

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science Directorate
Geologic Resources Division



Appomattox Court House National Historical Park

GRI Ancillary Map Information Document

Produced to accompany the Geologic Resources Inventory (GRI) Digital Geologic
Data for Appomattox Court House National Historical Park

apco_geology.pdf

Version: 6/10/2021

Geologic Resources Inventory Map Document for Appomattox Court House National Historical Park

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Geologic Resources Inventory Map Document



Appomattox Court House National Historical Park, Virginia

Document to Accompany Digital Geologic-GIS Data

[apco_geology.pdf](#)

Version: 6/10/2021

This document has been developed to accompany the digital geologic-GIS data developed by the Geologic Resources Inventory (GRI) program for Appomattox Court House National Historical Park, Virginia (APCO).

Attempts have been made to reproduce all aspects of the original source products, including the geologic units and their descriptions, geologic cross sections, the geologic report, references and all other pertinent images and information contained in the original publication.

This document contains the following information:

- 1) **About the NPS Geologic Resources Inventory Program** – A brief summary of the Geologic Resources Inventory (GRI) Program and its products. Included are web links to the GRI GIS data model, and to the GRI products page where digital geologic-GIS datasets, scoping reports and geology reports are available for download. In addition, web links to the NPS Data Store and GRI program home page, as well as contact information for the GRI coordinator, are also present.
- 2) **GRI Digital Map and Source Citation** – The GRI digital geologic-GIS map produced for this project along with the source used in its completion. In addition, a brief explanation of how the source map was used is provided.
- 3) **Map Unit List** – A listing of all geologic map units present on maps for this project, generally listed from youngest to oldest.
- 4) **Map Unit Descriptions** – Descriptions for all geologic map units.
- 5) **Ancillary Source Map Information** – Additional source map information. This consists of a geologic report describing mapped geologic units for the different provinces within the state of Virginia.
- 6) **GRI Digital Data Credits** – GRI digital geologic-GIS data and ancillary map information document production credits.

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About the NPS Geologic Resources Inventory Program

Background

The Geologic Resources Inventory (GRI) provides geologic map data and pertinent geologic information to support resource management and science-informed decision making in more than 270 natural resource parks throughout the National Park System. Geologic resources for management consideration include both the processes that act upon the Earth and the features formed as a result of these processes. Geologic processes include: erosion and sedimentation; seismic, volcanic, and geothermal activity; glaciation, rockfalls, landslides, and shoreline change. Geologic features include mountains, canyons, natural arches and bridges, minerals, rocks, fossils, cave and karst systems, beaches, dunes, glaciers, volcanoes, and faults.

The GRI is one of 12 inventories funded by the National Park Service (NPS) Inventory and Monitoring Program. The Geologic Resources Division of the NPS Natural Resource Stewardship and Science Directorate administers the GRI. The NPS Geologic Resources Division partners with the Colorado State University Department of Geosciences to produce GRI products. Many additional partners participate in the GRI process by contributing source maps or reviewing products.

The GRI team undertakes three tasks for each park in the Inventory and Monitoring program: (1) conduct a scoping meeting and provide a summary document, (2) provide digital geologic map data in a geographic information system (GIS) format, and (3) provide a GRI report. These products are designed and written for nongeoscientists.

Products

Scoping Meetings: These park-specific meetings bring together local geologic experts and park staff to inventory and review available geologic data and discuss geologic resource management issues. A summary document is prepared for each meeting that identifies a plan to provide digital map data for the park.

Digital Geologic Maps: Digital geologic maps reproduce all aspects of traditional paper maps, including notes, legend, and cross sections. Bedrock, surficial, and special purpose maps such as coastal or geologic hazard maps may be used by the GRI to create digital Geographic Information Systems (GIS) data and meet park needs. These digital GIS data allow geologic information to be easily viewed and analyzed in conjunction with a wide range of other resource management information data.

For detailed information regarding GIS parameters such as data attribute field definitions, attribute field codes, value definitions, and rules that govern relationships found in the data, refer to the NPS Geology-GIS Data Model document available at: <https://www.nps.gov/articles/gri-geodatabase-model.htm>

Geologic Reports: GRI reports synthesize discussions from the original scoping meeting, follow up conference call(s), and subsequent research. Chapters of each report discuss the geologic setting of the park, distinctive geologic features and processes within the park, highlight geologic issues facing resource managers, and describe the geologic history leading to the present-day landscape. Each report also includes a poster illustrating these GRI digital geologic-GIS data.

