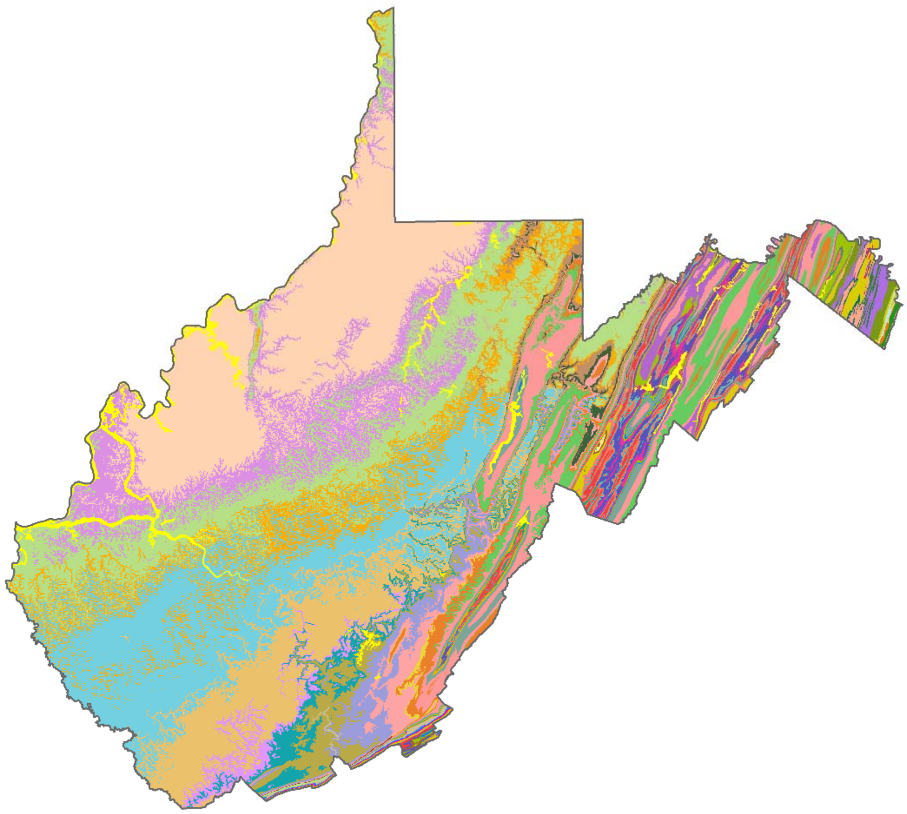
Plan for Geologic Mapping in West Virginia

2016



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WVGES
GEOLOGY UNDERLIES IT ALL

Table of Contents

Page

INTRODUCTION 1
General Location, Physiography, and Geology 1
The West Virginia Geological and Economic Survey 5
The Need for Geologic Maps 5
History of Geologic Mapping in West Virginia 6

MAPPING PROGRAMS AT THE WEST VIRGINIA GEOLOGICAL AND ECONOMIC SURVEY 7
Current Mapping and Mapping Progress 7
State and Federally Funded STATEMAP Program 7
State-Funded Coal Bed Mapping Program (CBMP) 7
Other Mapping 9
Geographic Information Systems and Other Digital Map Products 10

THE MAPPING PLAN 13
Purpose of this Document 13
Frequency of this Document 13
History of the Mapping Panel and the Mapping Plan 14
Long-Term Goal 16
Mid-Term Priorities 17
Short-Term Priorities 19
Priorities Table and Map 19

REFERENCES 31

Tables

Table 1 Quadrangles Mapped to Date at 1:24,000 scale

Table 2 STATEMAP Awards to WVGES

Table 3 Geologic Mapping Panel Members as of September 2016

Table 4 Priority Matrix for Evaluating STATEMAP West Virginia Quadrangles, MapPlan16

Table 5 Geologic Mapping Priorities by Quadrangle (Unmapped) as of December 2016

Table of Contents (continued)

Figures

Figure 1 Location Map

Figure 2 Physiographic Province Map with Plateau/Fold-Belt Boundary

Figure 3 Generalized Geologic Map of West Virginia

Figure 4 Bedrock Mapping Status 2016

Figure 5 Mapping Priorities by Quadrangle

Appendix

Appendix A GIS Data Model and Map-Digitizing Procedures

Plan for Geologic Mapping in West Virginia

INTRODUCTION

General Location, Physiography, and Geology

West Virginia is located in the mid-Atlantic region of the United States (Figure 1). It is a rural state surrounded by five other states: Pennsylvania, Maryland, Virginia, Kentucky, and Ohio. It lies within two main physiographic provinces, the Appalachian Plateau and the Valley and Ridge, with a very small portion of a third province, the Blue Ridge Physiographic Province (Figure 2).

The western two-thirds of West Virginia comprise the Appalachian Plateau Physiographic Province, with relatively flat-lying to gently folded rocks containing extractable coal and natural gas. The eastern third of the state comprises the Valley and Ridge Physiographic Province, with folded and faulted rocks containing relatively little coal or natural gas compared to the Plateau. The Allegheny Structural Front marks the boundary between the two provinces. A very small portion of the Blue Ridge Physiographic Province lies in the extreme eastern end of the state and contains the oldest exposed rock units in West Virginia. The Appalachian Plateau Physiographic Province is further divided into the Allegheny Mountain Section or subprovince; the Valley and Ridge Physiographic Province is further divided into the Great Valley subprovince, as shown in Figure 2.

Bedrock at the surface becomes progressively younger from east to west across West Virginia (Figure 3). The oldest rocks in the state are the very late Precambrian Catoctin Formation in the eastern tip of West Virginia's eastern panhandle, and the youngest sedimentary rocks are located in the northwestern portion of the state and are assigned to the Dunkard Group, which spans the Upper Pennsylvanian-Lower Permian boundary. A nearly complete section of Paleozoic strata is exposed in the state. No significant Mesozoic or Cenozoic rocks are present in West Virginia except for relatively small exposures of Jurassic (Mesozoic) and Middle Eocene (Cenozoic) igneous intrusives in the east-central portion of the state near Virginia. Quaternary (Cenozoic) alluvium is found in larger stream valleys.

