Geologic Map of the Relay Quadrangle, Anne Arundel, Baltimore, and Howard Counties and Baltimore City, Maryland

by
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2021

Description of Map Units

Artificial fill

Heterogeneous unconsolidated materials including sand, gravel, clay, slag, construction debris, and dredge spoil. Only major areas of filled ground have been mapped.

Alluvium

Boulders, cobbles, gravel, sand, silt, and clay of varied composition and sorting. Boulders and cobbles are present in higher-gradient stream channels and consist of amphibolite, varieties of felsic gneiss, granitic pegmatite, vein quartz, and subordinate ultramafic rock types and anthropogenic materials. Sand and gravel are typically well-bedded but also occur in poorly sorted deposits with cobbles and boulders. Deposits in lower-gradient channels are dominated by poorly sorted mud, polymict sand, and silt, and in some places include abundant organic material. Deposits interfinger with sparse colluvium at the bases of some slopes and in some upland gathering areas.

Thickness approximately 0 to 15 ft.

Terrace and upland deposits

Interbedded gravel, sand, silt, and clay with rare cobbles and boulders. Adjacent to streams near the Fall Line (approximate boundary between the Coastal Plain and Piedmont physiographic provinces), deposits are chiefly gravel dominated by quartz and quartzite, with minor clasts of lithologically diverse crystalline rock, all in a matrix of sand with minor clay and silt. Abundant layered, coarse sand occurs locally. Along the banks of the Patapsco River downstream of the most eastward exposure of Relay Felsite, and on adjacent uplands to the south and north, unit is chiefly medium to coarse quartzose sand with minor to abundant gravel and rare isolated boulders of varying lithology.

Thickness approximately 3-40 ft.

Potomac Group

Kpc clay-silt

Clay, silt, and subordinate fine to medium-grained sand with clay and silt. Clay-silt deposits range from sandy clay to nearly pure kaolinitic clay. Includes subordinate lenses of quartzose, poorly sorted sand with abundant clay and silt.

Kps sand-gravel

Interbedded sand, pebbly sand, gravel, and subordinate silt and clay. Sands range from fine- to coarse-grained and are predominantly quartzose. Gravels are predominantly vein quartz and quartzite. Silt and clay typically occur as thin or massive lenses or as matrix material. Deposits are commonly iron-oxide-stained and may be weakly cemented.

Sediments occur as a thin veneer draped along the Mid-Atlantic Fall Line (approximate boundary between the Coastal Plain unconsolidated sediments and the Piedmont bedrock) in the northwest of the quadrangle, and gradually thicken to the southeast, eventually reaching over 700 ft in thickness in the southeast corner of the quadrangle (Hansen and Edwards, 1986).

Pegmatitic granite

Pinkish-orange muscovite-microcline-albite-quartz pegmatitic granite locally with garnet. Commonly forms isolated, rounded outcrops that protrude from hillsides and weather to very dark brownish gray. Generally occurs as swarms of anastomosing tabular bodies intruding Mt. Washington Amphibolite, although discrete bodies are variable and commonly irregular. Bodies range from several inches to hundreds of feet in thickness. Both swarms and individual bodies generally parallel the foliation of the rocks they intrude, although individual bodies commonly cut across wall rock foliation and layering. Locally exhibits layering defined by variations in grain size, composition, and texture.

Unit cuts all other crystalline rock units in the Relay Quadrangle. Absolute age of unit is uncertain.

Note: unit is mapped where pegmatitic granite constitutes at least 50% of bedrock.

Ellicott City Granodiorite

Pinkish-gray, medium- to coarse-grained, foliated biotite granodiorite. Subordinate quartz monzonite occurs within the interiors of intrusive bodies exposed to the north and west of the Relay Quadrangle (Hopson, 1964). The unit consists chiefly of plagioclase, quartz, K-feldspar (mostly microcline), and biotite. Epidote, allanite, apatite, titanite, zircon, monazite, and magnetite occur as accessory minerals (Hopson, 1964). The unit is porphyritic at some locations, with pinkish microcline phenocrysts up to an inch long. Inclusions consisting predominantly of plagioclase and biotite are common in the granodiorite, and appear to be highly sheared and flattened. Within the Relay Quadrangle, the unit is poorly exposed within a seemingly continuous, irregular mass that intrudes the Mt. Washington Amphibolite ca. ½ mile southeast of where the Patapsco River enters the quadrangle, although nearby float indicates the likely existence of additional unmapped masses.

