U.S. Department of the Interior
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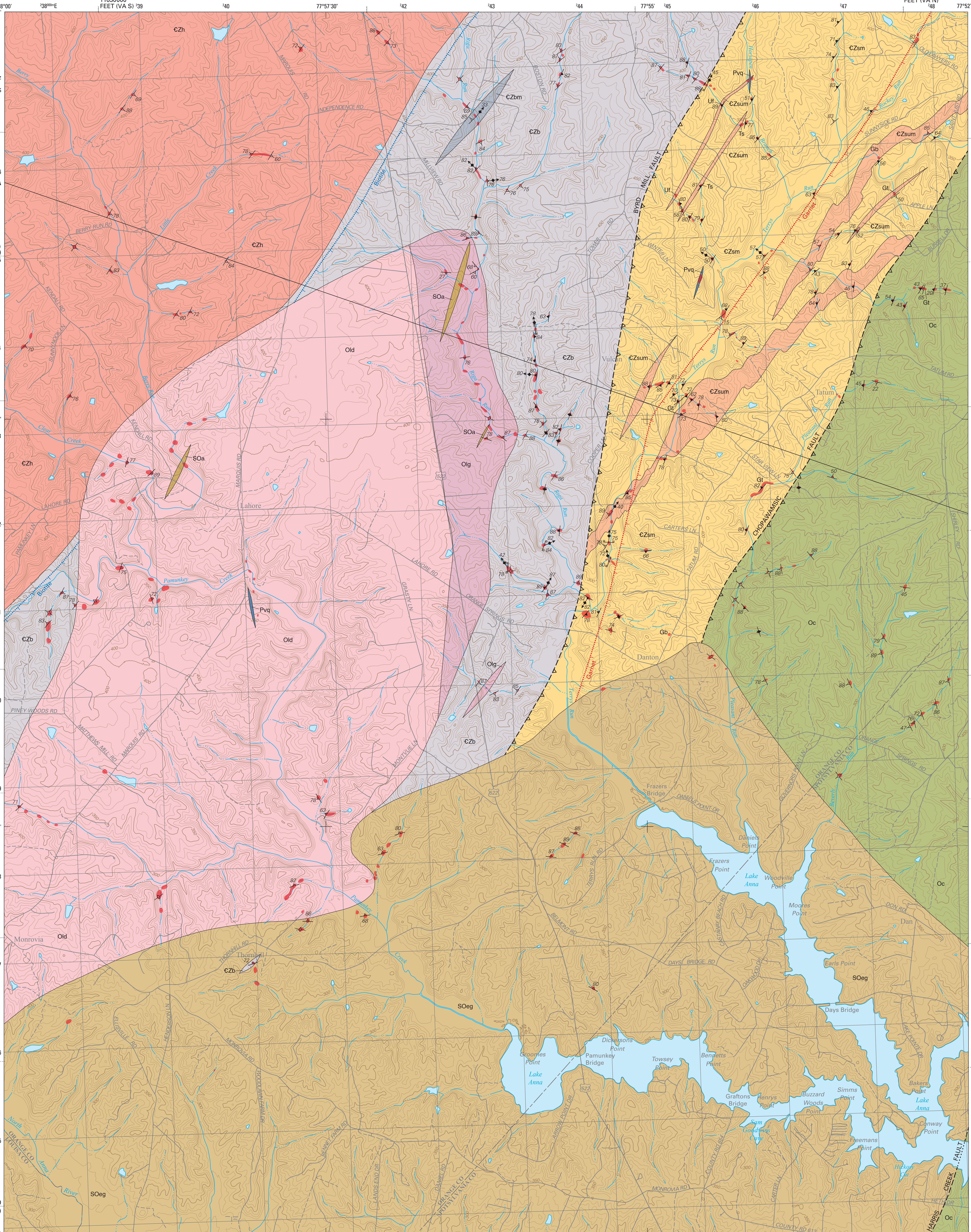
Open-File Report 2019–1110



Base from U.S. Geological Survey, Lahore, Virginia, 2016, scale 1:24,000
North American Datum of 1983
World Geodetic System of 1984
10,000-foot grid ticks based on Virginia coordinate system of 1983, north and south zones
Projection and 1,000-meter Universal Transverse Mercator grid, zone 18 south