For a complete listing of GRI products visit the GRI publications webpage: <https://go.nps.gov/gripubs>. GRI digital geologic-GIS data is also available online at the NPS Data Store: <https://irma.nps.gov/DataStore/Search/Quick>. To find GRI data for a specific park or parks select the appropriate park(s), enter "GRI" as a Search Text term, and then select the Search button.

For more information about the Geologic Resources Inventory Program visit the GRI webpage: <https://www.nps.gov/subjects/geology/gri.htm>. At the bottom of that webpage is a "Contact Us" link if you need additional information. You may also directly contact the program coordinator:

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The Geologic Resources Inventory (GRI) program is funded by the National Park Service (NPS) Inventory and Monitoring (I&M) Division. Learn more about I&M and the 12 baseline inventories at the I&M webpage: <https://www.nps.gov/im/inventories.htm>.

GRI Digital Map and Source Map Citation

The GRI digital geologic-GIS map for Appomattox Court House National Historical Park, Virginia (APCO):

Digital Geologic-GIS Map of Appomattox Court House National Historical Park and Vicinity, Virginia (*GRI MapCode APCO*)

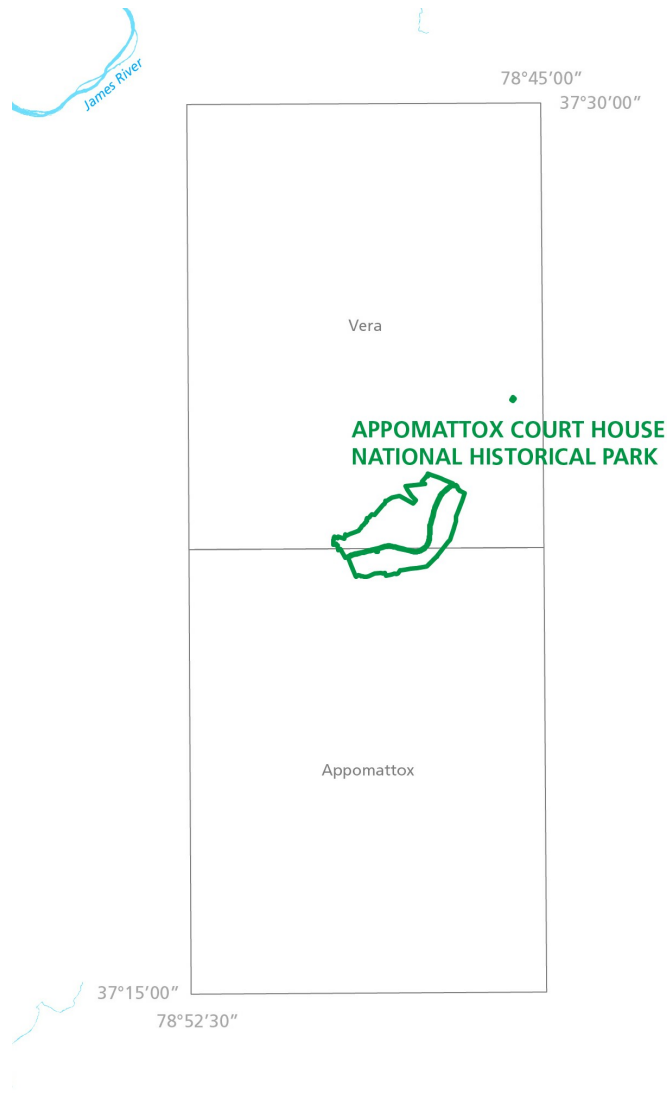
Virginia Division of Mineral Resources, 2021, Digital representation of the 1993 Geologic Map of Virginia: VaDMR Publication 174 [June 2021 digital data]; adapted from VADMR, 1993, Geologic Map of Virginia and Expanded Explanation, 1:500,000 ([Geologic Map of Virginia \(June 2021 Digital Representation\)](#)). (*GRI Source Map ID 7294*).

A partial extent of the source map was used, but all geologic features within this extent were captured.

Additional information pertaining to each source map is also presented in the GRI Source Map Information (APCOMAP) table included with the GRI geologic-GIS data.