U-Pb geochronology by SIMS on zircons extracted from Ellicott City Granodiorite yielded ages of 363 ± 10 Ma and 369 ± 4 Ma (Sinha et al., 2012).

Note: unit is mapped where Ellicott City Granodiorite constitutes at least 50% of bedrock.

Cold Spring Gneiss

Biotite-muscovite-microcline-quartz-plagioclase gneiss and schistose gneiss. Occurs as large masses along the Druid Hill Amphibolite-Mt. Washington Amphibolite contact and as swarms of smaller dikes and sills that intrude the Druid Hill Amphibolite, Mt. Washington Amphibolite, and possibly the Relay Felsite. The gneiss is typically fine- to medium-grained, with feldspar augen ranging from several millimeters to one centimeter in length. Sparse, quartz-rich layers with abundant muscovite and subordinate biotite occur locally. The gneiss is mylonitic and garnetiferous at locations along Soapstone Branch. At multiple locations proximate to the contact between Cold Spring Gneiss material and adjacent units, outcrops expose a chaotic assemblage of heavily sheared layers and lenses of rocks separated by sharp contacts and commonly cut by veins of quartz and quartzofeldspathic material. The heavily sheared rocks include mafic and felsic lithologies including biotite schist, chlorite schist, and serpentinite, although alteration to clay minerals typically obscures the original mineralogy.

U-Pb geochronology by LA-ICP-MS on zircons extracted from a felsic gneiss sample yielded ages that do not constitute a single population (likely due to inherited zircons and Pb loss) but form a statistical probability peak at 482 Ma (Fig. 2C).

Note: Areas mapped as Cold Spring Gneiss may include a considerable proportion of Relay Felsite or felsic gneiss associated with Druid Hill Amphibolite, as the varieties of felsic gneiss are commonly difficult to distinguish in the field. Unit is mapped where Cold Spring Gneiss constitutes at least 50% of bedrock.

Relay Felsite

Fine- to medium-grained, layered and massive quartz-plagioclase gneiss with minor, varying abundances of biotite and hornblende. Locally the gneiss contains minor magnetite, muscovite, chlorite, epidote, and/or garnet. Includes both massive and layered varieties, with textures ranging from granoblastic, to well foliated, to mylonitic. Quartz commonly occurs as rounded to elongated blebs and as veins and irregular blobs in some cases tens of feet in thickness. Lenses and twinned plagioclase crystals are common. Outcrops are cut by numerous joints of seemingly random orientation, and range widely in color from dark gray and reddish-brown to pinkish-tan to very pale pinkish-gray.

At the base of the Relay Felsite, amphibolite occurs interlayered with felsic gneiss and increases in abundance to the west, forming a gradational contact between the Relay Felsite and Druid Hill Amphibolite. The base of the Relay Felsite is mapped immediately east of the easternmost appearance of interlayered amphibolite. Relay Felsite reaches at least 1200 ft in thickness within the Relay Quadrangle; the total thickness of the unit is unknown as its eastern contact is buried by Coastal Plain sediments.

U-Pb geochronology results for the Relay Felsite from this (Fig. 2B) and other studies suggest a complex history of depositional, intrusive, and metamorphic events (see discussion).

Note: Areas mapped as Relay Felsite may include a considerable proportion of Cold Spring Gneiss, as the two units are difficult to distinguish in the field.

Druid Hill Amphibolite

Chiefly fine to medium-grained, layered and massive amphibolite and subordinate quartzo-feldspathic gneiss. Amphibolite consists predominantly of plagioclase and hornblende, with varying abundances of actinolite and locally with diopside or pyroxene. Amphibolite is well foliated and commonly includes distinct anastomosing zones of coarser-grained amphibolite.

