identification

Coastal flooding, elevated radon concentrations, minor earthquakes, landslides, sinkholes, shrink-swell clays, and acidic soils are known or potential geologic hazards in the project area.

Natural Resource Protection

Development pressures within the project area are causing changes in land use. These changes have both positive and negative effects on the region's natural resources. In many cases, the geology can play an important role in the nature and extent of these impacts. Detailed geologic maps will provide useful information to land-use planners, natural resource caretakers, and environmental consultants who work in the area.

Water contamination is a significant problem in many parts of the Williamsburg 30- x 60-minute quadrangle. Water quality in the region is impacted by a number of pollution sources, including contaminated water runoff and excessive sedimentation. Non-point and point source pollution in developing areas also contributes fertilizers, pesticides, petroleum products, solvents, and other chemicals to streams and aquifers. Development often results in large areas of impervious surfaces, resulting in increased surface overland flow into streams. Approximately 36 percent of monitored streams and rivers in the York River basin and 23 percent in the James River Basin are not supporting designated uses that include providing aquatic or wildlife habitat, fish or shellfish for consumption, public water supply, or outdoor recreation (Virginia Department of Environmental Quality, 2008). These rivers affect water quality in the Chesapeake Bay. Monitoring suggests that 50 percent of the Chesapeake Bay is not fully supporting designated uses (Virginia Department of Environmental Quality, 2008).

Roads and Infrastructure Development

Several major highway construction projects are underway or are being planned in the future, including the expansion and realignment of U.S. Highway 460 and widening of I-64 from Newport News to Richmond. Detailed geologic maps will provide useful information to the Virginia Department of Transportation, municipal and private utilities, and private and public land developers.

A new coal-fired power plant has been proposed in Surry County. Geologic mapping during the past year has better defined the geologic setting of the proposed facility and should assist in current planning, development, and land-use decisions.

Science Issues

The first permanent English colony in the New World began at Jamestown in 1607, as did exploration for natural resources. Gold was not discovered in Virginia until the early 1700s, but the making of iron and the search for ore resulted in the first commercial blast furnace in America in 1619. Local geologic mapping allows archaeological researchers and interpreters with Preservation Virginia, the National Park Service, Jamestown Settlement, and the Colonial Williamsburg Foundation to identify and interpret historic mining sites and lithic materials.

Although Virginia was not glaciated in the Pleistocene, the effects of those global sea-level changes are profoundly linked to Coastal Plain stratigraphy. The Tidewater area of Virginia is undergoing eustatic (and in some places more rapid) sea-level rise. With increased geologic mapping, the past may become the key to the present for understanding and prediction of potential events associated with local sea-level rise.

During the Pliocene, reverse faulting occurred along the Fall Zone (Berquist and Bailey, 1999) and possibly on the Malvern Hill and Providence Forge faults. At approximately the same time, massive sediment deposition resulted in the Yorktown and Bacons Castle Formations, which contain sand and gravel resources, as well as the concentration of heavy minerals. Younger growth faults related to the outer rim of the Chesapeake Bay Impact Crater have affected Coastal Plain sediments through the Pliocene. Mapping between Richmond and Williamsburg allows for the identification of stratigraphic relationships between nearshore and marine Yorktown sediments, and fluvial to estuarine (tidal prism) sediments of the Bacons Castle Formation.

Strategy for Performing Geologic Compilation

Detailed (1;24,000-scale) geologic mapping in the Virginia Coastal Plain began in 1968 in the Suffolk area. Since that time, numerous authors have contributed 11 detailed geologic maps with an evolving stratigraphic framework and nomenclature within the Williamsburg 30- by 60-minute quadrangle. Over the years, new map units have been defined, and some old map units were redefined and abandoned. In order to resolve quadrangle boundary “faults” between several published quadrangles and produce a coherent stratigraphy with modern nomenclature, some additional remapping will be necessary. Specifically, attention will be focused on the Pleistocene Allostratigraphic map units and the regional extent of the Late Pliocene(?) Sedley Formation, Moorings unit, and Windsor Alloformation. In some areas, previous mapping has been found to be in error and by focused drilling, the questionable sediments are found to be merely extended facies within the Bacons Castle Formation A work-in-progress by the USGS is a basement map of a part of the Atlantic Coastal Plain, and includes Virginia. Several new faults are proposed, one is within the lower Chickahominy River (Walkers and Toano quadrangles) (D.S.