Index Map

The following index map displays the extent of the GRI digital geologic-GIS map produced for Appomattox Court House National Historical Park (APCO). The GRI map covers the Vera and Appomattox 7.5' quadrangles in Virginia (gray outline). The boundary for Appomattox Court House National Historical Park (as of March 2021) is outlined in green.



Index Map by Jim Chappell (Colorado State University).

Map Unit List

The geologic units present in the digital geologic-GIS data produced for Appomattox Court House National Historical Park, Virginia (APCO) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Jd - Diabase). Units are listed from youngest to oldest. Information about each geologic unit is also presented in the GRI Geologic Unit Information (APCOUNIT) table included with the GRI geologic-GIS data.

Mesozoic and Paleozoic Eras

[MZPZmy](#) - Mylonite

Mesozoic Era

Jurassic Period

[Jd](#) - Diabase

Paleozoic Era

Ordovician Period

[Oas](#) - Arvonnia Formation, porphyroblastic garnet-biotite schist

[Olgn](#) - Lineated biotite granite gneiss

Cambrian Period

[Cfvs](#) - Felsic metatuff, mica schist, and gneiss

[Cmvs](#) - Greenstone or amphibole gneiss

[Cfv](#) - Foliated felsite

[Cmv](#) - Amphibolite, hornblende-biotite gneiss and schist

Paleozoic and Precambrian Eras

Cambrian Period and Proterozoic Eon

[CZac](#) - Alligator Back Formation, banded marble

[CZmy](#) - Alligator Back Formation, feldspathic metagraywacke

[CZfm](#) - Fork Mountain Formation

[CZpm](#) - Metagraywacke, quartzose schist, and melange

Map Unit Descriptions

Descriptions of all geologic map units, generally listed from youngest to oldest, are presented below.

MZPZmy - Mylonite (Mesozoic and Paleozoic)

Includes protomylonite, mylonite, ultramylonite, and cataclastic rocks. Lithology highly variable, depending on the nature of the parent rock, and on intensive parameters and history of deformation. In most mapped belts of mylonite and cataclastic rock (my), tectonized rocks anastomose around lenses of less-deformed or undeformed rock. In the Blue Ridge, some of these lenses are large enough to show at 1:500,000 scale. In many places mylonitic and cataclastic rocks are gradational into less deformed or undeformed adjacent rocks, and location of contacts between tectonized rocks (my) and adjacent units is approximate or arbitrary.

Most mapped belts of mylonite represent fault zones with multiple movement histories. In the Blue Ridge, Paleozoic age contractional deformation fabrics are superimposed on Late Precambrian extensional fabrics (Simpson and Kalaghan, 1989; Bailey and Simpson, 1993). Many Piedmont mylonite zones contain dextral-transpressional kinematic indicators that formed during Late Paleozoic collisional tectonics (Bobyarchick and Glover, 1979; Gates and others, 1986). Paleozoic and older faults were reactivated in many places to form extensional faults during the Mesozoic (Bobyarchick and Glover).

Description from source map: [Geologic Map of Virginia \(June 2021 Digital Representation\)](#)

Jd - Diabase (Lower Jurassic)

Fine- to coarsely-crystalline, subaphanitic or porphyritic with aphanitic margins; dark-gray mosaic of plagioclase laths and clinopyroxene, with some masses characterized by olivine or bronzite, others granophyric. Also occurs as dikes and sills in the Valley and Ridge, Piedmont, and Blue Ridge physiographic provinces. Description from source map: [Geologic Map of Virginia \(June 2021 Digital Representation\)](#)

Oas - Arvonion Formation, porphyroblastic garnet-biotite schist (Ordovician)

Porphyroblastic mica schist, characterized by 1- to 2-mm garnet porphyroblasts in an anastomosing, greenish-black biotite-rich, schistose matrix. Most exposures show complex microstructures suggestive of polyphase deformation and superimposed shearing. In Appomattox and Campbell counties, and locally elsewhere, this unit includes quartzose muscovite schist along the western and eastern margins of the outcrop belt (presumed base of the stratigraphic section); locally the unit contains thin interbeds of calcareous mica schist and marble.

Mineralogy: biotite + garnet + muscovite + quartz + plagioclase + magnetite ± kyanite ± calcite.
Geophysical signature: characterized by elongate positive magnetic and radiometric anomalies.