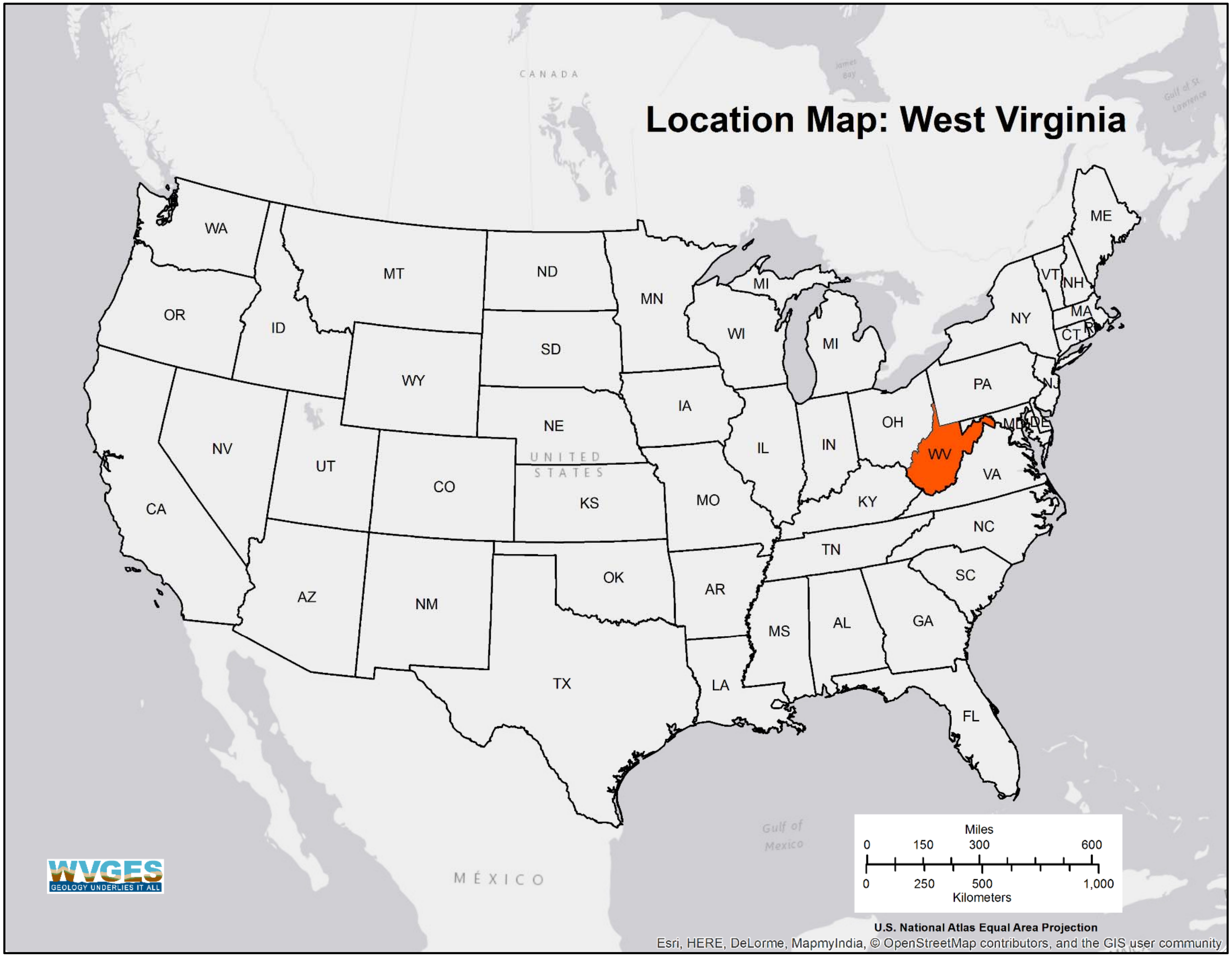

Figure 1. Location Map

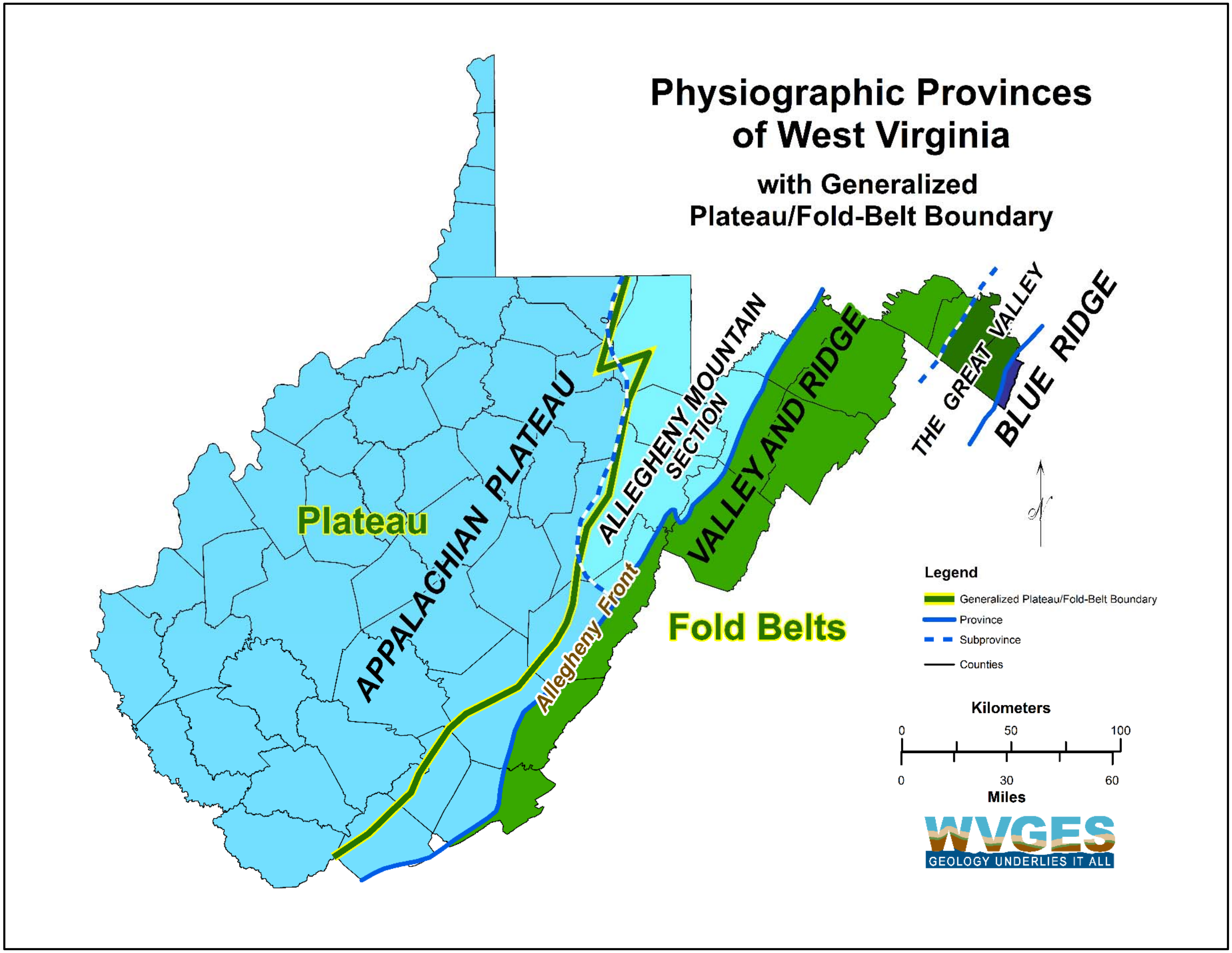

Figure 2. Physiographic Province Map with Plateau/Fold-Belt Boundary

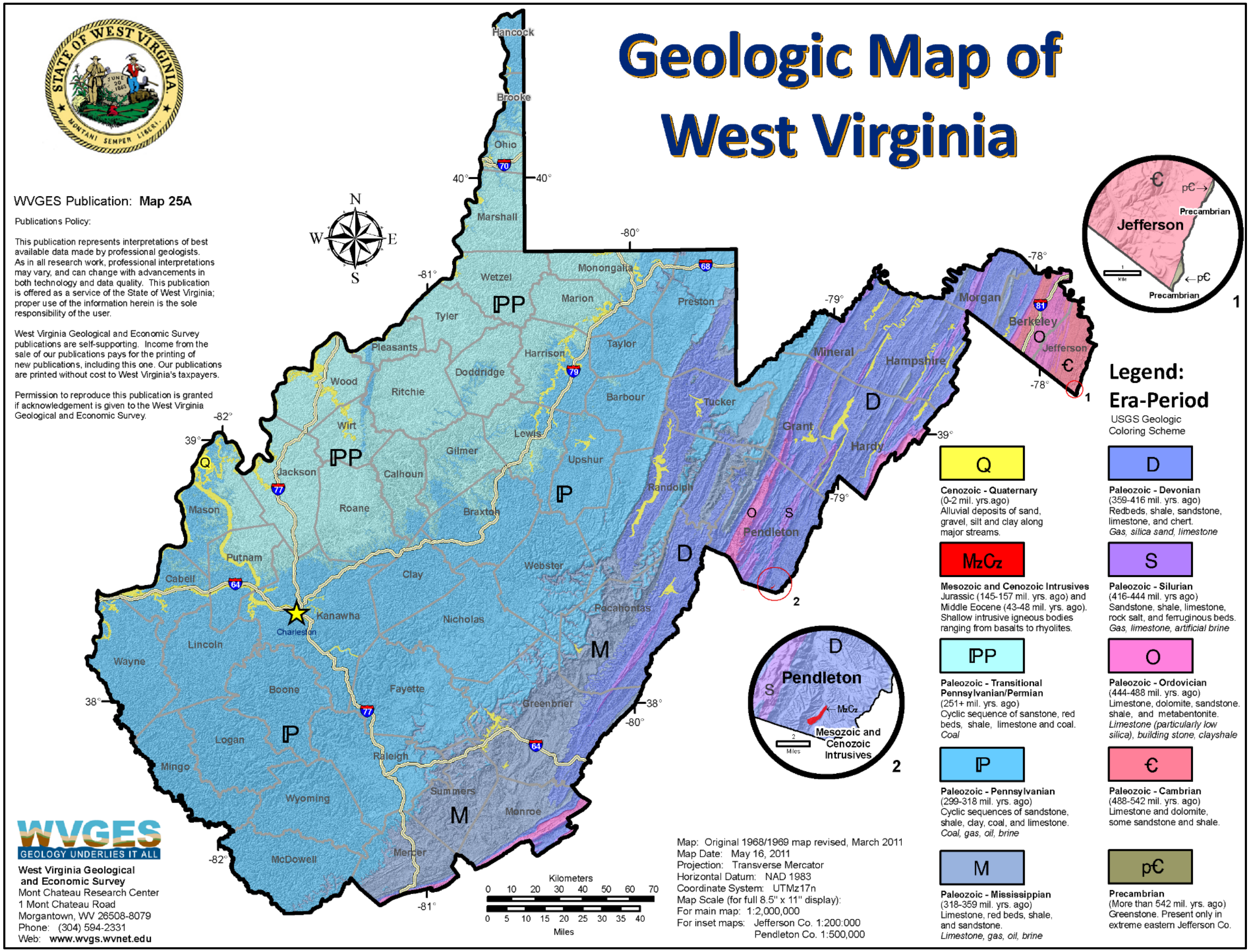

Figure 3. Generalized Geologic Map of West Virginia

The West Virginia Geological and Economic Survey

The West Virginia Legislature created the West Virginia Geological and Economic Survey (WVGES) in 1897 and it is currently part of the West Virginia Department of Commerce. Six directors have served the agency since its inception, from Israel Charles (I.C.) White to the current director, Michael E. Hohn. WVGES studies the geology of the state and disseminates geological information to the public, industry, government, and educators. Under its enabling legislation (WV Code Chapter 29 Article 2 Part 5), WVGES is tasked with conducting

> (a) An examination of the geological formations of the state, with special reference to their economic products, namely: Building stones and other constructive materials and resources, clays, ores and other mineral substances and fuels, the prevention of their waste, and the utilization of by-products;
>
> (b) An examination of the physical features of the state with reference to their practical bearing upon the occupations of the people, the industrial development and the material prosperity of the several portions of the state, having due regard to their varying resources, conditions and needs;
>
> (c) The preparation of special geological and economic maps to illustrate the resources of the state;
>
> (d) The preparation of special reports, with necessary illustrations and maps, which shall embrace both a general and detailed description of the geology and natural resources of the state;
>
> (e) The consideration of such other scientific and economic questions as in the judgment of the director shall be deemed of value to the people of the state. The director may enter into cooperative agreements, grants and contracts and establish accounts for such purposes.

The Need for Geologic Maps

Site-specific geologic knowledge is essential for anything that sits upon or lies beneath the land surface. Geologic maps are necessary for

- Resource identification (coal, oil and gas, industrial minerals, surface water, and groundwater);
- Land-use planning and decision making;
- Understanding the environment (identifying environmentally susceptible areas, locating waste-disposal facilities, remediating contaminated sites, and identifying critical species habitat);
- Avoiding and mitigating natural hazards (karst, landslides, earthquakes, mine subsidence);
- Civil engineering design (roads, bridges, railroads, dams, foundations, pipelines and other utility corridors);
- Property evaluation (resource valuation and taxation); and
- Providing for public health and safety.

To date, approximately one third of West Virginia is mapped at a 1:24,000 scale. By contrast, Kentucky had bedrock maps at a 1:24,000 scale for all of its 7½-minute topographic quadrangles by the late 1990s, and was the first state fully mapped at that scale. A study of Kentucky's map program completed by the Illinois State Geological Survey (Bhagwat and Ipe, 2000) found, "The value of the geologic maps to the users was at least 25 to 38 times higher than the cost of the mapping program." Bernknopf and others (1993) provided several detailed examples and cost analyses of geologic map use in specific instances, including siting a landfill in Loudon County, Virginia and choosing alternatives for a highway around Washington, DC. They concluded that geologic maps were worth far more than the cost to produce them.

History of Geologic Mapping in West Virginia

Before the United States Geological Survey (USGS) was established in 1879, the Commonwealth of Virginia had its own geological survey, the Geological Survey of Virginia, established in 1835. Mapping in western Virginia began before West Virginia became a state in 1863.

The USGS began constructing a Geologic Atlas of the United States and published 227 folios between 1894 and 1945 before halting the project (Texas A&M University Libraries, 2016). Twelve of these folios, published between 1896 and 1912, cover West Virginia or parts of West Virginia and adjacent states. In order to continue the geologic mapping of the entire United States in the spirit of these early Geologic Atlas folios, Congress enacted the National Geologic Mapping Act of 1992. Under this Act, USGS distributes funds to systematically map the bedrock and surficial geology of the states at a scale and in a format useful to all potential users.

WVGES produced bedrock maps on a county-by-county basis in the early 1900s at a scale of 1:62,500, and those maps became part of the County Geologic Reports. The 1:250,000-scale statewide geologic map (Cardwell and others, 1968) was created from these early county maps, with minor revisions and updates published in 1986. Subsequent mapping, mostly by graduate students for theses and dissertations, generally covered relatively small areas on a piecemeal basis. While all of these maps are useful as a starting point, newer mapping at a higher resolution on modern base maps is desperately needed for the entire state.

MAPPING PROGRAMS AT THE WEST VIRGINIA GEOLOGICAL AND ECONOMIC SURVEY

Current Mapping and Mapping Progress

WVGES has a three-pronged approach to geologic mapping in the state: the federally funded-state matched STATEMAP program, the state-funded Coal Bed Mapping Program (CBMP), and "other funding." As of December 2016, WVGES has completed bedrock mapping of 168 of the roughly five hundred 7½-minute topographic quadrangles in the state. Nine more quadrangles are in progress. Geologic quadrangles mapped at a 1:24,000 scale since publication of the early County Geological Reports are listed in Table 1 and are shown in Figure 4.

State and Federally Funded STATEMAP Program

The STATEMAP program administered by USGS disburses federal funds to state geological surveys for geologic mapping on a 1:1 Federal to State dollar match. WVGES produces quadrangle-based 1:24,000-scale bedrock geology maps using a combination of field work and available subsurface data. Surficial geology is mapped when expertise is available. One or more cross sections are drawn and a report is written for each geologic quadrangle mapped. The result is a complete geologic map at a 1:24,000 scale. Over ninety 7½-minute quadrangles have been mapped or digitally converted with funding aid from the STATEMAP program. STATEMAP projects completed by WVGES to date are listed in Table 2.

State-Funded Coal Bed Mapping Program (CBMP)

The CBMP began at WVGES in 1995 and is creating a Geographic Information System (GIS) of coal beds in the state. This GIS is available online and can be queried to view isopach (thickness), outcrop, and structure-contour maps for each coal bed (WVGES, 2016a). Data points from borings, mine maps, and outcrop observations are used to calculate the extent and location of coal beds. This information is employed by the state's Tax Department to levy property tax on unmined coal.

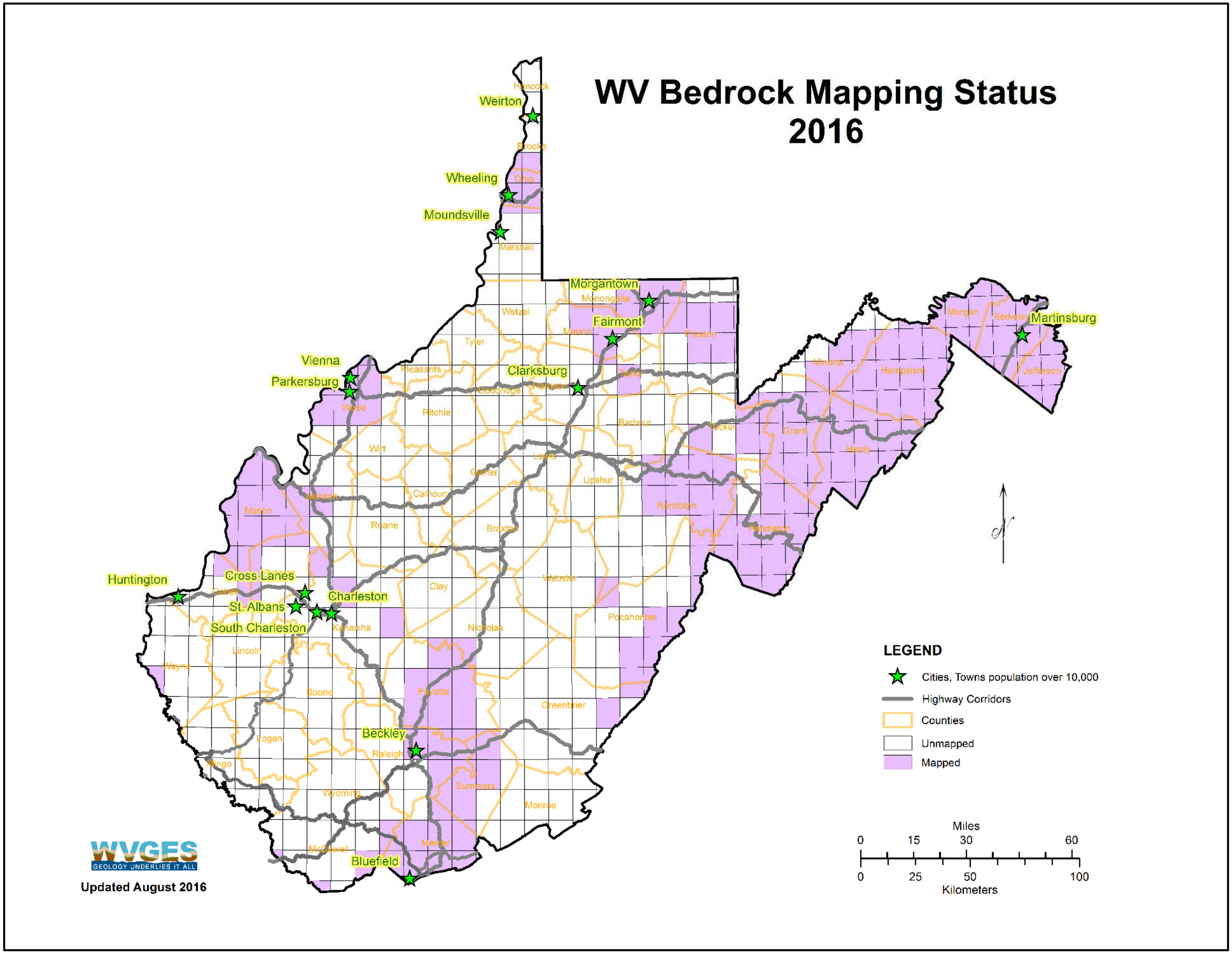

Figure 4. Bedrock Mapping Status 2016

This GIS is also useful for mapping bedrock in the Appalachian Plateau physiographic province, as some coal beds are proxies for contacts between units. Draft geologic maps can be created by drawing the intersection of the coal bed elevations with the surface topography. To produce deliverables compatible with STATEMAP requirements, additional work is needed to field check digitally produced CBMP maps and to field map contacts for units located between coal beds. WVGES, with funding aid from the STATEMAP program, has mapped several quadrangles in the coal-producing area of the state previously identified by the Mapping Panel as high priorities.

Other Mapping

"Other funding" includes financial support to map particular areas for special projects. One such project began in 2009 to map the bedrock geology of the fourteen 7½-minute quadrangles containing the Gauley River, Bluestone River, and New River National Park units, and for mapping the surficial geology within the three Park-unit boundaries (WVGES, 2016b). The project is complete and WVGES currently has no funding other than STATEMAP for field mapping, as of the date of this Plan.

Also included under "other funding" is mapping developed by the Oil and Gas Program at WVGES, usually for externally-funded projects through the US Department of Energy. These projects use core and other subsurface data to map specific units and create isopach and structure-contour maps. Examples of these projects include Appalachian Basin Tight Gas Plays, Regional Geology of the Ordovician Trenton-Black River Formations, Geology of the Marcellus Shale, Utica Shale Play (WVGES, 2016c), and the WV Geothermal Map (WVGES, 2016d), among others.

Geographic Information Systems and Other Digital Map Products

As technology advances, mapping products produced by WVGES also advance. WVGES has digitally scanned all paper copies of publications into portable document file (PDF) format or tagged image format (tif), and is in the process of digitizing all paper maps into a form used in Esri ArcMap and other ArcGIS-compatible software. Digital conversion of older paper maps is completed as time and funds allow. New digital geologic maps conform to the WVGES data model, a copy of which is included as Appendix A. Files submitted with all digital map orders include the following:

- A full geologic-map layout in Esri ArcMap .mxd format.
- The geodatabase or shapefiles for unit contacts, polygons, structural axes, fault traces, and other applicable features.
- Report documents in PDF.
- High-resolution PDF of map.
- Scanned copies of author's original source maps, text, and other materials.
- A Geologic Lookup Table of map units that can be joined with the unit polygons and sorted by geologic age.
- A "Readme" file.
- The data model and digitizing procedures handbook in PDF format (included herein as Appendix A).
- A quadrangle index map shapefile for the project.
- A county boundary shapefile for the project county.
- A magnetic declination shapefile for West Virginia.
- The GeoAge true-type font (fgdcgeoage.ttf) used to symbolize the map layout.
- The stratigraphic column for the state of West Virginia.
- A map showing the status of geologic mapping to date.