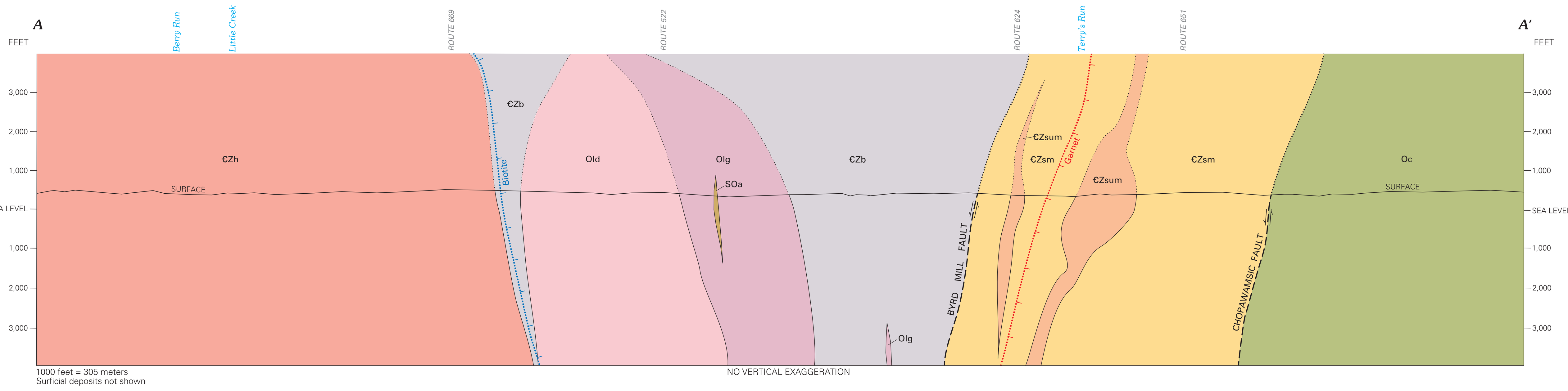
APPROXIMATE MEAN DECLINATION, 2019

SCALE 1:24 000

CONTOUR INTERVAL 10 FEET
NORTH AMERICAN VERTICAL DATUM OF 1988

VIRGINIA
MAP LOCATION

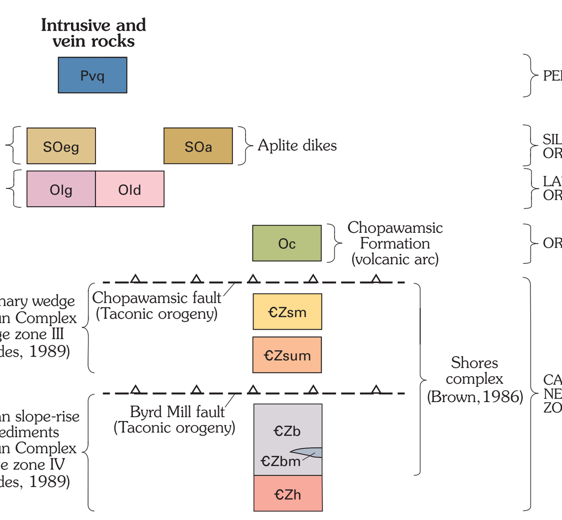
Bedrock geology mapped by William C. Burton (2012–2015)
GIS database and cartography by E. Allen Crider Jr. (2019)
Cartography by Linda M. Masonic (2019)
Edited by David A. Shields (2019)



1000 feet = 305 meters
Surficial deposits not shown

NO VERTICAL EXAGGERATION

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

[Minerals were identified in hand sample only and are listed in increasing order of abundance]

INTRUSIVE AND VEIN ROCKS

Pvq **Vein quartz (Permian?)**—White, massive, coarse-grained vein quartz

SOeg **Granodiorite of Ellisville pluton (Silurian to Ordovician)**—Pale-yellow to white, massive to locally foliated, fine- to medium-grained, biotite-microcline-quartz-plagioclase granodiorite. Uranium-lead (U-Pb) zircon crystallization ages of 444±3 mega-annum (Ma, million years before present) and 437±4 Ma are reported by Hughes and others (2013)