This unit was mapped in strike-belts southwest of, and not physically connected to the type section at Arvonion.

Description from source map: [Geologic Map of Virginia \(June 2021 Digital Representation\)](#)

Olg - Lineated biotite granite gneiss (Ordovician?)

Dominantly leucocratic to mesocratic, medium- to coarse-grained, strongly-lineated granite gneiss; includes porphyritic granite gneiss.

Mineralogy: quartz + potassium feldspar + plagioclase + biotite + muscovite ± garnet. Geophysical signature: western portion coincides with strong positive radiometric anomaly.

This unit likely includes more than one intrusive body; portions may be derivative of felsic volcanogenic rocks. These rocks intrude and are interlayered with metavolcanic rocks of probable Cambrian age. The unit includes granite gneiss of Nelson (1992), and may be correlative in part with the Shelton Formation (Ost).

Description from source map: [Geologic Map of Virginia \(June 2021 Digital Representation\)](#)

Cfvs - Felsic metatuff, mica schist, and gneiss (Cambrian)

Includes light-gray to grayish-pink, very-fine-grained to aphanitic, thin-bedded dacitic metatuff, locally containing subhedral to euhedral plagioclase phenocrysts; very-light-gray pinstriped quartz-rich, muscovite and biotite-muscovite schist; and, medium-gray fine-grained salt-and-pepper biotite-muscovite gneiss.

Mineralogy: quartz + plagioclase + muscovite ± biotite + epidote + magnetite.

These lithologies are interlayered with subordinate amounts of greenstone metabasalt and amphibole gneiss.

Description from source map: [Geologic Map of Virginia \(June 2021 Digital Representation\)](#)

Cmvs - Greenstone or amphibole gneiss (Cambrian)

Includes dark- to dusky-green, schistose actinolite-chlorite metabasalt with epidote-quartz segregations; and, layered hornblende-plagioclase gneiss. These lithologies are interlayered with subordinate amounts of dacitic metatuff, quartz-muscovite schist, and fine-grained salt-and-pepper biotite-muscovite gneiss.

Description from source map: [Geologic Map of Virginia \(June 2021 Digital Representation\)](#)

Cfv - Foliated felsite (Cambrian)

Grayish-orange-pink to white, fine- to medium-grained, foliated to granular metavolcanic rocks range in composition from rhyolite to dacite. Includes muscovite-feldspar-quartz schist, gneiss and granofels; massive crystal metatuff; welded ash flow tuff; and, inequigranular metavolcanic breccia. Relict primary volcanic textures are recognizable where metamorphic grade is low (Henika, 1975; 1977).

This unit includes felsic gneiss with less common mafic and rare calcareous gneiss mapped by Tobisch (1972), in part the metamorphosed volcanic sequence of Gates (1981), and dominantly felsic-composition units mapped by Nelson (1992). The unit contains numerous granitic dikes, sills, and lit-par-lit injections where it occurs in close proximity to Shelton Formation (Ost).

Felsites occur interlayered with amphibolite, amphibole gneiss and schist (Cmv), quartzofeldspathic biotite gneiss (Cbg), sillimanite-quartz-muscovite schist and gneiss (Csg), and ferruginous quartzite

(Cfq).

Description from source map: [Geologic Map of Virginia \(June 2021 Digital Representation\)](#)

Cmv - Amphibolite, hornblende-biotite gneiss and schist (Cambrian)

Black to moderate-olive-brown, medium- to coarse-grained, lineated and foliated; light-greenish-gray quartz-epidote stringers are common.

Mineralogy: hornblende + tremolite-actinolite + oligoclase + biotite + epidote + garnet.

Includes Blackwater Creek Gneiss and Catawba Creek amphibolite member of Hyco Formation of Baird (1989), hornblende gneiss of LeGrand (1960), gneiss unit of Kreisa (1980), and dominantly mafic-composition units mapped by Nelson (1992). Amphibolite is interlayered with biotite gneiss.

Description from source map: [Geologic Map of Virginia \(June 2021 Digital Representation\)](#)

CZac - Alligator Back Formation, banded marble (Cambrian to Late Proterozoic)

Light- and dark-gray, laminated fine to medium-grained marble, calcareous gneiss, and schist.

Mineralogy: calcite + quartz + biotite + muscovite + plagioclase + pyrite + magnetite-ilmenite.