Table 1. Quadrangles Mapped to Date at 1:24,000 scale

Addison	Doe Hill	Mannington	Rig
Alvon	Elkins (pending)	Marietta	Rio
Amonate	Elmwood	Marlinton	Ripley
Anawalt	Fairmont West	Martinsburg	Rivesville
Ansted	Fallsburg	Masontown	Robertsburg
Antioch	Fayetteville	Matoka	Romney
Apple Grove	Flat Top	Maysville	Round Hill
Arlee	Fort Seybert	Meadow Bridge	Sang Run
Artemas	Franklin	Meadow Creek	Sector
Athens	Gallipolis	Medley	Shady Spring
Augusta	Glady	Middleway	Sharp Knob
Baker	Glengary	Milam	Shepherdstown
Beckley	Glenwood	Minnehaha Springs	Sinks of Gandy
Beckwith	Gore	Moatstown	Sissonville
Beech Hill	Grafton	Moorefield	Snowy Mountain
Bellegrove	Grant Town	Morgantown North	South Parkersburg
Bergton	Great Cacapon	Morgantown South	Springfield
Berryville	Greenland Gap	Mount Alto	Spruce Knob
Bethany	Hancock	Mount Olive	Stephenson
Beverly East (pending)	Hanging Rock	Mount Storm Lake	Stotlers Crossroads
Beverly West (pending)	Harman	Mountain Falls	Sugar Grove
Big Chimney	Harpers Ferry	Mountain Grove	Summersville Dam
Big Pool	Headsville	Mozer	Sunrise
Blackbird Knob	Hedgesville	Mustoe	Tablers Station
Blackwater Falls	Hightown	Needmore	Talcott
Bluefield	Hinton	New Haven	Terra Alta (pending)
Bowden	Hopeville (pending)	Oak Hill	Thornwood
Bramwell	Hurricane	Oakland (pending)	Thurmond
Brandywine	Inwood	Oakvale	Tiltonsville
Bruceton Mills	Junior (pending)	Old Fields	Upper Tract (pending)
Burlington	Kanawha	Oldtown	Valley Grove
Capon Bridge	Keedysville	Orkney Springs	Valley Mills
Capon Springs	Keyser	Osage	Valley Point
Charles Town	Kingwood (pending)	Paddy Knob	Wardensville
Cherry Run	Lake Lynn	Palo Alto	Wheeling
Cheshire	Lake Sherwood	Parkersburg	White Hall
Chester	Largent	Parsons (pending)	Whitmer
Circleville	Lerona	Paw Paw	Williamsport
Clover Lick	Levels	Petersburg East	Winona
Cottageville	Little Hocking	Petersburg West (pending)	Wolf Gap
Cow Knob	Lost City	Pipestem	Woodstock
Crumpler	Lost River State Park	Pomeroy	Yellow Spring
Cuzzart	Louisa	Prince	
Danese	Lubeck	Princeton	
Davis	Mammoth	Ridge	

Table 2. STATEMAP Awards to WVGES

Federal Fiscal Year	Project or Quadrangles
2016	Parsons, Kingwood, Terra Alta and Oakland (WV only)
2015	Alvon, Bowden, Valley Point, Cuzzart, and Sang Run (WV only)
2014	Masontown, Harman, Lake Sherwood and Mountain Grove (WV only)
2013	Oak Hill, Marlinton, Whitmer
2012	Minnehaha Springs, Sunrise (WV only), Glady
2011	Clover Lick
2010	Greenland Gap
2009	Antioch, Paddy Knob, Mustoe
2008	Medley, Sharp Knob, Hightown
2007	Burlington
2007	Valley Grove, Mannington, Bethany (PA)
2006	Milam, Cow Knob, Headsville
2006	Wheeling, Tiltonsville, Bethany (WV)
2005	Mozer, western Springfield, southern Patterson Creek
2005	Grant Town
2004	Ft. Seybert, eastern Romney, eastern Springfield
2004	Osage and Rivesville
2003	Morgantown North and South
2003	Franklin, eastern Old Fields, western Romney
2002	western Old Fields, western Rig, Lake Lynn
2002	Circleville and Thornwood
2001	Petersburg East and eastern Rig
2001	Snowy Mountain and Spruce Knob
2001	Lerona and Matoaka
2000	Oakvale and Athens
2000	Sector and Moorefield
2000	Brandywine
1999	Bluefield and Princeton
1999	Moatstown
1999	Capon Bridge and Rio
1998	Doe Hill and Sugar Grove
1998	Winchester and Front Royal
1997	Blackbird Knob
1997	Largent and Levels
1997	Palo Alto
1997	Cumberland and Winchester
1996	Hagerstown and Frederick
1996	Great Cacapon and Paw Paw
1995	Canaan Valley - Mt. Storm Quadrangle
1994	Canaan Valley - Davis Quadrangle
1994	Big Pool and Glengary
1993	Canaan Valley

THE MAPPING PLAN

Purpose of this Document

As discussed, WVGES has been mapping West Virginia since the agency's creation in 1897. The first geologic maps of West Virginia were published in the early 1900s before plate tectonics and other modern geologic principles were developed, and the topographic base maps used were produced before the days of photogrammetry. These older base maps had an unspecified cartographic projection so that overlaying them onto newer base maps is difficult.

In addition, formation names and geologic interpretations have changed through time, more data are available, humans continue to reshape the landscape, and mapping technology has advanced. Modern topographic maps have a higher accuracy, a known cartographic projection, and provide a much better base for modern geologic mapping and interpretation than the older maps used for the County Geologic Reports. Formation names have changed significantly since publication of the County Geologic Reports, geologists' understanding of structural relationships has developed over time, and recent geologic mapping disagrees with some of the earlier mapping. New, more accurate, mapping is needed with a higher resolution, updated geologic interpretation, and current terminology.

For these reasons, WVGES is mapping the bedrock geology of the entire state at a 1:24,000 scale according to modern standards using USGS 7½-minute topographic quadrangles and digital elevation models as a base. WVGES relies heavily on funding through the federal STATEMAP program to achieve this ambitious goal. As a guide for this work, WVGES created a State Geological Mapping Plan (the Plan) to coordinate all mapping efforts at WVGES and provide a measure by which quadrangles are prioritized for STATEMAP funding.

Frequency of this Document

This Plan is updated every five to ten years as mapping goals and priorities evolve for West Virginia. It was last updated in 2009, seven years ago.

History of the Mapping Panel and the Mapping Plan

The West Virginia Geologic Mapping Panel (the Panel) is a diverse collection of scientists and administrators from government, industry, and academia. Membership in the Panel is voluntary and changes over time as personal and employer obligations allow. The head of the Panel is the president of the Appalachian Geological Society, an organization promoting geology, particularly petroleum geology, in the Appalachian region. Table 3 lists the Panel members as of December 2016.

In 1992, the same year the National Geologic Mapping Act of 1992 was enacted, the West Virginia Geologic Mapping Panel met to identify areas in West Virginia with significant environmental challenges, coal resources, economic development, tourism, and water resources. The Panel created a list of USGS 7½-minute topographic quadrangles of particular concern based on discussions during this meeting, and these became the geologic mapping priorities for West Virginia.

In June 2002, the Panel met to update the Plan and set a revised course for future mapping in the state. Areas where karst is present were given priority, and quadrangles along major highway corridors were also identified as priorities. As a result, quadrangles in the Eastern Panhandle were given the highest priority because they contain highways, karst, are undergoing relatively rapid economic development, and contained some geologic mapping already completed by WVGES and USGS.

Geologic mapping priorities were revisited and revised by the Panel again in 2009. The status of current mapping was discussed along with proposed geologic mapping to be funded by STATEMAP and other sources. During that meeting, the Panel devised a simplified physiographic model to divide the state into two broad regions for setting mapping priorities, the Appalachian Plateau and the Eastern Fold Belts (Figure 2). The Eastern Fold Belts region includes structurally complex features as well as karst and other environmentally sensitive areas. The Appalachian

Table 3. Geologic Mapping Panel Members as of September 2016

NAME	POSITION	AFFILIATION	EXPERTISE	Voting Member
Ed Rothman	Chair of Mapping Panel; President, Appalachian Geological Society; Chief Geologist at EDI	Energy Development and Investment (EDI) Group LLC	oil and gas exploration, stratigraphy and structure	yes
Pete Sullivan	Past Chair of Mapping Panel; Past President, Appalachian Geological Society; VP of Exploration at ECA	Energy Corporation of America (ECA)	oil and gas exploration, stratigraphy and structure	yes
Steve Ball	Hydrologist, Technical Support Section	Office of Surface Mining, formerly at WVDEP	hydrogeology and coal geology	yes
Joe Carte	Geotechnical Unit Leader	WV Department of Transportation	geotechnical engineering, hazards, highway construction	yes
George Chappell	Geologist	WV Department of Transportation	geologic structure, stratigraphy and hazards	yes
Hussein El Khansa	Geospatial Information	WV Department of Transportation	mapping, especially digital mapping	yes
Nick Fedorko	O&G and Coal Consultant	Cove Geological Services	coal geology, oil and gas exploration, geologic stratigraphy and structure	yes
Steve Kite	Geology and Geography Professor	West Virginia University	geomorphology, stratigraphy, structure	yes
Al Lisko	Director of Mitigation and Recovery	WV Div. of Homeland Security & Emergency Management	emergency management	yes
Ron Martino	Geology Professor	Marshall University	geology and stratigraphy	yes
Craig Neidig	WV Geospatial Liaison to USGS	United States Geological Survey (USGS)	geologic mapping	yes
Jessica Perkins	GIS Analyst	WV DNR, Wildlife Resources Section	mapping and biology, especially digital mapping	yes
Tony Simental	State GIS Coordinator	WV Geological and Economic Survey	GIS, lidar, and other imagery	yes
Barb Sargent	WV Natural Heritage Program	WV DNR, Wildlife Resources Section	threatened and endangered species and habitat	yes
Ed Snyder	Geology and Environmental Science Prof.	Shepherd University	stratigraphy, structure, and environmental geology	yes
Ann Steketee	Geographic Information Specialist	US Forest Service	mapping, especially digital mapping	yes
Jaime Toro	Geology Professor	West Virginia University	structural geology and stratigraphy	yes
Linda Tracy	Geologist	US Forest Service, retired	geologic mapping, geology and habitat, road building	yes
Mike Hohn	State Geologist and Director	WV Geological and Economic Survey (WVGES)	State Geologist, WVGES Director	no

WV: West Virginia GIS: Geographic Information Science DNR: Department of Natural Resources

Plateau region includes many of the state's highway corridors, larger metropolitan areas outside of the eastern panhandle, natural gas reserves, and coal reserves. Delineating potential karst areas in the Fold Belts region and new highway corridors remained a high priority in the 2009 Plan updates. During the meeting in 2009, the Panel also created a Priority Matrix for ranking specific quadrangles using criteria such as urbanization potential, environmental vulnerability, mineral resources, and current issues. The Panel used the Matrix every year thereafter to evaluate and rank individual quadrangles proposed for mapping under STATEMAP.

The Panel met again in 2015 and 2016 to update the Mapping Plan with new mid-term priorities along with revising the Priority Matrix, and the results are included in this document. Mapping the Eastern Panhandle, designated as a high-priority area in previous mapping plans, is now complete except for a few outlying quadrangles. Therefore, the Eastern Panhandle as a whole is no longer listed as a separate mapping priority in this current Mapping Plan.

Each year, the Mapping Panel meets to review specific quadrangles proposed by WVGES geologists for mapping and examines and updates the State Mapping Plan if needed. These meetings usually occur in August or September, and the proposals are due to USGS in early November.

Long-Term Goal

WVGES' long-term goal is to map the bedrock geology of the entire state at a 1:24,000 scale using modern base maps. The strategy for meeting this goal within the constraints of declining agency budgets is to apply STATEMAP grants to quadrangles that will not be mapped with other funding sources, and to field check and make complete bedrock geologic maps for those quadrangles for which the CBMP GIS is available. WVGES will continue to seek additional funding sources to complete mapping.

Mid-Term Priorities

Several topics were identified as priorities in the 2015 and 2016 Panel meetings, and geologic mapping in the next five to ten years will focus on areas where these topics coincide. Quadrangles where priorities overlap the most are given the highest rank. These topics, in no particular order, are as follows:

- State and National Parks, Wildlife Management Areas, and State and National Forests: public lands set aside for wildlife, timber management, recreation, etc.
- Urban development and existing highway corridors: major highways are corridors of relatively high population growth, economic development, and environmental pressure. Highway construction exposes large rock outcrops and offers tremendous opportunity for geologic observation not usually available in this highly forested state.
- Rural development: development such as the Hatfield-McCoy Trail System and other investment in southern West Virginia including the Hobet Mine redevelopment proposal.
- New, proposed major utility, pipeline, or transportation corridors: major pipeline corridors such as the Atlantic Coast and Mountain Valley pipelines, new highway construction, such as continuing Corridor H/US 48, the Coalfields Expressway, the King Coal Highway, and new construction along Corridor G/US 119, for example. Items of concern for the West Virginia Department of Transportation's Division of Highways include deep soils and geologic structure.
- Mine subsidence and inactive mining: including abandoned mine lands.
- Slope failure and mass wasting.
- Solid and industrial waste disposal.
- Potential karst (areas of carbonate rock outcrop): areas of karst occur throughout the eastern counties. Karst and potential karst terrains exist in much of the Eastern Fold Belts region, especially in the unmapped portions of Greenbrier and Monroe counties.
- Biologically sensitive areas and sensitive watersheds: these include high-priority Conservation Focus Areas for the WV Department of Natural Resources (WVDNR), elk re-introduction areas, and deer cross-over counties.
- Groundwater: a source of drinking water and industrial water in the state.
- Surface water: also a source of drinking water and industrial water in the state.

- Coal, oil, and gas: West Virginia's economy is closely tied to the resource extraction needed for energy production.
- Industrial minerals (limestone, sandstone, building stone, clay, sand and gravel, road metal, etc.): another source of economic development for West Virginia.
- Geologic features and uniqueness: understanding geologically complex areas lends insight into geologic processes and may result in the discovery of new economic resources.
- Contiguity to completed mapping: large blocks of maps show regional trends and other larger-scale features not obvious on a single quadrangle. Mapping quadrangles as a block is more efficient as geologists become familiar with the stratigraphy and geologic structure and apply that knowledge when mapping adjacent quadrangles.
- Lost opportunity: due to pending retirement of experienced geologists, covering of large excavations, and grassing over of large rock exposures.
- Located in the Dunkard Group: red beds of the Dunkard Group are particularly difficult for highway construction and road building needed for timbering and petroleum extraction. Rock exposed by recent activity will soon be reseeded and exposures will become overgrown making mapping more difficult.
- Lidar availability: access to high-resolution imagery such as lidar has become a necessity for geologic mapping due to West Virginia's rugged terrain and dense forest cover. Large portions of the state still do not have such imagery available.
- Other geographic areas of interest to the Panel including:
  - Webster County: lidar is available (privately flown), it is geologically interesting, and is a mapping void in the state.
  - Barbour and Taylor counties: contain active coal mining and gas extraction.
  - Teays Valley: a pre-glacial river valley filled with unconsolidated material that provides unique features and challenges. Part of the ancient Teays Valley coincides with the relatively populated and developing corridor linking West Virginia's largest cities, Huntington and Charleston. This area has environmental concerns including surface water, waste water, groundwater, valley fills, and slope instability. Surficial mapping is needed in the area when WVGES has that expertise available.

Short-Term Priorities

The Priority Matrix allows the mapping plan to be flexible and adjust to changing short-term priorities, such as recent flooding and other natural hazards, planned highway construction, and proposed utility corridors. This 2016 update to the State Geologic Mapping Plan incorporates revisions made by the Mapping Panel in 2015 and 2016, including changes to the Priority Matrix. Table 4 is the most recent version of the Priority Matrix.

Priorities Table and Map

WVGES prepared a new priorities table using headings from the updated Priority Matrix and two topics from the mid-term priorities not listed in the matrix (Dunkard Group and lidar availability). GIS was used to the extent possible to find quadrangles intersecting multiple high-priority features. For example, lines and polygons available for existing major highways, proposed major highways, WVDNR priority areas, rock units in the Dunkard Group, major new oil and gas plays, carbonate outcrops, publically known caves, proposed major pipelines, the Hatfield-McCoy Trail system, public lands, active mining, abandoned minelands, lidar availability, etc., were overlain using GIS software.