SOa **Aplite dikes (Silurian to Ordovician)**—Pink to white, medium-fine-grained to locally coarse-grained, quartz-plagioclase-potassium feldspar aplite dikes. The dikes crosscut hornblende diorite (Old) and granodiorite (Olg) of the Lahore pluton, indicating they are possibly contemporaneous with granodiorite of Ellisville pluton (SOeg). The dikes are usually less than 1 meter wide, but two larger outcrops are mapped in the northwest part of the map area

Olg **Biotite diorite and granodiorite of Lahore pluton (Late Ordovician)**—Light- to medium-gray weathering, greenish-gray when fresh, massive to locally well foliated, medium-grained biotite diorite and granodiorite; represents a felsic to intermediate phase of Lahore pluton. A U-Pb zircon crystallization age on monzonite of 446±5 Ma is reported by Sinha and others (2012)

Old **Hornblende diorite of Lahore pluton (Late Ordovician)**—Light- to medium-gray weathering, greenish-gray when fresh, massive to locally well foliated, medium-grained hornblende diorite (±pyroxene) and minor gabbro

METASEDIMENTARY, METAVOLCANIC, MAFIC, AND ULTRAMAFIC ROCKS

Oc **Chopawamsic Formation (Ordovician)**—Medium- to dark-gray, fine-grained, ±muscovite-biotite-quartz-plagioclase granofels and schist; and lesser pale-yellow, fine-grained, muscovite-potassium feldspar(?)-quartz-plagioclase metafelsite. Garnet was identified in hand sample at locations identified as "Gt" on map

€Zsm **Metagraywacke, schist, and metasiltstone of Shores complex (Brown, 1986) (Cambrian to Neoproterozoic?)**—Medium- to dark-gray, fine-grained, muscovite-biotite-quartz-plagioclase metagraywacke and schist, with minor quartz-laminated metasiltstone. Garnet was identified in hand sample at locations identified as "Gt" on map. Shores complex named by Brown (1986) for exposures along the James River in Virginia

€Zsum **Mafic and ultramafic rocks of Shores complex (Cambrian to Neoproterozoic?)**—Dark-green, fine-grained, poorly foliated amphibolite; and well-foliated ±chlorite-amphibole schist. Contains rare bodies of massive, medium-grained gabbro ("Gb" on map). Includes isolated exposures within unit €Zsm of white, fine-grained, well-foliated talc schist ("Ts" on map) and two locations of ultramafic rock ("Uf" on map); and (in float only) massive, dark-green, fine-grained serpentinite(?)

€Zb **Byrd Mill formation (informal name) of Shores complex (Cambrian to Neoproterozoic?)**—Gray, fine-grained, finely foliated to layered, ±muscovite±chlorite-biotite-plagioclase-quartz metasiltstone and metagraywacke

€Zbm **Mafic body in Byrd Mill formation (informal name) of Shores complex (Cambrian to Neoproterozoic?)**—Finely layered chlorite-epidote-amphibole schist. Gabbro is present in nearby float

€Zh **Hardware formation (informal name of N.H. Evans, written commun., 2017) (Cambrian to Neoproterozoic?)**—Pale-yellow to white, fine-grained, sericite-quartz phyllite. The unit locally contains fine crystals of magnetite

EXPLANATION OF MAP SYMBOLS

Contact—Approximately located. In cross section, dotted where projected above the ground surface

FAULTS

Fault—Approximately located; dashed where concealed by water. Harris Creek fault of late Paleozoic (Alleghanian orogeny) from Burton and other (2019)

Taconic thrust fault—Location is inferred and based on the presence of ultramafic bodies; early Paleozoic age (Taconic orogeny) and overturned in the late Paleozoic (Alleghanian orogeny). In cross section, dotted where projected above ground surface and dashed below ground surface

PLANAR AND LINEAR FEATURES

Strike and dip of first-generation schistosity (S_1)—Defined by prograde metamorphic minerals, typically biotite, during regional metamorphism of metasedimentary and metavolcanic rocks during the Late Ordovician (Taconic orogeny); biotite is parallel to compositional layering, where present. Late Ordovician age is based on $^{40}Ar/^{39}Ar$ mineral age data from Burton and others (2019)