Thick to thin beds of marble are interlayered with graphitic phyllite and mica schist; the lithology grades from impure marble to calcareous metagraywacke depending on percentage of detrital calcite present. The unit includes the Arch Marble of Brown (1958) and the Archer Creek Formation of Espenshade (1954).

Description from source map: [Geologic Map of Virginia \(June 2021 Digital Representation\)](#)

CZmy - Alligator Back Formation, feldspathic metagraywacke (Cambrian to Late Proterozoic)

Heterogeneous assemblage of rock-types includes medium- to light-gray, laminated quartzofeldspathic to calcareous gneiss with thin mica schist partings; white and gray, fine- to coarse-grained, generally laminated marble; gray to greenish-gray fine-grained graphitic mica schist and quartzite; light-gray, medium- to fine-grained mica schist; massive quartzite and micaceous blue quartz granule metasandstone; and, dark-greenish-black actinolite schist.

Mineralogy: (1) quartz + potassium feldspar + plagioclase + biotite + muscovite + calcite + epidote + titanite + magnetite-ilmenite; (2) quartz + muscovite + chlorite + graphite + titanite + ilmenite; (3) quartz + albite + muscovite + biotite + titanite + ilmenite; (4) quartz + muscovite + garnet + kyanite; (5) chlorite + tremolite + magnetite-ilmenite; (6) chlorite + actinolite-tremolite + talc + dolomite + magnetite-ilmenite; (7) quartz + albite + actinolite + biotite + epidote + magnetite.

Units here mapped as Alligator Back Formation were previously mapped as the Evington Group (Espenshade, 1954; Brown, 1958; Redden, 1963; Gates, 1986; Patterson, 1987) and considered to be

younger than the Lynchburg Group. Regional mapping by Henika (1991) and Scheible (1975) indicates that rocks assigned to Alligator Back Formation by Rankin and others (1973) are continuous with the upper part of the Lynchburg Group in the type section along the James River at Lynchburg (Jonas, 1927) and that the Alligator Back consistently dips southeast beneath the overlying Candler Formation from the Virginia-North Carolina border to the James River at Lynchburg. Sedimentary and structural facing criteria indicate that rock units immediately southeast of the Candler Formation in an outcrop belt from Stapleton on the James River, southwest to Leesville Dam on the Roanoke River, are older than the Candler (Henika, 1992). Although previously mapped as upper Evington Group (Espenshade, 1954; Brown, 1958; Redden, 1963; Patterson, 1987), these rocks are herein correlated with the Alligator Back Formation (upper Lynchburg Group), having been uplifted against the Candler Formation to the northwest along the Bowens Creek fault (Henika, 1992). Rocks in the same outcrop belt along strike to the southwest of the Leesville Reservoir were previously correlated with the Alligator Back Formation by Conley (1985).

The sequence of lithologic units within the Alligator Back Formation southeast of the Bowens Creek fault is the same as that proposed by Brown (1951; 1958), and Espenshade (1954) for the formations in the Evington Group, that are structurally above the Candler Formation. The sequence is based on the detailed structural and stratigraphic relationships first established by Brown (1958) in the Lynchburg 15-minute quadrangle.

Description from source map: [Geologic Map of Virginia \(June 2021 Digital Representation\)](#)

CZfm - Fork Mountain Formation (Cambrian to Late Proterozoic)

(Conley and Henika, 1973; Conley, 1985). Light- to medium-gray, fine- to medium grained, polydeformed and polymetamorphosed porphyroblastic aluminosilicate-mica schist, interlayered with medium-gray irregularly-layered garnetiferous biotite gneiss, migmatitic in part; calcsilicate granofels; amphibolite; rare white marble; and, coarse calc-quartzite lenses.

Complex schistosity, multiple crenulation cleavages, and partly-retrograded, polymetamorphic aluminosilicate and garnet porphyroblasts are diagnostic of Fork Mountain schists. Primary sedimentary structures rarely are preserved. A spectacular polymictic breccia bed that can be traced along strike for several miles within the Fork Mountain near Stuart is a notable exception. Medium- to coarse-granular, blue-quartz lenses, angular to rounded inclusions of boudinaged fine-grained, color-laminated, calc-silicate rock, and thick beds of coarse, clast-supported, epidotized lithic breccia are typical of the Fork Mountain biotite gneiss.