The degree of overlap for each quadrangle was quantified and the quadrangles were ranked. In order to develop a ranking score, a “1” was placed in each column applicable for a specific quadrangle. The numbers were summed and individual quadrangles were ranked accordingly from 0 to 9, where the higher the score, the higher the priority. Quadrangles already mapped were assigned a score of zero, or no priority.

A color ramp was then assigned to the quadrangles based on these scores, with red being the highest ranked (or “hottest”) and blue being the lowest, except for the mapped quadrangles, which are shown as clear/white. Middle ranks were assigned yellow and orange. The resulting map is shown in Figure 5. Table 5 is a color-coded list of all unmapped quadrangles sorted by highest score and then listed in alphabetical order within their respective score ranking.

Table 4. Priority Matrix for Evaluating STATEMAP West Virginia Quadrangles, MapPlan16

	Economic Development				Geologic Hazards			Environ-mental		Geologic Resources				Geologic Merit			Total
Please rank each criterion on a scale of 1 to 10.	State and National Parks, Forest, and Wildlife Areas	Urban Development, Existing Highway Corridors	Rural Development	New, Proposed Major Utility, Pipeline, or Transportation Corridors	Mine Subsidence, Inactive Mining	Slope Failure and Mass Wasting	Karst	Solid and Industrial Waste Disposal	Biologically Sensitive Areas, Sensitive Watersheds	Groundwater	Surface Water	Industrial Minerals (Limestone, Sandstone, Building Stone, Clay, Sand and Gravel, Road Metal, etc.)	Coal, Oil & Gas	Geologic Features, Uniqueness	Contiguous to Completed Mapping	Lost Opportunity *	TOTAL
Project 1 Name:																	
Project 2 Name:																	
Project 3 Name:																	
Project 4 Name:																	

* *Lost Opportunity* could include excavation that may be covered over in a relatively short period of time, the impending loss of experienced personnel, etc.

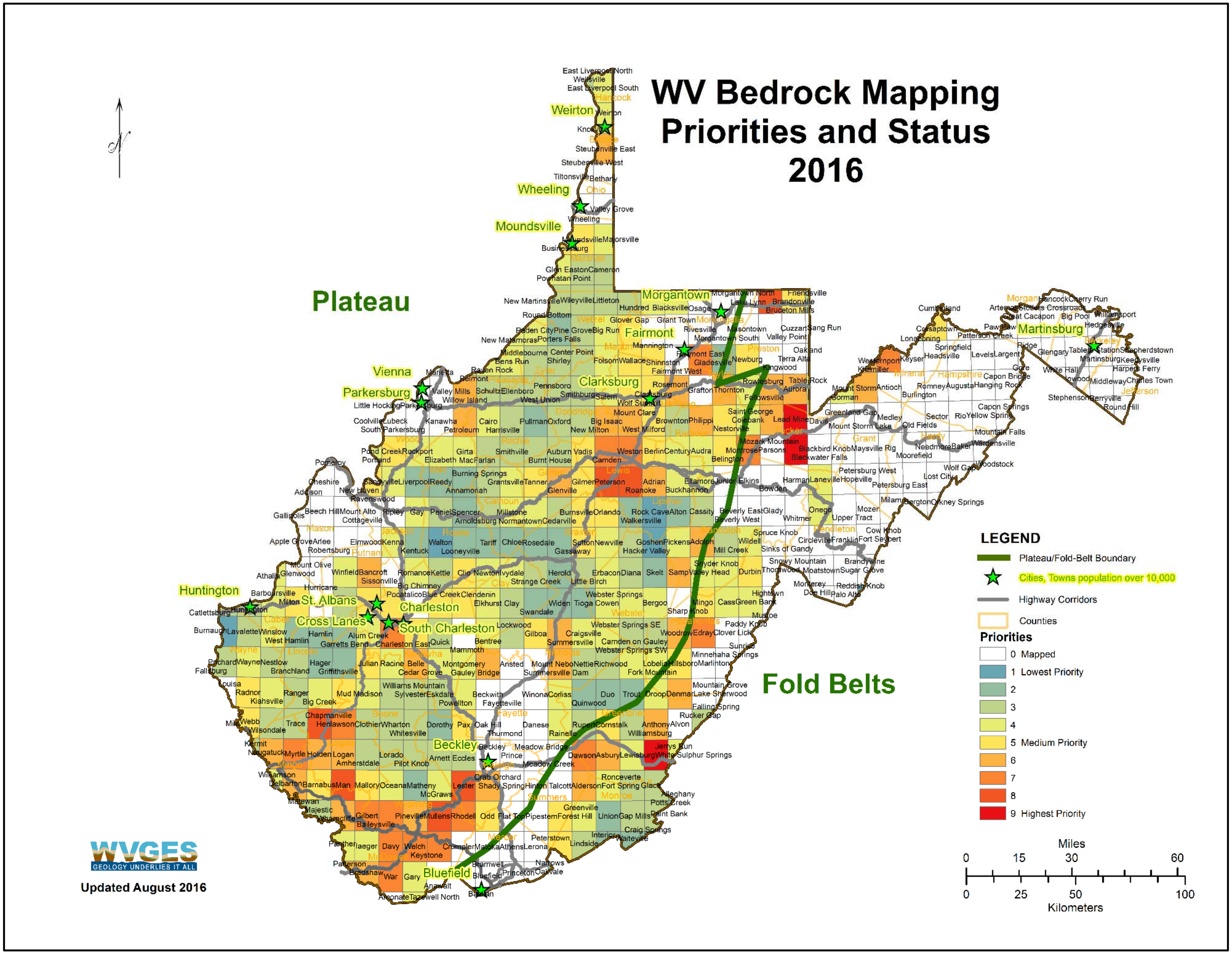

Figure 5. Mapping Priorities by Quadrangle (Unmapped quadrangles are listed by color in Table 5)

Table 5. Geologic Mapping Priorities by Quadrangle (Unmapped) as of December 2016

TOPONAME	TotalScore	PrkFrstWMA	UrbHghExst	RuralDev	UtilTransP	MineSubsIn	SlopFailMW	Karst	SldIndWast	BioWtrSens	Grndwtr	SurfWtr	IndMins	CoalOilGas	GeoUnique	Contiguous	LostOpp	Dunkard	Lidar
Lead Mine	9	1	1	1	1	1		1						1		1			1
Mozark Mountain	9	1	1	1	1	1		1						1		1			1
Bruceton Mills	8	1	1	1		1		1						1		1			1
Chapmanville	8	1	1	1		1				1		1					1		1
Lester	8		1	1	1	1				1						1	1		1
Mullens	8	1	1	1	1	1				1							1		1
Peterson	8	1	1		1	1						1		1				1	1
Roanoke	8	1	1	1		1						1		1				1	1
Camden	7	1	1		1	1								1				1	1
Charleston West	7	1	1	1		1						1					1		1
Davy	7	1	1		1	1				1							1		1
Dawson	7	1	1		1			1		1						1			1
Edray	7	1			1			1		1		1				1			1
Fairmont East	7	1	1			1						1		1		1			1
Henlawson	7	1	1			1				1		1					1		1
Man	7	1	1	1		1				1		1							1
Montrose	7	1	1		1			1						1		1			1
Rhodell	7		1		1	1				1						1	1		1
War	7	1	1		1	1				1							1		1
Welch	7	1	1		1	1				1							1		1
Westernport	7	1				1		1				1		1		1			1
Weston	7	1	1		1	1						1		1				1	
White Sulphur Springs	7	1	1					1		1		1			1	1			
Adolph	6	1			1	1		1								1			1
Adrian	6	1	1		1	1								1				1	
Alderson	6				1			1		1		1				1			1
Anthony	6	1						1		1		1			1	1			
Asbury	6		1					1		1		1			1				1
Aurora	6	1	1					1						1		1			1
Baileysville	6	1	1			1				1		1							1
Bancroft	6	1				1						1				1		1	1
Belle	6	1	1			1				1		1							1
Big Isaac	6	1			2									1				1	1
Bradshaw	6		1		1	1				1							1		1
Crab Orchard	6		1		1	1										1	1		1
Denmar	6	1						1		1		1			1	1			
Gauley Bridge	6	1				1				1		1				1			1
Gilbert	6	1	1			1				1		1							1

Table 5. Geologic Mapping Priorities *(continued)*

TOPONAME	TotalScore	PrkFrstWMA	UrbHghExst	RuralDev	UtilTransP	MineSubsIn	SlopFailMW	Karst	SldIndWast	BioWtrSens	Grndwtr	SurfWtr	IndMins	CoalOilGas	GeoUnique	Contiguous	LostOpp	Dunkard	Lidar
Glenville	6	1	1			1								1				1	1
Holden	6	1	1			1				1							1		1
Keystone	6		1	1		1				1						1			1
Kitzmiller	6	1				1						1		1		1			1
Logan	6		1	1		1				1		1							1
Mount Nebo	6	1	1							1		1				1			1
Mount Storm	6					1		1		1				1		1			1
Myrtle	6	1	1			1				1							1		1
Patterson	6	1	1		1					1							1		1
Petroleum	6	1	1	1										1		1		1	
Philippi	6	1				1						1		1		1		1	
Pineville	6		1		1	1				1							1		1
Rosemont	6	1	1			1								1		1		1	
Rowlesburg	6	1	1					1						1		1			1
Saint George	6	1	1		1			1						1					1
Samp	6	1			1	1		1								1			1
Steubenville East	6	1				1						1		1		1		1	
Summersville	6	1	1			1				1		1							1
Thornton	6	1	1									1		1		1			1
West Milford	6	1	1		1	1								1				1	
Willow Island	6	1	1									1		1		1		1	
Woodrow	6	1		1				1		1						1			1
Belington	5	1				1						1		1		1			
Berlin	5		1		1	1								1				1	
Blue Creek	5		1			1						1				1			1
Brandonville	5		1			1								1		1			1
Burnsville	5	1	1			1												1	1
Businessburg	5	1										1		1		1		1	
Charleston East	5	1	1			1						1							1
Clarksburg	5	1	1			1								1				1	
Clendenin	5	1				1						1				1			1
Clio	5	1	1									1						1	1
Cornstalk	5	1	1					1		1					1				
Cresaptown	5							1		1		1				1			1
Delbarton	5		1	1		1				1									1
Durbin	5	1		1				1		1						1			
Forest Hill	5	1								1		1				1			1
Gilboa	5	1				1				1		1							1
Gilmer	5		1			1								1				1	1

Table 5. Geologic Mapping Priorities *(continued)*

TOPONAME	TotalScore	PrkFrstWMA	UrbHghExst	RuralDev	UtilTransP	MineSubsIn	SlopFailMW	Karst	SldIndWast	BioWtrSens	Grndwtr	SurfWtr	IndMins	CoalOilGas	GeoUnique	Contiguous	LostOpp	Dunkard	Lidar
Glover Gap	5	1												1		1		1	1
Hillsboro	5	1						1		1		1				1			
Julian	5		1			1				1							1		1
Mallory	5	1				1				1		1							1
Milton	5	1	1													1		1	1
Mingo	5	1			1			1		1									1
Moundsville	5	1										1		1		1		1	
Mount Clare	5	1	1			1								1				1	
Mud	5	1	1							1							1		1
Naugatuck	5	1	1							1							1		1
Nestorville	5	1				1						1		1					1
Newburg	5	1				1								1		1			1
Odd	5	1	1							1						1			1
Orlando	5	1		1	1							1							1
Pax	5	1	1			1										1			1
Peterstown	5	1						1				1				1			1
Pocatalico	5		1			1						1				1			1
Pond Creek	5		1									1		1		1		1	
Radnor	5	1								1		1				1			1
Ravenswood	5	1	1									1				1		1	
Saint Albans	5	1	1			1						1							1
Shinnston	5					1								1		1		1	1
Sutton	5	1	1									1						1	1
Tanner	5	1	1											1				1	1
Vadis	5		1			1								1				1	1
Wallace	5				1	1								1				1	1
Wharncliffe	5		1			1				1		1							1
Wolf Summit	5		1		1	1								1				1	
Alum Creek	4		1									1					1		1
Athalia	4	1										1						1	1
Audra	4	1				1						1		1					
Barboursville	4		1	1								1							1
Barnabus	4		1			1				1									1
Bens Run	4	1										1		1				1	
Bentree	4					1				1						1			1
Bergoo	4	1				1										1			1
Big Creek	4	1								1		1							1
Big Run	4	1			1									1				1	
Blacksville	4	1												1		1		1	
Buckhannon	4		1		1	1								1					

Table 5. Geologic Mapping Priorities *(continued)*

TOPONAME	TotalScore	PrkFrstWMA	UrbHghExst	RuralDev	UtilTransP	MineSubsIn	SlopFailMW	Karst	SldIndWast	BioWtrSens	Grndwtr	SurfWtr	IndMins	CoalOilGas	GeoUnique	Contiguous	LostOpp	Dunkard	Lidar
Cairo	4	1	1											1				1	
Camden on Gauley	4	1			1							1							1
Cass	4	1						1		1									1
Cedar Grove	4		1			1						1							1
Century	4		1			1								1				1	
Colebank	4	1						1						1					1
Corliss	4				1					1						1			1
Cowen	4	1			1	1													1
Craigsville	4	1			1							1							1
Droop	4	1						1		1		1							
East Liverpool South	4	1				1						1		1					
Elizabeth	4	1												1		1		1	
Elkhurst	4	1				1						1							1
Ellamore	4		1			1								1		1			
Erbacon	4	1			1							1							1
Fellowsville	4		1					1						1					1
Folsom	4	1			1									1				1	
Fork Mountain	4	1		1		1				1									
Fort Spring	4							1		1		1							1
Gary	4					1				1						1			1
Gay	4	1	1													1		1	
Girta	4	1		1										1				1	
Gorman	4					1								1		1			1
Grantsville	4	1												1				1	1
Green Bank	4	1						1		1						1			
Greenville	4				1			1		1									1
Iaeger	4	1				1				1									1
Ivydale	4	1	1									1							1
Jerrys Run	4	1	1							1						1			
Kenna	4	1	1													1		1	
Kiahsville	4	1								1		1							1
Laneville	4	1	1	1				1											
Lewisburg	4		1					1		1		1							
Lobelia	4	1		1				1		1									
Lonaconing	4							1		1		1							1
Madison	4		1							1							1		1
Majorsville	4	1												1		1		1	
McGraws	4	1				1				1									1