Texturally and compositionally various felsic rocks, including gneiss, schistose gneiss, and granofels, occur as lenses and layers within the amphibolite and as irregular blobs and veins that cut amphibolite layering. Lenses and layers range from less than an inch to tens of feet in thickness. At many locations, the felsic rocks resemble Relay Felsite, consisting primarily of quartz and plagioclase with minor biotite, chlorite, epidote, and/or garnet. Where the amphibolite and felsic rocks resembling Relay Felsite are interlayered, contacts between layers range from sharp to gradational, and in some locations the two rock types exhibit interfingering relationships. At other locations felsic rocks resembling Relay Felsite cut amphibolite layering. In a well exposed section along the south bank of the Patapsco River just west of Interstate-95, the proportion of felsic layers and lenses sharply increases to the east until no amphibolite remains, at which point the rocks are mapped as Relay Felsite. At various locations within the map unit and most abundantly along Soapstone Branch, rocks occur that more closely resemble gneiss and schistose gneiss of the Cold Spring Gneiss, consisting primarily of quartz, plagioclase, and varying abundances of microcline, biotite and muscovite. Felsic rocks that resemble Cold Spring Gneiss occur within the amphibolite as concordant lenses and layers with sharp contacts and as irregular masses that cut amphibolite layering. Sparse, small lenses of biotite-quartz rock and quartzite of unit qtz occur locally in the Druid Hill Amphibolite. The nature and structural and genetic relationships between the various felsic rocks and the amphibolite.

qtz quartzite

Highly resistant, quartz-rich rock. The unit crops out as a seemingly continuous, SSW-striking, steeply dipping lenticular body at least 1000 ft long and 75 ft thick along the western flank of Soapstone Branch. Most outcrops appear to consist of nearly pure quartz deposited as veins, although one outcrop includes zones of quartzite interlayered with garnet-chlorite-muscovite schist layers ranging from a few millimeters to several centimeters in thickness. Mineralogy and layering are interpreted as evidence of a metasedimentary protolith for at least a portion of the unit. The unit appears to be in contact with felsic gneiss of the Druid Hill Amphibolite along Soapstone Branch; the unit appears to consist of nearly pure quartz, and layering in the quartzite roughly parallels the orientation of the overall lens, as well as foliations in adjacent outcrops of gneiss to the west and the gneiss and amphibolite to the east. The relationships between the quartzite lens and adjacent gneiss and amphibolite are unclear, as contacts between the quartzite lens and surrounding units are not exposed.

U-Pb geochronology by LA-ICP-MS on zircons extracted from a sample of interlayered quartzite and garnet-chlorite-muscovite schist yielded ages that do not constitute a single population (possibly due to Pb loss) but form a statistical probability peak at 480 Ma (Fig. 2A).

chl chlorite schist

Talc-chlorite granofels and medium- to coarse-grained talc-chlorite schist locally with relic pyroxene. In addition to map-scale bodies, numerous similar bodies ranging in thickness from less than an inch to tens of feet occur as layers and lenses within the Druid Hill Amphibolite.

The nature and existence of the contact separating the Druid Hill Amphibolite and Mt. Washington Amphibolite remains enigmatic. The Druid Hill Amphibolite appears to be around 1500 ft thick, although the exact thickness is difficult to determine as no section exists for which the locations of both the upper and lower contacts are confidently known.

The absolute age of the Druid Hill Amphibolite remains unclear, although it must be similar to the age of Relay Felsite rocks into which it grades (see discussion).

Mt. Washington Amphibolite

Predominantly fine- to medium-grained, layered and massive amphibolite. Includes subordinate layers of actinolite hornfels, actinolite granofels, and actinolite-talc schist; rare layers of fine- to medium-grained pyroxenite, locally with garnet; and rare zones up to tens of feet thick of chlorite granofels and coarse-grained schist with relic pyroxene. Amphibolite consists predominantly of plagioclase and hornblende, with varying abundances of actinolite and quartz, and locally with pyroxene. Locally, garnet occurs with epidote within amphibolite layers. The amphibolite is typically well foliated, although large (tens of feet thick) zones of massive amphibolite occur as isolated outcrops in several locations. Amphibolite commonly includes distinct layers and/or anastomosing zones of coarser-grained amphibolite up to several inches in thickness. The unit includes minor intermediate and felsic rocks that include biotite-microcline-quartz-plagioclase gneiss, plagioclase-rich amphibolite, hornblende-feldspar gneiss, and other feldspathic and quartzo-feldspathic rocks. These intermediate and felsic rocks occur as layers within the amphibolite and as irregular blobs and veins that cut amphibolite layering. In a few locations, mafic and felsic components form a very hard, resistant rock with a migmatitic texture.

chl chlorite schist

Talc-chlorite granofels and medium- to coarse-grained talc-chlorite schist with relic pyroxene. In addition to map-scale bodies, numerous similar bodies of smaller size occur within the Mt. Washington Amphibolite.