56 **Inclined**

Vertical

Strike and dip of foliation in plutonic rocks—Defined by planar-aligned mafic minerals, typically biotite or amphibole. Probably an igneous flow foliation of early Paleozoic age, but may have tectonically-influenced mineral orientation near contacts due to synkinematic timing of intrusion

78 **Inclined**

Vertical

Strike and dip of second-generation schistosity (S_2)—Defined by retrograde metamorphic micas, typically muscovite, during the late Paleozoic (Alleghanian orogeny). Late Paleozoic (Pennsylvanian) age is based on $^{40}Ar/^{39}Ar$ mineral age data from Burton and others (2019)

78 **Inclined**

Vertical

Strike and dip of axial plane of second-generation fold (F_2)—Defined as plunging open folds to tight crenulations that are late Paleozoic age (Alleghanian orogeny)

64 **Inclined**

Vertical

18 **Trend and plunge of F_2 fold axis**—Represented by mineral lineations, micro-crenulations, or mullion fabric. Combined with either S_1 or S_2 schistosity or the F_2 axial plane. May indicate tectonic transport direction where steeply plunging

Taconic biotite isograd—Represents the first appearance (southeast side of isograd) of biotite in regional metamorphic mineral assemblages

Taconic garnet isograd—Represents the first appearance (southeast side of isograd) of garnet in regional metamorphic mineral assemblages

Outcrop—Rock outcrop location examined in the map area

INTRODUCTION

Bedrock geologic mapping of the Lahore, Va., 7.5-minute quadrangle was completed as part of a broader project, undertaken jointly between the U.S. Geological Survey, the Virginia Division of Geology and Mineral Resources, and other Federal and State agencies to better understand the causative mechanisms of the magnitude-5.8 (M5.8) earthquake that occurred near Mineral, Va., on August 23, 2011. This project involves detailed mapping of at least eight quadrangles in the epicentral region of the Mineral, Va., earthquake in order to improve our understanding of the geologic framework of the central Virginia seismic zone, which has a long record of historical and prehistoric seismicity (Tarr and Wheeler, 2006; Tuttle and others, 2015). Preliminary mapping results are summarized in Burton and others (2014, 2015).

The Lahore 7.5-minute quadrangle contains the contact between Ordovician to Silurian, dioritic and granodioritic rocks of the Lahore (Olg, Old) and Ellisville plutons (SOeg) and older metasedimentary and metavolcanic rocks. The older metasedimentary and metavolcanic rocks include the Ordovician Chopawamsic Formation (Oc) to the east (of volcanic arc affinity) and informally named units to the west that were previously mapped as parts of mélange zones III and IV of the Mine Run Complex of Pavlides (1989), which include the following map units: (1) the Hardware formation (€Zh) of N.H. Evans, written commun., 2017; (2) the Byrd Mill formation (€Zbm and €Zb) of the Shores complex of Brown (1986); and (3) units €Zsm and €Zsum, also within the Shores complex of Brown (1986). The Lahore quadrangle is northeast of the Ferncliff and Louisa, Va., quadrangles, where the Shores complex is intruded by the Ellisville pluton (SOeg) along the pluton's southwestern margin (Burton and others, 2019). The new mapping in the Lahore quadrangle shows that the Shores complex continues northeast of the Ellisville pluton. A northeast-trending mafic- and ultramafic-bearing belt within the Shores complex (€Zb, €Zbm, and €Zh) is a fault-bounded accretionary zone (accretionary wedge) between rocks of the Chopawamsic Formation (Oc) and Laurentian slope-and-rise deposits (€Zsm and €Zsum) (Burton and others, 2019); this tectonic boundary extends from at least the James River to the south, to the Maryland Piedmont to the north (Burton and Southworth, 2017). In the Lahore quadrangle, this belt contains several mappable, northeast- to southwest-trending mafic bodies (€Zsum) and also includes small exposures of gabbro (Gb) and talc schist (Ts), as well as ultramafic float (Uf); just to the northeast of the Lahore quadrangle this belt contains an inactive serpentinite quarry in Verdiersville, Va. (Mixon and others, 2000).