Table 5. Geologic Mapping Priorities *(continued)*

TOPONAME	TotalScore	PrkFrstWMA	UrbHghExst	RuralDev	UtilTransP	MineSubsIn	SlopFailMW	Karst	SldIndWast	BioWtrSens	Grndwtr	SurfWtr	IndMins	CoalOilGas	GeoUnique	Contiguous	LostOpp	Dunkard	Lidar
Millstone	4	1	1															1	1
Montgomery	4					1						1				1			1
New Matamoras	4	1										1		1				1	
Newton	4	1	1									1							1
Newville	4	1			1							1							1
Normantown	4	1	1															1	1
Oceana	4	1				1				1									1
Onego	4	1	1					1								1			
Paden City	4	1										1		1				1	
Panther	4	1				1				1									1
Pickens	4	1			1	1													1
Portland	4	1										1		1				1	
Powellton	4		1			1										1			1
Powhatan Point	4	1										1		1				1	
Racine	4	1				1				1									1
Rainelle	4				1	1				1						1			
Raven Rock	4	1										1		1				1	
Rockport	4		1											1		1		1	
Romance	4	1														1		1	1
Salem	4		1		1									1				1	
Sandyville	4		1											1		1		1	
Snyder Knob	4	1				1		1		1									
Table Rock	4		1					1						1					1
Tazewell North	4					1				1						1			1
Valley Head	4	1			1			1											1
Wadestown	4													1		1		1	1
Wayne	4	1								1		1							1
Webb	4	1								1		1							1
Webster Springs	4	1				1		1											1
Weirton	4	1				1						1		1					
Wildell	4	1		1				1								1			
Williamson	4		1			1				1									1
Winfield	4											1				1		1	1
Winslow	4	1		1								1							1
Amherstdale	3					1				1									1
Annamoriah	3													1				1	1
Arnett	3					1				1									1
Arnoldsburg	3		1															1	1

Table 5. Geologic Mapping Priorities *(continued)*

TOPONAME	TotalScore	PrkFrstWMA	UrbHghExst	RuralDev	UtilTransP	MineSubsIn	SlopFailMW	Karst	SldIndWast	BioWtrSens	Grndwtr	SurfWtr	IndMins	CoalOilGas	GeoUnique	Contiguous	LostOpp	Dunkard	Lidar
Auburn	3													1				1	1
Belmont	3	1										1		1					
Branchland	3									1		1							1
Brownton	3					1								1				1	
Burnt House	3													1				1	1
Cameron	3	1												1				1	
Cassity	3				1	1										1			
Catlettsburg	3		1									1							1
Cedarville	3	1																1	1
Center Point	3	1												1				1	
Clay	3					1						1							1
Clothier	3					1				1									1
Coolville	3											1		1				1	
Cumberland	3							1				1							1
Diana	3				1	1													1
Eccles	3		1													1			1
Ellenboro	3		1											1				1	
Eskdale	3		1			1													1
Fleming	3	1										1		1					
Friendsville	3		1											1					1
Gap Mills	3	1						1		1									
Glace	3	1						1		1									
Glen Easton	3	1												1				1	
Hacker Valley	3	1			1														1
Harrisville	3	1												1				1	
Hundred	3													1				1	1
Huntington	3		1									1							1
Kermit	3					1				1									1
Kettle	3		1															1	1
Lavalette	3	1										1							1
Lindside	3				1			1											1
Little Birch	3	1	1																1
Littleton	3	1												1				1	
Lockwood	3					1				1									1
Lorado	3					1				1									1
MacFarlan	3	1												1				1	
Majestic	3					1				1									1
Matewan	3					1				1									1

Table 5. Geologic Mapping Priorities *(continued)*

TOPONAME	TotalScore	PrkFrstWMA	UrbHghExst	RuralDev	UtilTransP	MineSubsIn	SlopFailMW	Karst	SldIndWast	BioWtrSens	Grndwtr	SurfWtr	IndMins	CoalOilGas	GeoUnique	Contiguous	LostOpp	Dunkard	Lidar
Middlebourne	3	1												1				1	
Mill Creek	3	1						1								1			
Nestlow	3	1								1									1
Nettie	3				1	1													1
New Martinsville	3											1		1				1	
New Milton	3													1				1	1
Oxford	3													1				1	1
Paint Bank	3	1						1		1									
Peniel	3	1	1															1	
Pennsboro	3		1											1				1	
Pilot Knob	3					1				1									1
Pine Grove	3	1												1				1	
Prichard	3											1				1			1
Quick	3					1										1			1
Ranger	3									1		1							1
Richwood	3	1				1													1
Ronceverte	3							1		1		1							
Rucker Gap	3	1								1						1			
Rupert	3	1	1		1														
Schultz	3		1											1				1	
Scott Depot	3		1													1			1
Shirley	3	1												1				1	
Smithburg	3		1											1				1	
Smithville	3													1				1	1
Steubenville West	3											1		1				1	
Strange Creek	3		1									1							1
Sylvester	3					1				1									1
Trace	3					1				1									1
Webster Springs SE	3	1		1															1
Webster Springs SW	3	1		1															1
Wellsville	3	1										1		1					
West Union	3		1											1				1	
Wharton	3					1				1									1
Whitesville	3					1				1									1
Wileyville	3	1												1				1	
Williams Mountain	3					1				1									1

Table 5. Geologic Mapping Priorities *(continued)*

TOPONAME	TotalScore	PrkFrstWMA	UrbHghExst	RuralDev	UtilTransP	MineSubsIn	SlopFailMW	Karst	SldIndWast	BioWtrSens	Grndwtr	SurfWtr	IndMins	CoalOilGas	GeoUnique	Contiguous	LostOpp	Dunkard	Lidar
Williamsburg	3							1		1					1				
Wilsondale	3	1								1									1
Alleghany	2	1						1											
Alton	2				1	1													
Bastian	2		1					1											
Burning Springs	2													1				1	
Chloe	2																	1	1
Dorothy	2					1													1
Duo	2					1				1									
East Liverpool North	2											1		1					
Falling Spring	2	1								1									
Garretts Bend	2	1																	1
Gassaway	2																	1	1
Gladesville	2													1					1
Griffithsville	2									1									1
Hager	2	1								1									
Hamlin	2															1			1
Herold	2		1																1
Interior	2	1						1											
Kentuck	2	1																1	
Knoxville	2											1		1					
Liverpool	2													1				1	
Looneyville	2																	1	1
Matheny	2									1									1
Milo	2									1									1
Narrows	2		1					1											1
Porters Falls	2													1				1	
Potts Creek	2	1						1											
Pullman	2													1				1	
Quinwood	2				1	1													
Reedy	2													1				1	
Rosedale	2																	1	1
Round Bottom	2											1		1					
Skelt	2					1													1
Spencer	2		1															1	
Swandale	2					1													1
Tariff	2																	1	1
Tioga	2					1													1
Trout	2							1		1									

Table 5. Geologic Mapping Priorities *(continued)*

TOPONAME	TotalScore	PrkFrstWMA	UrbHghExst	RuralDev	UtilTransP	MineSubsIn	SlopFailMW	Karst	SldIndWast	BioWtrSens	Grndwtr	SurfWtr	IndMins	CoalOilGas	GeoUnique	Contiguous	LostOpp	Dunkard	Lidar
Union	2							1		1									
Waiteville	2	1						1											
Walkersville	2	1																	1
West Hamlin	2											1							1
Widen	2		1			1													1
Burnaugh	1											1							
Craig Springs	1	1																	
Goshen	1	1																	
Reddish Knob	1	1																	
Rock Cave	1	1																	
Walton	1																	1	

Attribute Fields	-	Description
TOPONAME	-	7½-min. Quadrangle Name
Mapped	-	Already Mapped or Not
PrkFrstWMA	-	State and National Parks, Forest, and Wildlife Areas
UrbHghExst	-	Urban Development, Existing Highway Corridors
Rural_Dev	-	Rural Development
UtilTransP	-	New, Proposed Major Utility, Pipeline, or Transportation Corridors
MineSubsIn	-	Mine Subsidence, Inactive Mining
SlopFailMW	-	Slope Failure and Mass Wasting
Karst	-	Karst
SldIndWast	-	Solid and Industrial Waste Disposal
BioWtrSens	-	Biologically Sensitive Areas, Sensitive Watersheds
Grndwtr	-	Groundwater
SurfWtr	-	Surface Water
IndMins	-	Industrial Minerals (Limestone, Sandstone, Building Stone, Clay, Sand and Gravel, Road Metal, etc.)
CoalOilGas	-	Coal, Oil & Gas
GeoUnique	-	Geologic Features, Uniqueness
Contiguous	-	Contiguous to Completed Mapping
LostOpp	-	Lost Opportunity
Dunkard	-	Located in the Dunkard Group
Lidar	-	Lidar Availability Now
TotalScore	-	Sum of above fields

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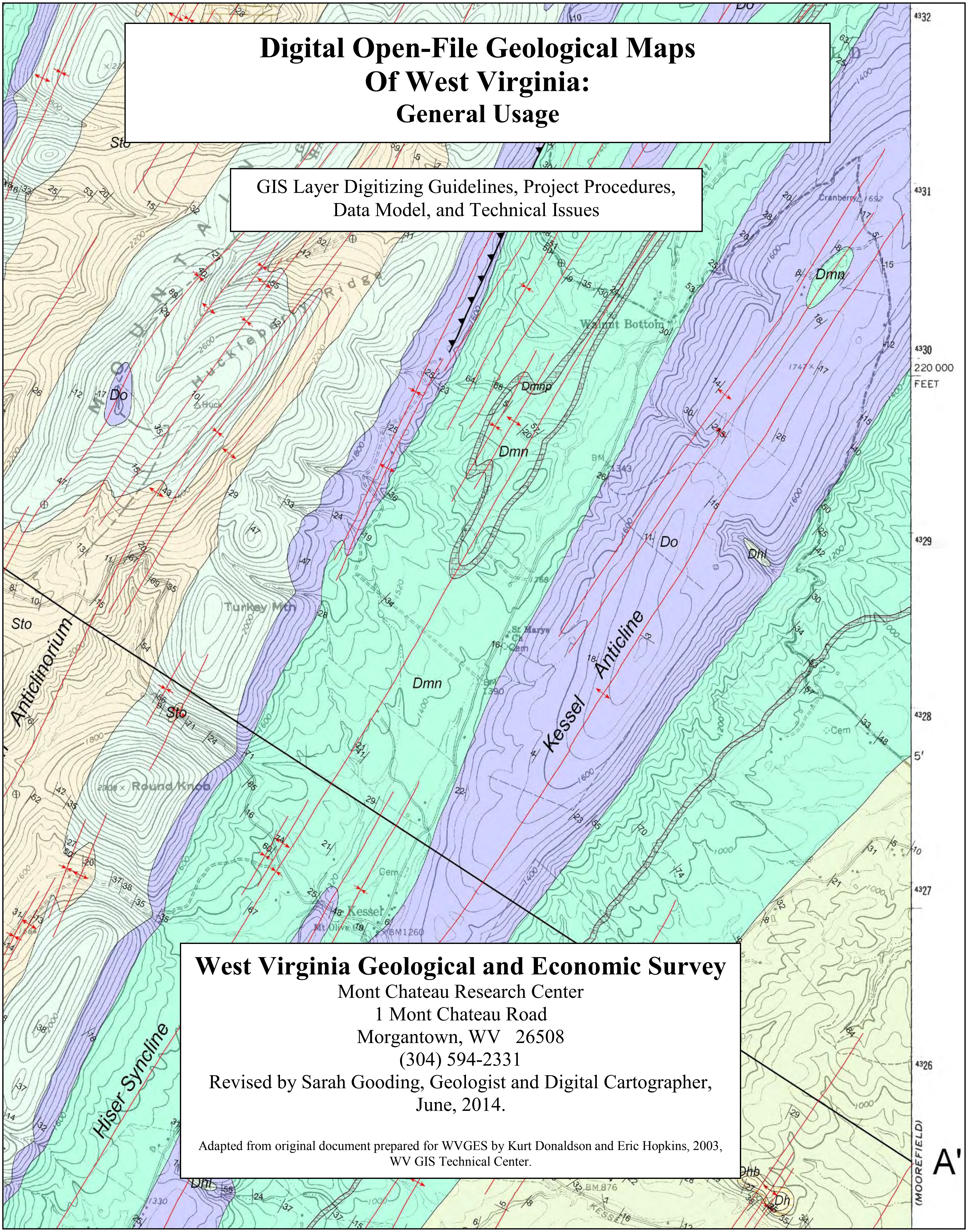
APPENDIX A

GIS Data Model and Map-Digitizing Procedures

Digital Open-File Geological Maps Of West Virginia:
General Usage

GIS Layer Digitizing Guidelines, Project Procedures, Data Model, and Technical Issues



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June, 2014.

Adapted from original document prepared for WVGES by Kurt Donaldson and Eric Hopkins, 2003, WV GIS Technical Center.

Table of Contents

Introduction …………………………………..………………………………….. 1

Project Scope and Setting……………………...…………………………………… 1
Conversion process….………..……………………………………………………….. 4

I. Scanning and georeferencing geologic quadrangle maps………………………….. 4

II. Capturing geologic features
Feature collection sequence, layers collected …………………………………... 6

III. Feature attribution and symbology
Polygon, line, and point features.. 10

IV. Edgematching………………………………………………………………… 12

V. Quality control………………………………………………………………… 13

Appendices

Appendix I. Geology GIS layer descriptions, Data Model….………………………… 14
Appendix II. Cartographic symbol legend…………………………………………….. 21

On the DVD-ROM:

- Digital Copy of this Document in Adobe PDF format
- Quadrangle Index Map shapefile for the project *idx_24k_utm83.shp* (or in UTM 27)
- WV county boundary shapefile for the project *county_24k_drg_utm83.shp* (or UTM 27)
- ESRI-format geodatabase or shapefiles for the Open File quadrangle
- Scanned copies of author's original source maps, text, and other materials
- ArcGIS map document format and pdf or jpg format versions of final published Open File map, if applicable

INTRODUCTION

Purpose

Digital map conversion (Figure 1) of geologic features drawn by the West Virginia Geological and Economic Survey (WVGES) and others on U.S. Geological Survey (USGS) 1:24,000-scale topographic base maps (Figure 2) is an important, long-term goal. This handbook describes the procedures to be followed by project members and the expected final product specifications for the conversion of hand-drawn geologic maps into a form usable in a geographic information system (GIS). To ensure consistent and high-quality edgematched GIS-ready geologic and surficial maps in time to meet tight project deadlines, it is very important that all project members, in all locations, use the same digitizing, processing and quality control procedures and the same project data model, all of which are provided in the text and appendices of this handbook.

Figure 1: Hand-drawn geologic features on USGS 1:24,000-scale topographic map.

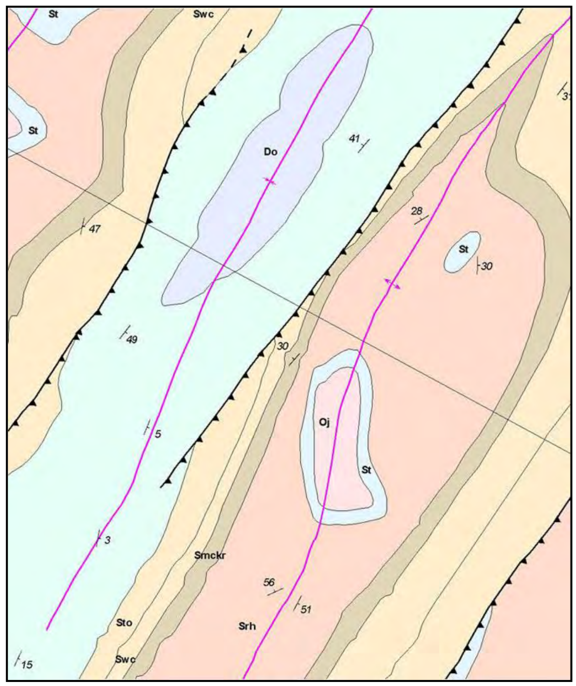

Figure 2: Geologic map digital conversion.