Powars, personal communication). Additional deeper drilling will be focused in this area to confirm the proposed fault.

Rick Berquist will complete this project. **Students** will assist with drilling, other fieldwork, and map production.

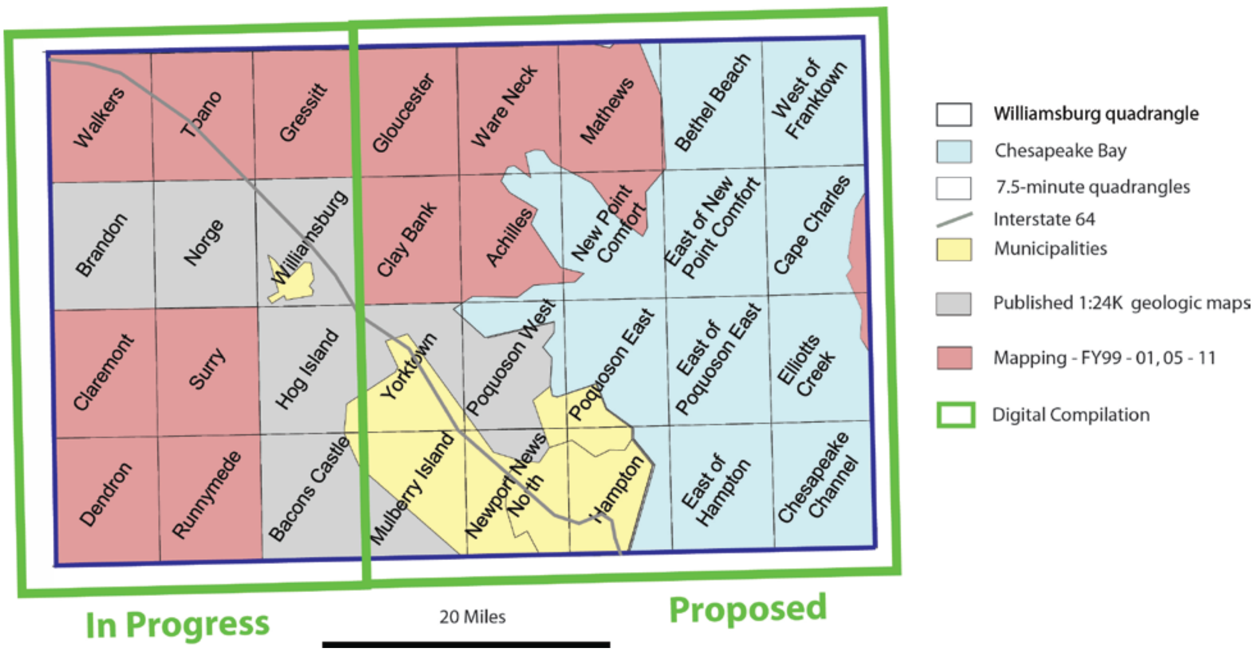


Figure 8. 7.5-minute quadrangles proposed for new mapping within the Williamsburg 30- x 60-minute quadrangle project area. FY = Federal fiscal year.

Preliminary Results and Previous Work

Geologic mapping of the Williamsburg quadrangle will be complete in June 2012. More than half of the mapping of the quadrangle was completed through the STATEMAP program. Compilation of the westernmost twelve quadrangles is underway. We have found that previously mapped Windsor sediments are actually part of the lower Bacons Castle Formation. We have recently been able to identify the contact between Yorktown and Eastover sediments based solely on lithologic criteria. We have also found a consistent abundance of heavy minerals in the lower Bacons Castle Formation in eastern Surry County as well as in the Sedgfield and Lynnhaven members of the Tabb Formation in the Chickahominy and other rivers. Geochemical analyses are currently being done to define the mineral suite and its quality.

Deliverable Geologic Maps

The deliverables for this project will be:

1. Geologic map of the Williamsburg 30- x 60-minute quadrangle.

REFERENCES

Berquist, C.R., Jr., and Bailey, C.M., 1999, Late Cenozoic Reverse Faulting in the Fall Zone, Southeastern Virginia: Journal of Geology, v. 107, p. 727-732.