Prograde regional metamorphic mineral assemblages: (1) quartz + muscovite + biotite + garnet + staurolite + magnetite-ilmenite + rutile; (2) quartz + muscovite + paragonite + plagioclase + garnet + staurolite + sillimanite + magnetite-ilmenite + rutile; (3) quartz + biotite + sillimanite + potassium feldspar + plagioclase + garnet + magnetite-ilmenite; (4) quartz + plagioclase + biotite + muscovite + sillimanite + garnet + tourmaline; (5) quartz + plagioclase + potassium feldspar + biotite + hornblende + epidote + ilmenite; (6) quartz + plagioclase + potassium feldspar + muscovite + biotite + sillimanite + magnetite-ilmenite + garnet + kyanite.

Retrograde metamorphic mineral assemblages: (1) quartz + muscovite + chlorite; (2) quartz + muscovite + chloritoid + chlorite; (3) quartz + muscovite + staurolite + chloritoid; (4) quartz + muscovite + kyanite.

Contact metamorphic mineral assemblages: (1) andalusite + sillimanite + kyanite + corundum; (2) corundum + spinel + magnetite + kyanite.

Geophysical signature: The Fork Mountain has a characteristic "curly maple" pattern on magnetic contour maps. This pattern is the result of isolated concentrations of highly magnetic minerals that produce rounded, high-intensity, positive and negative anomalies.

The aluminosilicate-mica schist is the upper part of the Fork Mountain Formation and forms a series of northeastward-trending ridges along the northwest side of the Smith River allochthon. The garnetiferous biotite gneiss is at a lower structural level of the Fork Mountain Formation near Martinsville where lower strata have been intruded by the Martinsville igneous complex, and the remaining metasedimentary rocks contain extensive thermal metamorphic zones localized along the intrusive contacts (Conley and Henika, 1973). Biotite gneiss in the Fork Mountain Formation has been interpreted to be a highly metamorphosed diamictite (Rankin, 1975; Conley, 1985; and Pavides, 1989).

At the northeastern limit of the Fork Mountain outcrop belt, in Appomattox and Buckingham counties, the dominant lithologies are polydeformed yellowish-gray chloritoid-chlorite- muscovite quartzose phyllite and quartz-rich mica schist. Tightly-folded, transposed pinstriped segregation layering at a high angle to the penetrative schistosity defined by phyllosilicate minerals is characteristic; polycrystalline quartz-rich boudins are abundant. These rocks are lithologically indistinguishable from those along the highly-tectonized western margin of the metagraywacke, quartzose schist, and melange (CZpm) outcrop belt; current interpretation is that the Fork Mountain is correlative to some degree with CZpm.

Description from source map: [Geologic Map of Virginia \(June 2021 Digital Representation\)](#)

CZpm - Metagraywacke, quartzose schist, and melange (Cambrian to Late Proterozoic)

Metagraywackes are quartzose chlorite or biotite schists containing very fine to coarse granules of blue quartz; primary graded laminations have been transposed by shearing into elongate lozenges that give the rock a distinctive pin-striped appearance in weathered surfaces perpendicular to schistosity. A mylonitic fabric is superimposed in varying degrees, as are late-stage chevron-style folds. In Buckingham, Appomattox, and Campbell Counties, rocks in this unit are progressively more tectonized from east to west across the outcrop belt; in the western portion, the dominant lithology is a polydeformed, mylonitic mica schist with abundant quartz-rich boudins; transposed pinstriped lamination or segregation layering at a high angle to mylonitic schistosity is characteristic. Metagabbroic blocks ranging in size from 5 cm to 3 m across and larger have been identified at widely scattered locations throughout the outcrop belt.

Mineralogy: quartz + albite + epidote + chlorite + muscovite + magnetite $\pm$ chloritoid $\pm$ calcite; biotite- and staurolite-bearing assemblages occur in Appomattox and Campbell Counties. Detrital minerals identified in thin section include plagioclase, perthite, epidote, magnetite, tourmaline, and titanite. Lithic fragments include dacite tuff, gabbro, and monocrystalline quartz with zircon and biotite inclusions (Evans, 1984).