Project Scope and Setting:

This project includes all West Virginia geologic quadrangles mapped under the federal 1:24,000-scale STATEMAP project. Other West Virginia quadrangles mapped under other projects are also planned to be digitized and converted into GIS layers, to create a complete digital collection of all geologic mapping at 1:24,000-scale in West Virginia.

The goal of this project is to produce 1:24,000-scale digital surficial and bedrock geologic maps along with their respective geodatabases using an appropriate and well-documented data model.

OVERALL GIS PACKAGE CONTENTS:

Final map products in GIS format will include:

- A digital geologic map for each 7.5-minute topographic quadrangle in ESRI ArcGIS® 10.x, or latest version, and a copy of same map in pdf or jpg format;
- All maps seamlessly edge matched with each other and with other mapping on adjacent quadrangles;
- A personal geodatabase (.mdb), or set of shapefiles, for each digital geologic-GIS map. All geologic features on the published map(s) will be present as GIS data layers, described in the following chapters.
- Accompanying text and graphics containing map explanatory information, such as a description of map units;
- A cross section showing sub-surface interpretation;
- A stratigraphic column depicting stratified units, where applicable;
- Where applicable, a correlation diagram showing age relationships of map units;
- An explanation of map symbols; and
- Copies of all original source maps, text and other materials from map authors.

These digital products will be delivered via CD-ROM, or some other agreed-upon electronic medium.

Need for Better Resolution Geologic Maps

The digitized 1968 *Geologic Map of West Virginia* is the only seamless geology GIS file that exists for the entire State. Because of its poor spatial resolution and generalized geologic unit representation, it was determined that this 1:250,000-scale geologic map should be updated with more accurate 1:24,000-scale geologic data (Figure 3).

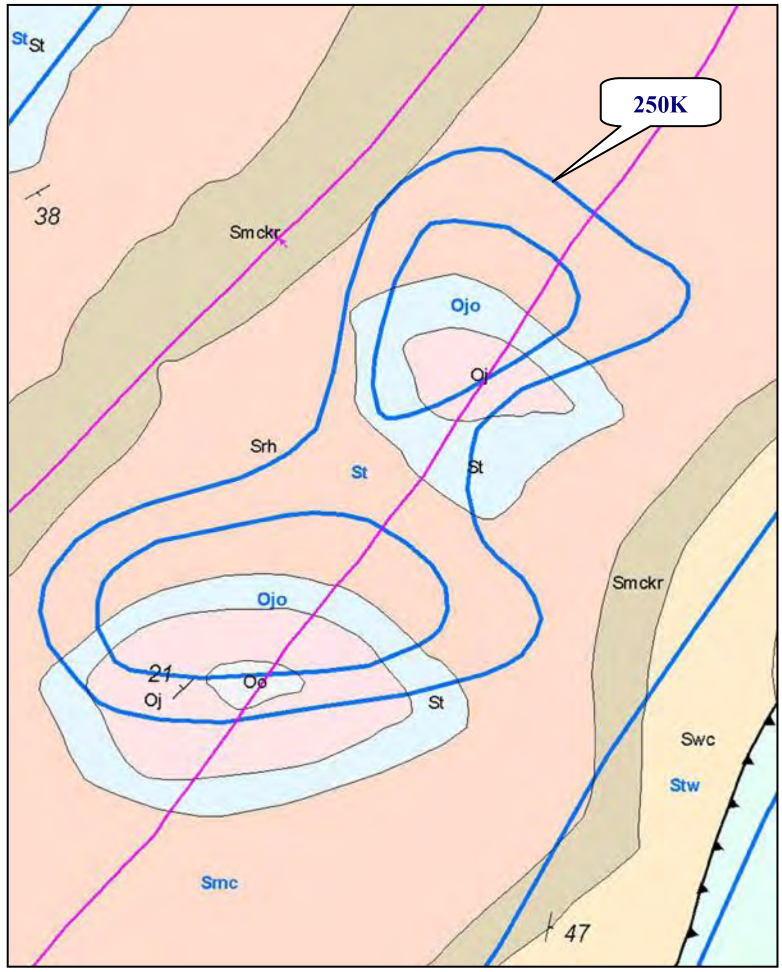

Figure 3: Comparison of 1:250,000-scale geologic map (dark blue lines and labels) with more accurate 1:24,000-scale geologic map.

GIS Software Platform

WVGES uses ESRI's ArcGIS software, along with various vector data formats (e.g., ArcInfo coverages, shapefiles, and geodatabases), and raster images (Grids, JPG, TIFF) to perform the conversion. The main vector file formats preferred for this project are shapefiles and geodatabases, due to their portability and widespread compatibility with other types of GIS and CAD software. The main raster file format preferred for this project is 400dpi indexed-color TIFF file-format scanned images of original maps due to their superior image quality and ease of georeferencability.

Coordinate System

All GIS layers are cast on the Universal Transverse Mercator (UTM) projection, Zone 17, most using datum NAD 83, with units in meters. However, some quadrangles might use datum NAD 27, and the datum used is usually noted in the filename of the quadrangle boundary polygon shapefile that accompanies each set of GIS geology layers. Projection files (with a .prj file extension) must also be provided for each shapefile layer in the project. World files (.tfw or .jpgw file extensions, ArcMap .aux files, etc) must also be provided for any georeferenced raster layers that accompany the vector data.

Ownership

All digital and hardcopy products are the property of the WVGES and will be distributed by them on a request basis. WVGES reserves the right to maintain, edit, and update all digital and hardcopy products without notice to the consumer.

Disclaimer

The Open-File Geological Map publications represent interpretations of best-available data made by professional geologists. As in all research work, professional interpretations may vary, and can change with advancements in both technology and data quality. These publications are offered as a service of the State of West Virginia; proper use of the information herein is the sole responsibility of the user.

THE CONVERSION PROCESS: A Quick Overview:

The initial steps of the digital conversion require that the geological information on the original map be scanned and georeferenced. Digitizing in ArcMap then captures the various geological features such as faults, folds, strike & dip points and contacts. Then linear or polygon topology is created, validated and checked, and finally features are attributed. Next, attributed features are edgematched to corresponding features of adjacent quadrangles. In the cartographic map production phase, hardcopy or print-ready electronic versions are made with the appropriate map symbols and annotation. Throughout the conversion process, quality control checks are done (Figure 4).

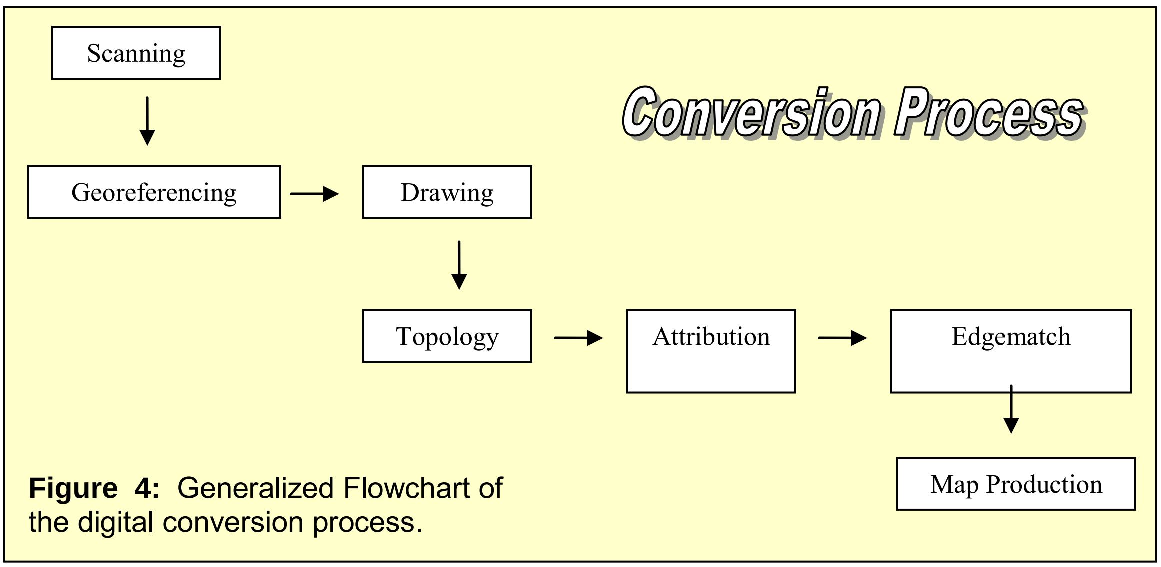

Figure 4: Generalized Flowchart of the digital conversion process.

THE CONVERSION PROCESS: Details:

I. Scanning and Georeferencing 1:24,000 Geologic Quadrangles

Scanning

Paper or mylar topographic quadrangles with hand-drawn geologic information, created by WVGES geologic mapping teams, are scanned directly to greyscale or indexed-color TIFF files using a high-resolution scanner at an optical resolution of 400dpi (usually) (Figure 1a).

Georeferencing in ArcMap

The scanned geologic quadrangle maps are next georeferenced in ArcGIS to the UTM NAD 1983, 7.5-minute Quadrangle Index Map shapefile ***idx_24k_utm83.shp***.

II. Capturing Geologic Features

- Arc Directionality: Direction matters! Arcs for linear features such as faults and folds have a directional component to correspond with the correct mapping symbols for printed maps. Note that some feature symbols are not symmetrical, e.g., thrust faults with "saw teeth" to one side only, or have directionality, e.g., plunging or overturned fold axes. Features need to be flipped after drawing (symbolize the feature to check the direction of thrust fault teeth, etc) or initially drawn in the correct direction to save the extra step. Features like this usually also contain an attribute in the data model that specifies the type and direction of movement, such as the *Fault_Type* attribute in the FLT (Faults) layer.

- Pseudonodes: Pseudonodes are added at intentional locations to capture changes in attributes of line features such as the confidence value attribute of geologic contact lines. When a contact line changes from a solid (certain) line style to a dashed (approximately located) line style, a pseudonode will exist between the two line segments. Each line segment will have the appropriate value from the data model for its *Confidence* attribute, and can then be symbolized differently on the resulting map.

- Snapping: It is expected that all line intersections will have correct topological integrity. This means that only line "ends" of line-type feature class layers can interact with each other. Snapping in ArcGIS must be set to "Line Ends" ONLY. (Only the quadrangle polygon can have snapping set to "Edge". Lines may snap to the "Edge" of the quad boundary, but may only be snapped to "ENDS" of each other within the map layer. If lines get snapped to other line "Edges" within a map layer, this will *not* be topologically correct and might be the source of intersection errors.)

FEATURE COLLECTION SEQUENCE

1. Geologic Formation Contacts, CNT (Line and Polygon)

Bedrock geology is mapped according to its geologic time period, i.e. Eocene, Mississippian, Devonian, Silurian, etc; and geographic type location, i.e., Marcellus Shale, Oriskany Sandstone, Tonoloway Limestone, or Juniata Formation (a group of several related rock types). The "contacts" are lines separating different geologic units, and are drawn solid, dashed, or dotted, according to how confident the author is in the line's location. Care should be used in interpreting the confidence value of contact lines that coincide with faults, to ensure that the two layers match.

Marker beds, such as thin sandstones and coal beds, that *also* form geologic unit boundaries, and are too thin at 1:24000 scale to be a polygon, are drawn in the CNT line layer, and are also given the unit abbreviation attribute. Marker beds and coal beds that are significant enough to be mapped, but *do not* form geologic unit boundaries, are captured in another layer, the COAL line layer, see description below.

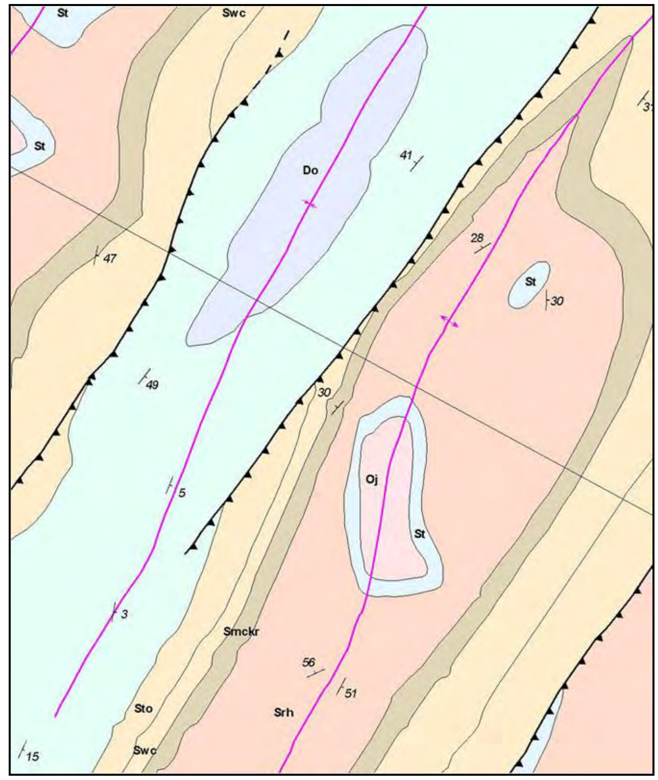

Figure 5: Digitized geologic features: formation units, faults, folds, strike/dip measurements, and cross-sectional lines.

Geologic formation contacts are collected as lines, which are then used with the quadrangle boundary to *generate* formation polygons. This is done to ensure that the contact lines are completely co-incident with the polygon boundaries, and minimizes topological problems such as gaps, overlaps, and doubled-up polygon boundaries caused when polygons are digitized as polygons instead of generated from linework. The polygons formed by the contacts are then run through several cycles of topological checking to resolve any digitizing errors in the linework and make sure that all polygons are formed.

Polygons are then labeled with the letter symbols used to represent the geologic units, i.e., "Do" for Devonian Oriskany, or "Sto" for Silurian Tonoloway Limestone, and so on. Unit Abbreviation Symbols and descriptions of geologic units for each quadrangle can be found in the Open-File Report of Investigations document that usually accompanies each Open-File Geological Map. Attempts have been made to use a consistent and unique unit abbreviation symbol for each unit across all quadrangles mapped digitally.

Errors, omissions, and inconsistencies may be noted in the original open-file texts and paper maps; edits to the final digital GIS layers and map layouts should be made to ensure that the digitized version of the map is as accurate, up-to-date, consistent, and complete as possible. Any errors fixed during the GIS process, or any other deviations required from the original map are noted to document all changes made from the author's original work, subject to the author's final approval.

2. Faults, FLT (Line Features)

Faults, which are coincidental with geologic formation contacts, are collected right after contact lines. The fault vectors are copied and pasted from the CNT line layer to the FLT line layer, and then the attributes are converted to those of the Fault layer (See Appendix I) This method ensures that the coincident faults and contacts features have the same exact vertex coordinates, by making sure that the line is only ever drawn ONCE. Faults are shown on the paper maps as solid, dashed, or dotted lines to indicate the confidence in their placement. Thrust faults are distinguished from others by the added "saw tooth" line decoration which shows direction of movement of the thrust fault (Figure 5). Relative motion along normal fault lines is indicated by "U" (up) or "D" (down) on the map. Relative motion along strike slip faults is shown with arrows on each side of the fault line. The direction and type of motion is included in the GIS layer as an attribute, along with feature confidence attributes and fault names for structures that are named on the map. This layer is one of the layers in which line direction matters, so faults should be symbolized with the correct line symbol (especially thrust faults) to make sure the symbol faces the correct direction.