Bobyarchick, A.R., 1978, Reconnaissance geologic setting of the Petersburg Granite and regional framework for the Piedmont in southeastern Virginia, *in* Costain, J.K., Glover, L., III., and Sinha, A.K., Evaluation and targeting of geothermal energy resources in the southeastern United States: Virginia Polytechnic Institute and State University, Progress Report 5648-4, p. A-1 – A-27.

Butts, C., 1933, Geologic map of the Appalachian Valley of Virginia with explanatory text: Virginia Geological Survey Bulletin 42, scale 1:250,000.

Butts, C., 1940, Geology of the Appalachian Valley in Virginia: Virginia Geological Survey Bulletin 52, 568 p.

Calver, J.L., Hobbs, C.R.B., Jr., Milici, R.C., Spiker, C.T., and Wilson, J.M., 1963, Geologic map of Virginia: Virginia Department of Conservation and Economic Development, Division of Mineral Resources, scale 1:500,000.

Coiner, L.V., Rodriguez, M.A., and Heller, M.J., 2007, Preliminary results of geochemical sampling and implications for environmental investigations in the southern Shenandoah Valley, Virginia: Geological Society of America Abstracts with Programs, Vol. 39, No. 2., p. 31.

Coiner, L.V., and Wilkes, G.P., 2010, Four-Dimensional Kinematic Model for Brittle Faulting in the Little North Mountain Fault Zone, Southern Augusta County, Virginia: Geological Society of America Abstracts with Programs, Vol. 42, No. 1.

Coler, D., Wortman, G.L., Samson, S., Hibbard, J., Stern, R., 2000, U-Pb geochronologic, Nd isotopic, and geochemical evidence for the correlation of the Chopawamsic and Milton terranes, Piedmont zone, southern Appalachian orogen: Journal of Geology, 108, p. 383-390.

Daniels, P.A. and Onuschak, E., Jr., 1974, Geology of the Studley, Yellow Tavern, Richmond, and Seven Pines quadrangles, Virginia: Virginia Division of Mineral Resources Report of Investigation 38, 75 p.

Goodwin, B.K., 1980, Geology of the Bon Air quadrangle, Virginia: Virginia Division of Mineral Resources, Publication 18, 1:24,000-scale map with text.

Goodwin, B.K., 1981, Geology of the Glen Allen quadrangle: Virginia Division of Mineral Resources Publication 31, 1:24,000-scale map with text.

Heller, M.J., Whitmeyer, S.J., Holland, C., Arnette, D., Carter, M.W., and Coiner, L.V., 2007, Southeast-directed backthrusting and crustal thickening in the Massanutten Synclinorium, Rockingham and Page Counties, Virginia: Geological Society of America Abstracts with Program, Vol. 39, No. 2., p. 13.

Heller, M.J. and Eaton, L.S., 2010, Evidence of prehistoric debris-flow activity in the Massanutten Mountains, Virginia, Geological Society of America Abstracts with Program, Vol. 42, No. 1, p. 80.

Henika, W.S., 2006, Petrology and geochemistry of metamorphosed Proterozoic igneous rocks in the Blue Ridge and western Piedmont terranes near Roanoke, Virginia: Geological Society of America Programs with Abstracts, Vol. 38, No. 2.

Hughes, Stephen, 2011, Geology of the northern half of the Ferncliff 7.5-minute quadrangle, 2011 EDMAP deliverable, single sheet.

Kirby, J.B., Shufeldt, O.P., and Whitmeyer, S.J., 2008, New interpretation of the late Alleghanian Stanley Fault system within the Valley and Ridge of Page County, Virginia: Geological Society of America Programs with Abstracts, Vol. 40, No. 4.