The northern portion of the outcrop belt includes melange zone IV of the Mine Run complex of Pavides (1989; 1990). In Albemarle and Fluvanna counties, CZpm includes the lower chlorite-muscovite unit of Smith and others (1964) and Hardware metagraywacke of Evans (1984). In Appomattox and Buckingham Counties, polydeformed quartzose mica schists in the western portion of the outcrop belt are lithologically indistinguishable from schists mapped as Fork Mountain Formation in structural blocks that occur to the west; these units are considered to be at least in part correlative. In Campbell County, polydeformed metagraywacke and mica schist is intruded by the Cambrian-age Melrose Granite (Cm).

Description from source map: [Geologic Map of Virginia \(June 2021 Digital Representation\)](#)

Ancillary Source Map Information

The following section(s) present ancillary source map information associated with source(s) used for this project.

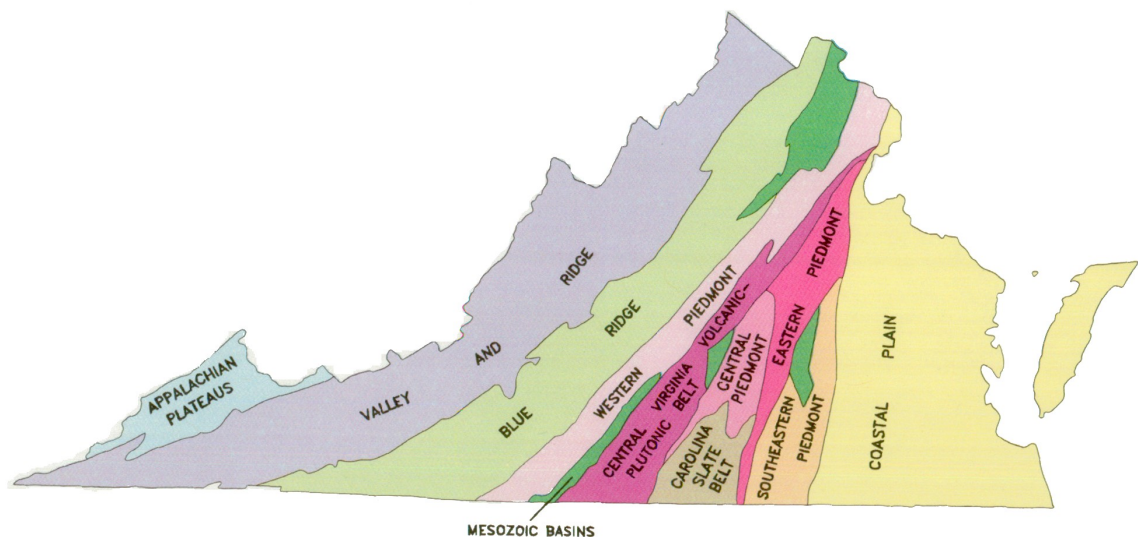
Geologic Map of Virginia (June 2021 Digital Representation)

The formal citation for this source.

Virginia Division of Mineral Resources, 2021, Digital representation of the 1993 Geologic Map of Virginia: VADMR Publication 174 [June 2021 digital data]; adapted from VADMR, 1993, Geologic Map of Virginia and Expanded Explanation, 1:500,000 (*GRI Source Map ID 7294*).

Prominent graphics and text associated with this source.

Geologic Provinces in Virginia



Graphic from source map: [Geologic Map of Virginia \(June 2021 Digital Representation\)](#)

Report

A [geologic report](#) containing correlations and addition geologic unit descriptions and discussion.
(Double-click link to open report document)

Report from source map: [Geologic Map of Virginia \(June 2021 Digital Representation\)](#)

GRI Digital Data Credits

This document was developed and completed by James Chappell (Colorado State University) for the NPS Geologic Resources Division (GRD) Geologic Resources Inventory (GRI) Program. Quality control of this document by Stephanie O'Meara (Colorado State University).

The information in this document was compiled from the GRI source map, and is intended to accompany the digital geologic-GIS map and other digital data for Appomattox Court House National Historical Park, Virginia (APCO) developed by Andrea Croskrey, James Chappell, Georgia Hybels and Stephanie O'Meara (see the [GRI Digital Map and Source Map Citation](#) section of this document for the source used by the GRI in the completion of this document and the related GRI digital geologic-GIS map).

GRI finalization by James Chappell (Colorado State University).

GRI program coordination and scoping provided by Bruce Heise, Jason Kenworthy and Tim Connors (NPS GRD, Lakewood, Colorado).