3. Structural Fold Axes, STR (Line)

Fold axes are distinguished from other lines by their double-headed arrow symbols; arrows pointing out for anticlines (convex upward folds) and in toward the axis line, for synclines (concave upward folds). A terminal arrow on one or both ends of the axis line itself indicates plunge. The confidence attributes used for faults and contacts also applies to this layer as well as fold names for structures that are named on the map. This layer is one of the layers in which line direction matters, so folds should be symbolized with the correct line symbol (especially plunging and overturned folds) to make sure the line symbol faces in the correct direction.

4. Bedding Orientation, BED (Point)

The orientation of rock layers is measured at various outcrops and depicted on the geology maps using strike and dip symbols. These points are in some cases first given arbitrary station numbers on paper, which are used in some quads to join the digitized points to an Excel spreadsheet of strike and dip information. Some quads do not need station numbers, as the bedding points and their data are digitized directly off the source map, or downloaded from a handheld field device.

In the WVGES data model, the strike and dip direction values should be converted from a relative direction field-style measurement (e.g., strike N10 deg W; dip 35 deg NE) into an azimuth measurement which uses an absolute value within a 360-degree system for strike and also for dip direction. Using above strike example this would be Azimuth = 350, Dip = 35, Dip-Direction = 80.

The azimuth-style values are used to correctly orient the strike and dip symbols using the "Rotation Field" option in advanced symbol settings, to calculate the dip direction field (which is always perpendicular to strike), and to place the dip angle labels in the correct position on the finished maps using the "Rotation field" options in the label symbology settings.

In some quadrangles, an absolute strike value is not available, just the strike symbol is oriented on the paper or mylar map. In this case, an angle measurement tool is used in ArcMap to measure the azimuth value from the strike symbol off the scanned and georeferenced original map.

5. Cross Section Location, XSC (Line)
These lines are drawn across the map where geologists plan to make more extensive subsurface interpretations of the surface geology. They are marked with letters at each end, e.g., A-A', B-B'. Confidence levels do not apply to these features, the only attribute is the quadrangle name and the endpoint letters for each line on the map. The cross section diagram itself is digitized in another set of feature classes/layers, discussed below.

Naming conventions: Cross section diagram layers are named with the lowercase "xsc" in the filename to differentiate them from this cross section location line map layer, which has "XSC" in the name in all-caps.

6. Igneous Intrusive Features, ILN (Line)
These small and rare features (e.g., dikes, sills) are captured in their own GIS layer. The confidence symbology used for faults and contacts applies to this layer. They are also given a unit abbreviation attribute and an attribute for composition/rock type, if known. Any intrusive features large enough to be polygons instead of lines at 1:24000 scale are included in the geological contacts line/polygon layers instead. These features are rare and are only usually exposed around Pendleton County, WV.

7. Coal Beds and Non-Contact Forming Marker Beds, COAL (Line)
Line layer for linear geologic features such as coalbeds, fireclays and sandstone marker beds that are only a line width at 1:24,000 scale, and *do not form unit contacts*. (Beds that form unit boundaries should be in the CNT geologic contacts line layer.) Attributes include Type, Confidence, Symbol, full marker bed/coal name, and unit abbreviation.

8. Coal (or Sandstone) Structural Contours, "*<Quadname>_<CoalName>*_STC" (Line)
Structure contour elevation lines drawn on a particular bed(s), usually coals or sandstones, with elevation, unit name abbreviation, confidence and symbol attributes. Some maps show contours for multiple beds, these should be drawn in separate layers, with the bed name in the layer title.

9. Surficial Geologic Contacts, SRF and/or QAL (Line and Polygon)

QAL: On maps showing simplified Surficial geology such as only Quaternary alluvium, terraces, artificial fill, mine dumps etc, the QAL line and QAL_poly layers can be captured *if the original map shows concealed bedrock contact lines*. If no concealed bedrock contacts are shown, QAL and related units will be included in CNT and CNT_poly as a unit abbreviation. QAL lines and polygons are captured using the same linework-generated polygon method as the CNT and CNT_poly layers, and should also be run through several cycles of topological checking to resolve any digitizing errors in the linework and make sure that all polygons are formed prior to giving them attributes.

SRF:** On maps where more detailed Surficial geology is shown, usually on a separate map sheet from the bedrock geology, the SRF line and SRF_poly layers can be captured. SRF lines and polygons are created using the same linework-generated polygon method as the CNT and CNT_poly layers. Surficial lines and polygons should also be run through several cycles of topological checking to resolve any digitizing errors in the linework and make sure that all polygons are formed prior to giving them attributes.

10. Digitized Cross Sections ("xsc"), and Stratigraphic Columns ("<*quad*>_Strat_#")
The cross section location line (i.e., A-A' line) is accurately measured off the original source map to an accuracy of hundredths of an inch. This measurement is used to build a cross section frame at the correct size at 1:24,000 scale (also commonly referred to as 1 inch : 2000 feet) in ArcMap, so that it will print out at the correct size on the finished map publication. The cross section frame is generally drawn at some rough distance below the map quadrangle, so that the cross section and the geologic map could be shown in the same map data frame, if desired. The cross section shares the same coordinate system as its corresponding geologic map for this reason (although this is an "artificial" and arbitrary geographic space for the cross section.) The sections do NOT have "Z" (3-D vertical) dimension values.

Cross sections are included for diagrammatic interpretive purposes, but their dimensions (size and scale) must match the map's exactly. The frame is built to 1:24,000 scale (1in:2000ft) horizontally *and* vertically, given elevation attributes along the vertical axis, and the scanned cross section image is then georeferenced to it. The cross section is digitized as line features, with a Type attribute for contacts/faults, and a Confidence attribute for line symbolization. Contact polygons are then generated using the contact lines and the cross section frame, and given the same unit abbreviation symbol attributes as the corresponding geological map. If there are any non-contact-forming coal beds or marker beds shown in the cross section, they are drawn in a separate line layer, and also given the same unit abbreviation symbol attributes as the corresponding geological map. On map layouts, geologic units are given the same symbols in both the map and the cross section, with the exception of units that do not crop out are rendered in shades of grey in cross section.

Naming conventions: These cross section diagram layers are named with the lowercase "xsc" in the filename to differentiate them from the cross section *location line* map layer, discussed previously, which has "XSC" in the name in all-caps.

III. Feature Attribution and Associated Symbols

Map features are first drawn and "cleaned" by creating and running topology to check for digitizing errors such as line intersections, overlaps, and dangles, before adding attributes. Certain features like faults and geologic contacts, and contact lines and polygons, must be collected in the proper sequence because of shared locations.

A crucial element in the processing and representation of abstracted map data through a GIS is the assignment of attributes to spatial features. Attributes function directly when querying features and indirectly by controlling cartographic symbol styles in electronic and hardcopy maps. See the GIS layer descriptions (GIS data dictionary) in **Appendix I** for a full list of attribute fields, data types, and acceptable value ranges.

A. *Polygon Features*

Polygons are labeled in the maps with the "*Unit_Abbrv*" field. This field contains the letter symbols used to represent the geologic units, i.e., "Do" for Devonian Oriskany, or "Sto" for Silurian Tonoloway Limestone, and so on. Unit Abbreviation Symbols and descriptions of geologic units for each quadrangle can be found in the Open-File Report of Investigations document that usually accompanies each Open-File Geological Map. Attempts have been made to use a consistent and unique unit abbreviation symbol for each unit across all quadrangles mapped digitally. A Geologic Unit Information table has been compiled for use in all maps from these unit descriptions and abbreviations used, that can be joined to the "*Unit_Abbrv*" field.

B. *Line Features*

Many line feature layers have several fields related to confidence and symbol style. These fields are short integer with, in the case of *Confidence*, increasing values indicating greater uncertainty, e.g., 1 = certain, 2 = approximately located, 3 = inferred, 4 = inferred, queried. The *Type* field in the contact arc feature class is used to distinguish quadrangle or state boundary from contact. *Symbol* field values are combined from one or more other fields. For example, the contact arc *Symbol* field may have a value of 12, indicating *Type* = 1 (contact) and *Confidence* = 2 (approximately located).

Line features are symbolized according to the confidence associated with the original geologic map features. Solid lines indicate a confidence level of "certain," while dashed, dotted, and question mark ('?') symbols indicate "approximately located," "inferred," and "inferred, queried," respectively.

C. *Point Features*

Bedding Orientation Points are sometimes identified using arbitrarily assigned station numbers, that can be matched to data recorded in a field journal or exported from a handheld device. Rock type and bedding orientation measurements are recorded by field geologists at the point locations. The horizontal compass direction, or strike, of the rock layer is recorded as, or converted to, an *Azimuth* value, which is an absolute value between 0 and 360 degrees vs. Strike, which needs a directional identifier such as "N 20deg.W". For example the "N 20deg W" Strike would be an *Azimuth* of 340 degrees.

The *Azimuth* value is unambiguous, and is used in the advanced symbol properties of ArcMap to rotate the bedding symbol on the map.

Dip_Angle, a measure of the rock's tilt downward and perpendicular to strike, is displayed in the map as a feature label, using the *Dip_Direct* field as a rotation field in advanced label placement properties to correctly place the labels around the bedding symbol. The *Dip_Direct* field should always be calculated from the *Azimuth* field values using the Field Calculator tool in the attribute table, and applying the formula "*Dip_Direct = Azimuth + 90"*. Any resulting values that are over 360 degrees should be adjusted by subtracting 360 from the value to get the correct azimuth-style value for dip direction. No *Azimuth* or *Dip_Direct* values can exceed 360 degrees. No *Dip_Angle* values can exceed 90 degrees. No *NULL* values are allowed in any fields. Zero ("0") is a real value for horizontal (flat-lying) bedding orientations (for *Azimuth, Dip_Angle,* and *Dip_Direct* fields).

The *Symbol* field contains one of six values determining how the bedding orientation symbol will appear on the map: 1 = inclined, 2 = horizontal, 3 = vertical, 4 = overturned, 5 = foliation, and 6 = crossbed measurements. See the legend in **Appendix II** to see what these symbols look like.

The ArcMap "Geology 24K" symbol set contains icons for the above bedding orientations used in the geologic quadrangles. This extra symbol palette can be accessed in the "Symbol Selector" dialog box by clicking on the "More Symbols" button and choosing "Geology 24K" from the list. The size of the point symbols can be adjusted as large as needed for clarity.

IV. EDGEMATCHING

Geologic features are usually mapped and digitized in discrete quadrangles. Polygons and linear geological features should, however, match seamlessly across quad boundaries. The 1:24,000-scale geological GIS files will eventually cover all of West Virginia, further emphasizing the need for seamless integration of all quadrangles. The National Parks Service has also specifically requested for their projects that "*All maps seamlessly edge match with each other and with other mapping on adjacent quadrangles.*"

Line and polygon locations and attributes should match across the quadrangle boundaries. Line locations may be adjusted slightly on one or both quadrangles to achieve a match. Adjacent quadrangle maps should be checked *before* polygons are generated to simplify this process, but this is not always possible. If geologic unit polygons already exist, Topology Editing Tools should definitely be used in order to edit co-incident features such as contact lines, polygon boundaries and fault lines, to maintain correct feature topology and co-incidence and not create new errors.

In some cases, multiple geological formations have been separated by geologists in one quadrangle but mapped in adjacent quads as a single, combined unit. Figure 6 is an example of this. The same polygon color can be used for both the combined and separated formations, thus simplifying the visual aspect of the map while preserving geological detail in the GIS. The quadrangle edge serves as the boundary between the differently-mapped geological contact units in cases such as this.

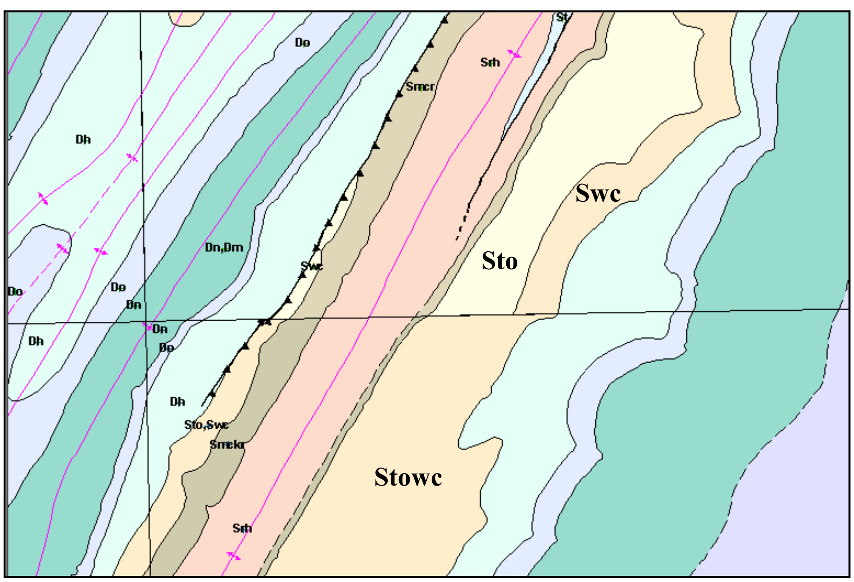

Figure 6: Combined Sto, Swc units (center orange unit, lower, labeled "Stowc") and separated Sto and Swc formation polygons (center yellow and orange units, upper) at quadrangle boundary.

V. QUALITY CONTROL

The following quality control measures are undertaken during the conversion process:

Checklist: The ***Geologic 7.5' Quad Digitizing*** and the ***QA/QC Checklists*** should be completed for each digitized quadrangle, and submitted along with the digital geologic map files to WVGES for the internal review process, prior to external review and publication. The checklists are designed to be a comprehensive review of the following:

- Positional Accuracy: Verify that scanned geological maps were georeferenced correctly with correct quadrangle index layer. Verify the quad boundary layer didn't get accidentally moved during digitizing process. Verify correct corner tics were used for NAD83.

- Topology & Direction: Linear and polygon geometric errors (e.g., undershoots, dangles, missing linework, intersections, etc.) and polygon label errors (e.g., misspelled, duplicate or missing labels) were checked and fixed. Final topology validated and error-free. Coincident features were edited with topological rules to ensure shared features were edited together. Line directions (e.g., for fault and fold symbology) were checked and fixed. Bedding point locations with missing, incomplete, or erroneous data were checked and fixed, and if necessary, deleted from the dataset. Points symbolized and checked they rotate correctly, if not, fixed.

- Content: Digitized layers were checked against scanned source material. Errors, omissions, and inconsistencies may be noted in the original open-file texts and paper maps; edits to the final digital GIS layers and map layouts should be made to ensure that the digitized version of the map is as accurate, up-to-date, consistent, and complete as possible. Any errors fixed during the GIS process, or any other deviations required from the original map should be noted on the ***Geologic 7.5' Quad Digitizing Checklist***, to document all changes made from the author's original work, subject to the author's final approval. Digitized map products will be reviewed by their authors and any errors or issues found, documented and fixed will be approved for the final version.

- Edgematch: All maps produced should seamlessly match both linework and attributes along the quadrangle edges to each other, and to the best extent possible, to any previously produced maps.