Marr, J.D., 2002, Geologic map of the western portion of the Richmond 30- x 60-minute quadrangle, Virginia Division of Mineral Resources Publication 165, one sheet.
Mixon, R.B., Berquist, C.R., Newell W.L., and Johnson, G.H., 1989, Geologic map and generalized cross-sections of the Coastal Plain and adjacent parts of the Piedmont, Virginia: U.S. Geological Survey Map I-2033, one sheet.
Powars, D.S., 2000, The Effects of the Chesapeake Bay Impact Crater on the geologic framework and the correlation of hydrogeologic units of Southeastern Virginia, south of the James River: U.S. Geological Survey Professional Paper 1622.
Rader, E.K. and Biggs, T.H., 1976, Geology of the Strasburg and Toms Brook quadrangles, Virginia: Virginia Division of Mineral Resources Report of Investigations 45, 104 p.
Rader, E.K. and Gathright, T.M., 2001, Geologic map of the Front Royal 30- x 60-minute quadrangle, Virginia: Virginia Division of Mineral Resource Publication 162, one sheet.
Spears, D.B. and Upchurch, M.L., 1997, Metallic mines, prospects, and occurrences in the gold-pyrite belt of Virginia, Virginia Division of Mineral Resources Publication 147, 77 p.
Spears, D.B., Owens, B.E. and Bailey, C.M., 2004, The Goochland-Chopawamsic terrane boundary, central Virginia Piedmont, *in* Southworth, S. and Burton, W., Geology of the National Capital Region - field trip guidebook, U.S. Geological Survey Circular 1264, p. 223-246.
U.S. Census Bureau, 2005, Interim Projections: Ranking of Census 2000 and Projected 2030 State Population and Change: 2000 to 2030, www.census.gov/**population/projections**/PressTab1.xls, accessed October 25, 2011.
U.S. Department of Agriculture, 2007, Census of agriculture: http://www.nass.usda.gov/census/, accessed October 20, 2009.
Virginia Department of Environmental Quality, 2008, 2008 305(b) Water Quality Assessment Report, http://www.deq.state.va.us/wqa/ir2008.html, accessed October 26, 2009.
Virginia Division of Geology and Mineral Resources, 1993, Geologic map of Virginia and expanded explanation, scale 1:500,000.
Virginia Employment Commission, 2003, City/County/State population projections, http://www.vawc.virginia.gov/, accessed October 20, 2009.
Ward, L.W. and Blackwelder, B.W., 1980, Stratigraphic revision of upper Miocene and lower Pliocene beds of the Chesapeake Group, middle Atlantic Coastal Plain, *in* Contributions to Stratigraphy, United States Geological Survey Bulletin 1482-D, 61 p.
Weldon-Cooper Center for Public Service, 2009, Online Population Estimate information, http://www.coopercenter.org/demographics/POPULATION%20ESTIMATES/, accessed October 20, 2009.
Whitmeyer, S., Heller, M., Kirby, J., Rangel, S., Cox, M., and Holland, C., 2009, A new appreciation of extensional faulting in the Page Valley, Virginia, based on recent 1:24,000-scale mapping, Geological Society of America Abstracts with Programs, Vol. 41, No. 1, p. 11.
Wieczorek, L.S., Eaton, L.S., Morgan, B.A., Wooten, R.M., and Morrissey, M., 2009, An examination of selected historical rainfall-induced debris-flow events within the central and southern Appalachian Mountains of the eastern United States, U.S. Geological Survey Open-file Report 2009-1155, 25 p.

Williams, S.T., Hibbitts, H.A., and Campbell, E.V., 2006, Digital compilation of geologic maps and new structural and stratigraphic interpretations in the southern Shenandoah Valley, Virginia: GSA Abstracts with Programs, Vol. 38, No. 2, 33-9.

Wright, J.E., Sinha, A.K., and Glover, L., III., 1975, Age of zircons from the Petersburg Granite, with comments on belts of plutons in the Piedmont: American Journal of Science, v. 275, p. 848-856.

Young, R.S. and Rader, E.K., 1974, Geology of the Woodstock, Wolf Gap, Conicville, and Edinburg quadrangles, Virginia Division of Geology and Mineral Resources Report of Investigation 35, 69 p.

SUMMARY OF PREVIOUS STATEMAP PRODUCTVITY

Our 2011 STATEMAP project ($216,572 federal funding) consists of geologic mapping of all or portions of seven quadrangles: Big Levels, Caledonia, Cape Charles, Collierstown, Elliott Creek, Ironto, and Tunstall; digital compilation of all or portions of three quadrangles: Blacksburg, Hanover Academy, and White Gate; and digital compilation of the western part of the Williamsburg 30- x 60-minute quadrangle.