The Lahore quadrangle contains structures of both early- and late-Paleozoic age (fig. 1) that correspond to the Taconic and Alleghanian orogenies, respectively. Taconic (Late Ordovician) S_1 schistosity in layered rocks is typically fine-grained and parallel to compositional layering, when present. Alleghanian (Pennsylvanian) S_2 schistosity is coarser and more micaceous than S_1, and is locally accompanied by a lineation that is represented by mineral lineations, micro-crenulations, or mullion fabric, and represents the hinges of F_2 folds. These lineations are more steeply plunging (fig. **1*D***) than their counterparts in the Ferncliff and Louisa quadrangles (Burton and others, 2019) (fig. **1*E***), which is perhaps a function of the interaction of the Ellisville pluton (SOeg) with a dextral-transpressive stress field (Burton and others, 2019). A foliation in the plutonic rocks is represented by an equilibrium assemblage of aligned mafic minerals and is early Paleozoic in age, possibly representing an igneous flow foliation that was locally affected by tectonic stresses during synkinematic intrusion.

Regionally, the most common trend and plunge of joints is northwest and subvertical, respectively, and orthogonal to the regional strike of foliation (Burton and others, 2019); however, the diversity of joint directions shown in the rose diagram of joint azimuths in the Lahore quadrangle (fig. **1*F***) resembles the joint pattern southeast of the "Ellisville neck" of the Ellisville pluton in the Ferncliff quadrangle, where early Mesozoic extension is thought to be a factor (Burton and others, 2019) (fig. **1*G***). Early Mesozoic extension may have also reactivated the Harris Creek fault, a late Paleozoic (Alleghanian orogeny) transpressional fault that marks the contact between granodiorite of the Ellisville pluton (SOeg) and the Chopawamsic Formation (Oc) (Burton and others, 2019). The Harris Creek fault, in the extreme southeast corner of the map, is a continuation of the fault mapped in the adjacent Mineral, Va., quadrangle by Carter and others (2019).

Metamorphic grade in the non-plutonic rocks of the Lahore quadrangle ranges from lower-greenschist to the northwest to upper-greenschist to the southeast, as represented by mineral assemblages in non-plutonic rocks. The biotite isograd may be, in part, lithologically controlled by the contact between the informally-named Hardware (€Zh) and Byrd Mill (€Zb) formations, and locally affected by contact metamorphism by the Lahore pluton (Old and Olg, in western part of map). The Taconic garnet isograd is defined by the sparse presence of small (<1 millimeter), euhedral garnet crystals. Both the biotite and garnet isograds continue along strike to the southwest into the Ferncliff and Louisa quadrangles (Burton and others, 2019), where the isograds have been identified as Ordovician age (Taconic orogeny) based on muscovite, biotite, and amphibole $^{40}Ar/^{39}Ar$ cooling ages reported by McAleer and others (2017).