- Database Integration: Verify all attribute fields in each map layer (field names, field types and lengths) and attribute values are consistent with WVGES data model, to assist in merging/appending of quads together in future, and minimize the time needed to publish the final map. Filenames for map layers must also be consistent with WVGES naming conventions and data model. Attributes of features should be double-checked for correctness and completeness.

Appendices

Appendix I: GIS map layer descriptions (Data Dictionary/Data Model)

The various data layers of the geologic map GIS are described below. The Brandywine quadrangle is used as an example here in place of <Quadname>.

Filenames are composed of the whole quad name plus a three-character layer descriptor:
<Quadname>_XXX   Use the underscore to separate parts of filename (NO spaces)

Field Names should be spelled exactly as shown and given field type shown in italics:
Attribute Field Names **:** *Field types (number indicates width of field)*:
List of allowed attribute codes in field and a short description of each

<u>A. Features with polygon and line topology:</u>

Layer: **Geological Formation Contacts, Lines: <Quadname>_CNT**
Layer file name: Brandywine_CNT
Layer type: Polyline
Line attribute fields:

Type : *short integer*
- -99 = Quadrangle boundary
- -88 = State or County boundary
- 1 = Contact

Confidence : *short integer*
- 1 = Certain (Solid line)
- 2 = Approximately located (Dashed line)
- 3 = Inferred (Dotted line)
- 4 = Inferred, Queried (Dotted line with question marks)

Symbol : *short integer*
- -99 = Quadrangle boundary
- -88 = State or County boundary
- 11 = Contact, Certain
- 12 = Contact, Approximately located
- 13 = Contact, Inferred
- 14 = Contact, Inferred, Queried

Unit_Abbrv : *text 10*
- 2 - 10 character unit abbreviation used on map
- *(For thin (only a line-width at 1:24,000 scale) marker beds, coal seams, etc that are <u>also geologic unit contacts</u>. Thicker than line-width units should be polygons. Non-contact forming units should be in the COAL layer)*

Layer: **Geological Formation Contacts, Polygons: <Quadname>_CNT_poly**
Layer file name: Brandywine_CNT_poly
Layer type: Polygon
Polygon attribute fields:

Unit_Abbrv : *text 10*
- 2 - 10 character unit abbreviation used on map

GeoAge_Lab : *text 10*
- 2 - 10 character unit abbreviation used on map, utilizes the geoageFullAlpha font (provided with the dataset) to properly symbolize geologic time period special characters (e.g., Ꞓ,ℙ symbols used for Cambrian, Pennsylvanian, etc).

Layer: **Quaternary Alluvium Contacts, Lines: <Quadname>_QAL** *(For maps showing only simplified Quaternary alluvium units, and with concealed bedrock contacts drawn in under the Qal. If no concealed bedrock contacts are shown, include Qal units in with the CNT line and polygon layers. For surficial deposits mapped in more detail, use **SRF** line and polygon layers.)*

Layer file name: Brandywine_QAL

Layer type: Polyline

Line attribute fields:

Type : *short integer*
- -99 = Quadrangle boundary
- -88 = State or County boundary
- 1 = Contact

Confidence : *short integer*
- 1 = Certain (Solid line)
- 2 = Approximately located (Dashed line)
- 3 = Inferred (Dotted line)
- 4 = Inferred, Queried (Dotted line with question marks)

Symbol : *short integer*
- -99 = Quadrangle boundary
- -88 = State or County boundary
- 11 = Contact, Certain
- 12 = Contact, Approximately located
- 13 = Contact, Inferred
- 14 = Contact, Inferred, Queried

Layer: **Quaternary Alluvium Contacts, Polygons: <Quadname>_QAL_poly**

Layer file name: Brandywine_QAL_poly

Layer type: Polygon

Polygon attribute fields:

Unit_Abbrv : *text 10*
- 2 - 10 character unit abbreviation used on map

Layer: **Surficial Geology Formation Contacts, Lines: <Quadname>_SRF **** *(For detailed surficial geology usually shown on separate map sheet)*

Layer file name: Brandywine_SRF

Layer type: Polyline

Line attribute fields: ***Kite(2003) Data Model to be used on NPS Surficial Maps*

Type : *short integer*
- -99 = Quadrangle boundary
- -88 = State or County boundary
- 1 = Contact

Confidence : *short integer*
- 1 = Certain (Solid line)
- 2 = Approximately located (Dashed line)
- 3 = Inferred (Dotted line)
- 4 = Inferred, Queried (Dotted line with question marks)

Symbol : *short integer*
- -99 = Quadrangle boundary
- -88 = State or County boundary
- 11 = Contact, Certain
- 12 = Contact, Approximately located
- 13 = Contact, Inferred
- 14 = Contact, Inferred, Queried

Layer: **Surficial Geology Contacts, Polygons: <Quadname>_SRF_poly ****
Layer file name: Brandywine_SRF_poly
Layer type: Polygon
Polygon attribute fields: ***Kite(2003) Data Model to be used on NPS Surficial Maps*

Unit_Abbrv : *text 10*

1 - 10 character unit abbreviation used on map

B. Features with line topology

Layer: **Faults: <Quadname>_FLT**
Layer file name: Brandywine_FLT
Layer type: Polyline
Line attribute fields:

Name *: text 25* (For faults named on map)

Type *: short integer*
- 1 = Normal
- 2 = Thrust (also called Reverse)
- 3 = Strike Slip (also called Lateral)

Confidence : *short integer*
- 1 = Certain
- 2 = Approximately located
- 3 = Inferred
- 4 = Inferred, Queried

Symbol : *short integer*
- 11 = Normal, Certain
- 12 = Normal, Approximately located
- 13 = Normal, Inferred
- 14 = Normal, Inferred, Queried
- 21 = Thrust, Certain
- 22 = Thrust, Approximately located
- 23 = Thrust, Inferred
- 24 = Thrust, Inferred, Queried
- 31 = Srike-slip, Certain
- etc

Fault_Type *: text 20* (type and direction of movement)
- Normal_up_NE (or NW, S etc.)
- Reverse_SE (or NW, W etc.)
- Strike Slip RL (right-lateral strike slip (direction of *top* arrow))
- Strike Slip LL (left-lateral strike slip (direction of *top* arrow))

Layer: **Structural Fold Axes: <Quadname>_STR**
Layer file name: Brandywine_STR
Layer type: Polyline
Line attribute fields:

Name : *text 50* (For major folds named on map)

Type : *short integer*
- 1 = Anticline
- 2 = Syncline
- 3 = Anticline, Overturned
- 4 = Syncline, Overturned

Fold_Type : *text* 25 (fold types as text values and overturned direction)
- Anticline
- Syncline
- Anticline, ot,e (or w, sw, etc)
- Syncline, ot,e (or w, sw, etc)

Confidence : *short integer*
- 1 = Certain
- 2 = Approximately located
- 3 = Inferred
- 4 = Inferred, Queried

Plunge : *short integer*
- 0 = Non-Plunging
- 1 = Plunging

Symbol : *short integer*
- 110 = Anticline, Certain
- 120 = Anticline, Approximately located
- 130 = Anticline, Inferred
- 140 = Anticline, Inferred, Queried
- 111 = Plunging Anticline, Certain
- 121 = Plunging Anticline, Approximately located
- 131 = Plunging Anticline, Inferred
- 141 = Plunging Anticline, Inferred, Queried
- 210 = Syncline, Certain
- 220 = Syncline, Approximately located
- 230 = Syncline, Inferred
- 240 = Syncline, Inferred, Queried
- 211 = Plunging Syncline, Certain
- 221 = Plunging Syncline, Approximately located
- 231 = Plunging Syncline, Inferred
- 241 = Plunging Syncline, Inferred, Queried
- 310 = Overturned Anticline, Certain
- 320 = Overturned Anticline, Approximately located
- 330 = Overturned Anticline, Inferred
- 340 = Overturned Anticline, Inferred, Queried
- 410 = Overturned Syncline, Certain
- 420 = Overturned Syncline, Approximately located
- 430 = Overturned Syncline, Inferred
- 440 = Overturned Syncline, Inferred, Queried
- etc.

Layer: **Igneous Intrusive Features: <Quadname>_ILN**
Layer file name: Brandywine_ILN
Layer type: Polyline
Line attribute fields:

Confidence : *short integer*
- 1 = Certain
- 2 = Approximately located
- 3 = Inferred
- 4 = Inferred, Queried

Unit_Abbrv : *text 10*
- 2 - 10 character unit abbreviation used on map

Rock_Type : *text 25*
- Rock type (e.g., andesite, basalt, pyroxene, etc.)

Layer: **Non-Contact-Forming Marker Beds/Coals: <Quadname>_COAL**
Layer file name: Brandywine_COAL
Layer type: Polyline
Line attribute fields:

Name : *text 50* (Full coal or sandstone bed name)
Type : *short integer*
- 1 = Coal
- 2 = Other marker bed type (Sandstone, Fireclay, Tuff, etc)

Confidence : *short integer*
- 1 = Certain
- 2 = Approximately located
- 3 = Inferred
- 4 = Inferred, Queried

Symbol : *short integer*
- 11 = Coal, Certain
- 12 = Coal, Approximately located
- 13 = Coal, Inferred
- 14 = Coal, Inferred, Queried
- 21 = Other marker bed type, Certain
- 22 = Other marker bed type, Approximately located
- 23 = Other marker bed type, Inferred
- 24 = Other marker bed type, Inferred, Queried

Unit_Abbrv : *text 10*

2 - 10 character unit abbreviation used on map (use official WVGES Coal Bed Mapping Project names and abbreviations for all COALS)

(For thin (only a line-width at 1:24,000 scale) marker beds, coal seams, etc that are NOT geologic unit contacts. Thicker than line-width units should be polygons. Contact forming units should also be in the CNT layer. This layer may contain ALL coal beds on map for cartographic convenience.)

Layer: **Coal/Sandstone Structural Contours: <Quadname>_<CoalName>_STC**
Layer file name: Brandywine_No5Block_STC
Layer type: Polyline
Line attribute fields:

Elev : *long integer (to leave enough spaces for negative numbers below sea level)*

Elevation of contour line

Confidence : *short integer*
- 1 = Certain
- 2 = Approximately located
- 3 = Inferred
- 4 = Inferred, Queried

Symbol : *short integer*
- -999 = Div Line (Dividing line or neatline shown in STC layer)
- 1 = Contour Line, Certain
- 2 = Contour Line, Approximately located
- 3 = Contour Line, Inferred
- 4 = Contour Line, Inferred, Queried

Unit_Abbrv : *text 10*

2 - 10 character unit abbreviation used on map

Layer: **Cross Section Location Line: <Quadname>_XSC**
Layer file name: Brandywine_XSC
Layer type: Polyline
Line attribute fields:

Name : *text 25* (<Quadname> A-A', etc. For example: Brandywine A-A')

Layer: **Cross Section Frame Lines: <Quadname>_xsc_frame**
Layer file name: Brandywine_xsc_frame
Layer type: Polyline
Line attribute fields:

Elev : *long integer (to leave enough spaces for negative numbers below sea level)*
-9999 = Frame axis (Vertical and Horizontal)
Elevation of tic marks on vertical axes (example: 2000, 0, -2000)

Layer: **Cross Section Contacts & Fault Lines: <Quadname>_xsc_cnt**
Layer file name: Brandywine_xsc_cnt
Layer type: Polyline
Line attribute fields:

Type : *short integer*
1 = Contact
2 = Fault
Confidence : *short integer*
1 = Certain
2 = Approximately located
3 = Inferred
4 = Inferred, Queried
Symbol : *short integer*
11 = Contact, Certain
12 = Contact, Approximately located
13 = Contact, Inferred
14 = Contact, Inferred, Queried
21 = Fault, Certain
22 = Fault, Approximately located
23 = Fault, Inferred
24 = Fault, Inferred, Queried
Unit_Abbrv : *text 10*
2 - 10 character unit abbreviation used on map
(For thin (only a line-width at 1:24,000 scale) marker beds, coal seams, etc that are ALSO geologic unit contacts. Thicker than line-width units should be polygons. Non-contact forming units should be in the xsc_coal layer)

Layer: **Cross Section Marker Beds/Coals: <Quadname>_xsc_coal**
Layer file name: Brandywine_xsc_coal
Layer type: Polyline
Line attribute fields:

Name : *text 50* (Full coal or sandstone bed name)
Type : *short integer*
1 = Coal
2 = Other marker bed type (Sandstone, Fireclay, etc)
Confidence : *short integer*
1 = Certain
2 = Approximately located
3 = Inferred
4 = Inferred, Queried
Symbol : *short integer*
11 = Coal, Certain
12 = Coal, Approximately located
13 = Coal, Inferred
14 = Coal, Inferred, Queried
21 = Other marker bed type, Certain
22 = Other marker bed type, Approximately located
23 = Other marker bed type, Inferred

24 = Other marker bed type, Inferred, Queried

Unit_Abbrv : *text 10*

2 - 10 character unit abbreviation used on map (use official WVGES-CBMP coal abbrvs) *(For thin (only a line-width at 1:24,000 scale) marker beds, coal seams, etc that are NOT geologic unit contacts. Thicker than line-width units should be polygons. Contact forming units should also be in the xsc_cnt layer. May contain ALL coals for Cartographic convenience.)*

Layer: **Cross Section Contacts Polygons: <Quadname>_xsc_cnt_poly**
Layer file name: Brandywine_xsc_cnt_poly
Layer type: Polygon
Polygon attribute fields:

Unit_Abbrv : *text 10*

2 - 10 character unit abbreviation used on map

GeoAge_Lab : *text 10*

2 - 10 character unit abbreviation used on map, utilizes the geoageFullAlpha font (provided with the dataset) to properly symbolize geologic time period special characters (e.g., Ꞓ,ℙ symbols used for Cambrian, Pennsylvanian, etc).

C. Features with point topology

Layer: **Bedding Orientations (Strike and Dip) : <Quadname>_BED**
Layer file name: Brandywine_BED
Layer type: Point
Point attribute fields:

Station : *short integer* (Station ID number, join field for Excel, not present in all quads)
Azimuth : *short integer* (0 – 360 degree value)
Dip_Angle : *short integer* (0 – 90 degree value) (point label field, rotated by Dip_Direct field)
Dip_Direct : *short integer* (0 – 360 degree value) (Dip Direction = Azimuth + 90)Adjust any >360
Symbol : *short integer* (symbol is rotated by Azimuth field)

1 = Inclined
2 = Horizontal
3 = Vertical
4 = Overturned
5 = Foliation
6 = Measurement taken in crossbedded rocks

Layer: **Data Point Locations for Control Point/Inset Maps : <Quadname>_PNT**
Layer file name: Brandywine_PNT
Layer type: Point
Point attribute fields: Not standardized at this time

This layer is for various point data used to create the map, such as: non-bedding field observation points from GPS, drill holes, gas well point locations, county geologic report points, points containing confidential data, and the like, purely for the purpose of including a control point inset map on the final published map layout.

Layer: **Cross Section Point Labels : <Quadname>_xsc_pointlabels**
Layer file name: Brandywine_xsc_pointlabels
Layer type: Point
Point attribute fields:

Name : *text 50* (for major structural, topographic and cultural features that “hover” over the cross section on the map layout)

Appendix II. Cartographic symbol legend