Our 2010 STATEMAP project ($207,815 federal funding) consisted of geologic mapping of all or portions of seven quadrangles: Broadway, Claremont, Cornwall, Dendron, Ironto, Luray, New Market, and Roxbury; and digital compilation of all or portions of five quadrangles: Chesterfield, Drewry's Bluff, Dutch Gap, Edinburg, and Glen Allen.

Our 2009 STATEMAP project ($176,410 federal funding) consisted of geologic mapping of all or portions of seven quadrangles: Beach, Claremont, Cornwall, Dendron, Montebello, Providence Forge, and Runnymeade; and digital compilation of all or portions of three quadrangles: Dublin, Elkton West, and Radford South.

Our 2008 STATEMAP project ($217,989 federal funding) consisted of geologic mapping of all or portions of nine quadrangles: Broadford, Cedar Springs, Collierstown, Cornwall, Dutch Gap, Elliston, Glen Allen, Stanley, and Surry; and digital compilation of all or portions of three quadrangles: Atkins, Goshen, and Vesuvius.

Our 2007 STATEMAP project ($215,340 federal funding) consisted of geologic mapping of all or portions of eleven quadrangles: Atkins, Broadford, Chesterfield, Drewry's Bluff, Dutch Gap, Elkton West, Elliston, Goshen, Montebello, Stanley, and Walkers; and digital compilation of all or portions of six quadrangles: Augusta Springs, Bent Mountain, Conicville, Edinburg, Redwood, and Saltville.

Our 2006 STATEMAP project ($209,354 federal funding) consisted of geologic mapping of all or portions of nine quadrangles: Atkins, Augusta Springs, Bent Mountain, Chesterfield, Claremont, Drewry's Bluff, Gloucester, Saltville, and Surry; and digital compilation of all or portions of ten quadrangles: Bon Air, Boones Mill, Brownsburg, Garden City, Hardy, Lexington, Radford North, Redwood, Seven Pines, and Staffordsville.

Our 2005 STATEMAP project ($227,186 federal funding) consisted of geologic mapping of all or a portion of seven quadrangles: Gloucester, Lexington, Marion, Redwood, Saltville, Vesuvius, and Ware Neck; a surficial geologic map of the northern half of the Grottoes quadrangle; and a geologic and digital compilation of all or portions of five quadrangles: Arnold Valley, Bon Air, Buchanan, Natural Bridge, Richmond and Seven Pines.

Our 2004 STATEMAP project ($171,151 federal funding) consisted of geologic mapping of the Boones Mill, Garden City, Hamburg, and Hardy quadrangles; a surficial geologic map of the northern half of the Grottoes quadrangle; and a geologic and digital compilation of four 1:24,000 quadrangles: Crimora, Parnassus, Waynesboro East, and Waynesboro West.

Our 2003 STATEMAP project ($95,955 federal funding) consisted of a geologic and digital compilation of eleven 1:24,000 quadrangles: Bridgewater, Broadway, Fort Defiance, Greenville, Grottoes, Harrisonburg, Mt. Sidney, New Market, Staunton, Stuarts Draft, and Tenth Legion.

Our 2002 STATEMAP project ($31,000 federal funding) consisted of mapping portions of five 1:24,000 quadrangles: Hayters Gap, Glade Spring, Chilhowie, Damascus, and the Virginia portion of Laurel Bloomery.

Our 2001 STATEMAP project ($14,899, federal funding) consisted of mapping three 1:24,000 quadrangles in the Virginia coastal plain (Mathews, Achilles, and New Point Comfort).

NATIONAL GEOLOGIC MAP DATABASE AND FGDC GEOLOGIC MAP STANDARDS

Virginia is up-to-date in entering new publications into the National Geologic Map database. Three years ago, we provided high resolution scans of most of our existing publications to the USGS for archiving and use in the database.

Virginia was one of the first states to begin using the FGDC standards in our map products. We developed a geologic map template in 2007 that incorporated the new standards and have refined the template over the past few years. The Providence Forge quadrangle was completed in 2010 using the NCGMP09 standard database schema. Most of our 2010-2011 projects and all of our 2011-2012 projects are being compiled in GIS using the NCGMP09 standard.

When a new map product is completed, authors are asked to review the GEOLEX database to ensure that no changes in usage or extent of formations have occurred.