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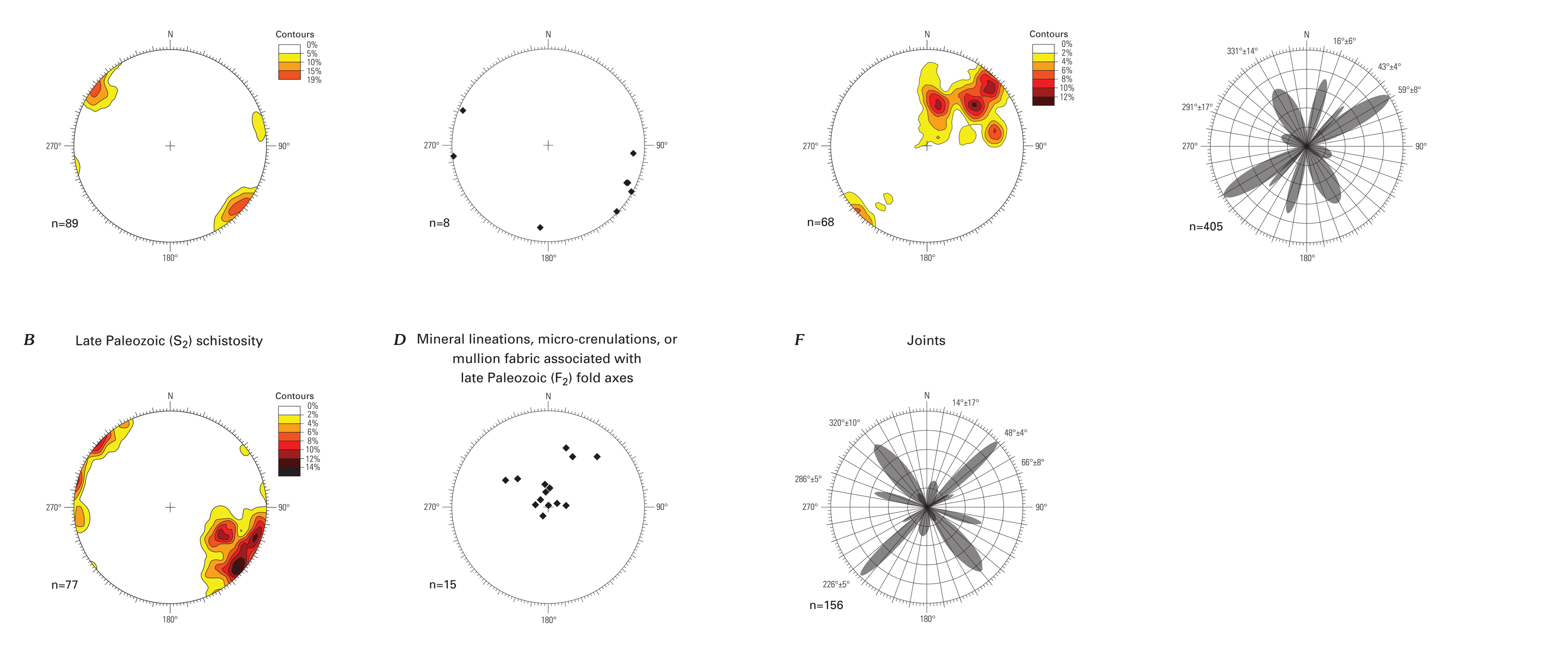

Figure 1.—Stereonets (***A–E***) and rose diagrams (***F–G***) showing results of the orientation of measured outcrop-scale planar and linear structures from mapped units in the Lahore quadrangle, Virginia, and from mapped units from the Ferncliff and Louisa quadrangles, Virginia. ***A***, stereonet results of early Paleozoic (S_1) schistosity in the Lahore quadrangle (contoured poles to planes); ***B***, stereonet results of late Paleozoic (S_2) schistosity in the Lahore quadrangle (contoured poles to planes); ***C***, stereonet results of late Paleozoic (F_2) fold axial planes in the Lahore quadrangle (poles to axial planes); ***D***, stereonet results of mineral lineations, micro-crenulations, or mullion fabric associated with late Paleozoic (F_2) fold axes in the Lahore quadrangle; ***E***, contoured stereonet results of late Paleozoic (F_2) fold hinges in the Ferncliff and Louisa quadrangles (from Burton and others, 2019); ***F–G***, rose diagram results of joints in the Lahore quadrangle (***F***) and joints located in the Ferncliff quadrangle (***G***) from Burton and others (2019); joints in ***G*** are located southeast of the "Ellisville neck" of the Ellisville pluton in the Ferncliff quadrangle. The numbers next to each principle peak (for example, 59°±8°) for joints in ***G*** corresponds to the average azimuth and standard deviation of the joint trend. The number of data measurements for each stereonet and rose diagram is indicated by "n." Stereonets and rose diagrams were plotted using the Structural Data Integrated System Analyzer (DAISY, version 5.05-8) software by Salvini (2015).

PRELIMINARY BEDROCK GEOLOGIC MAP OF THE LAHORE 7.5-MINUTE QUADRANGLE, ORANGE, SPOTSYLVANIA, AND LOUISA COUNTIES, VIRGINIA

By
William C. Burton
2019

For sale by U.S. Geological Survey, Box 25286, Denver Federal Center, Denver, CO 80225; http://store.usgs.gov; 1–888–ASK–USGS (1–888–275–8747)

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