The lower contact of the formation is not exposed within the Relay Quadrangle. The thickness of the formation is unknown.

Sinha et al., 1997 analyzed two zircon fractions separated from a plagiogranite and two from a quartz gabbro and obtained a TIMS U-Pb upper intercept age of 489 ± 7 Ma. This age is in agreement with a 490 ± 20 Ma Sm-Nd model age reported by Shaw and Wasserburg (1984) based on three rock samples.

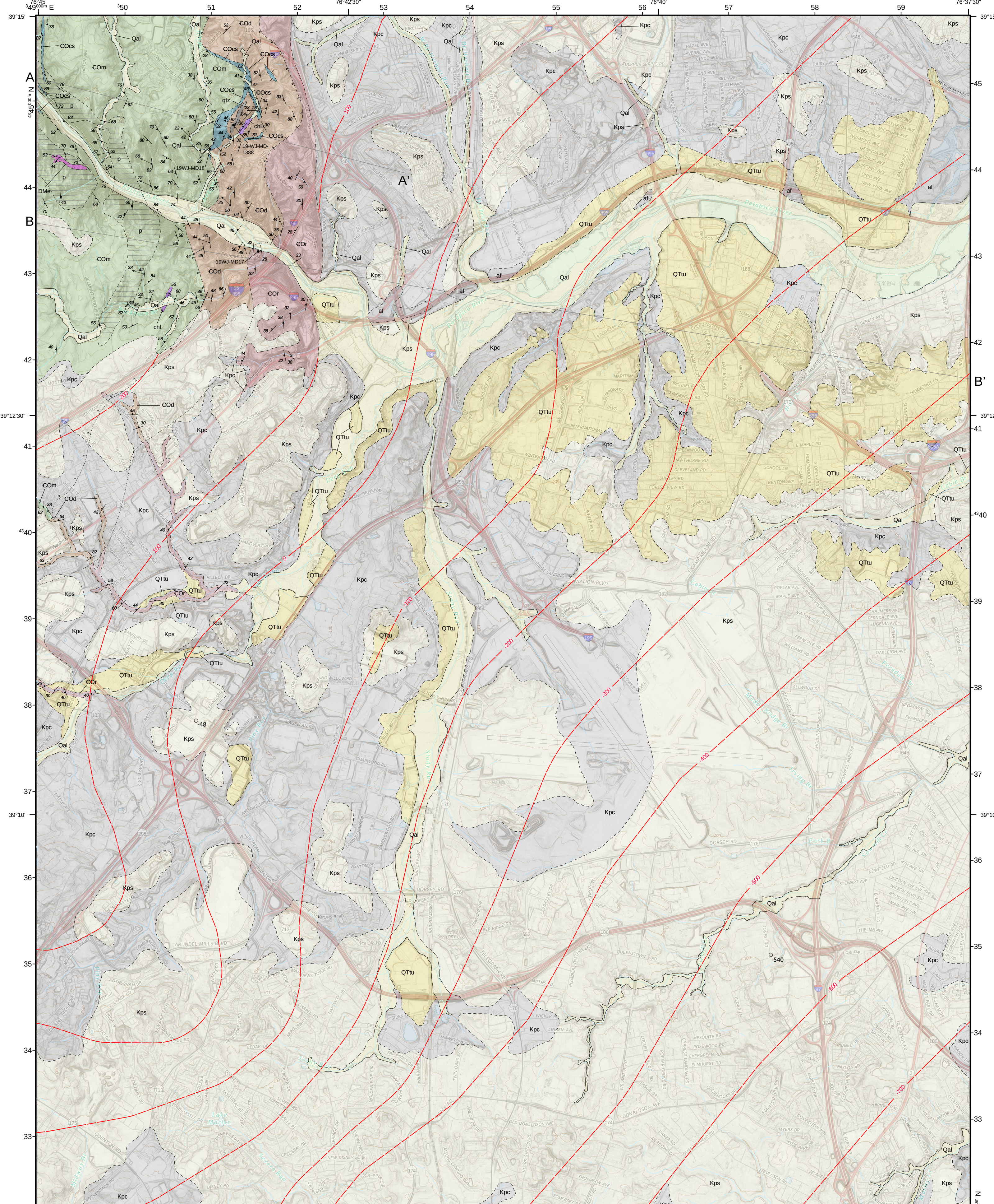
Quaternary

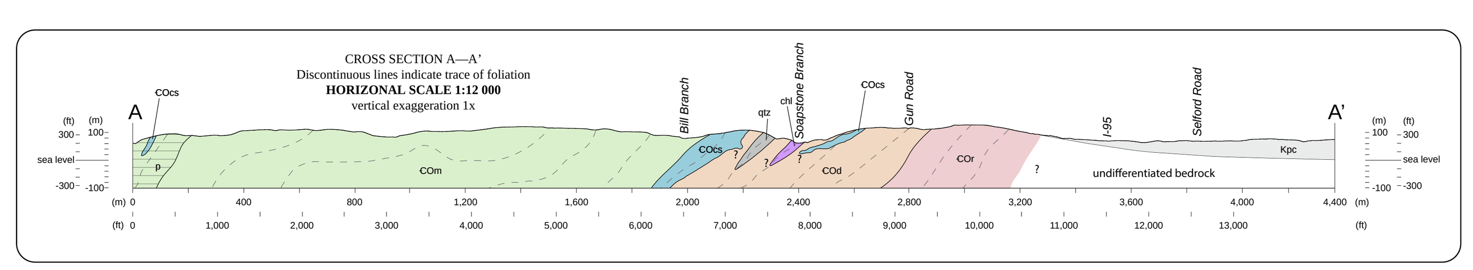
Tertiary (?)

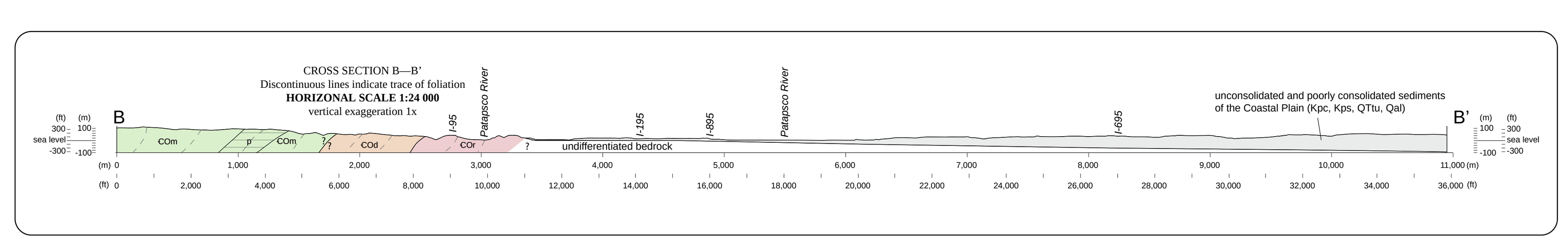
Cretaceous

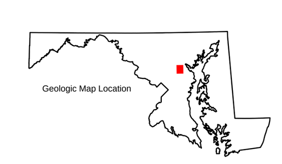
Devonian-Mississippian

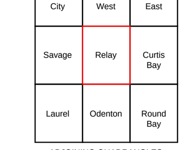
Cambrian-Ordovician











SCALE 1:24 000

Explanation of Map Symbols

Planar Features[1]

Strike and dip of foliation or schistosity (everywhere virtually parallel to compositional layering where present)

Strike and dip of joint

Strike and dip of fault surface

Linear Features

Trend and plunge of slickenline

Trend and plunge of mineral lineation

Geologic contacts[2]

Location accurate

Location approximate

Location inferred

Location concealed

(queried where identity or location is uncertain)

Structure contours[3]

Altitude (ft) of the top of Pre-Cretaceous basement rocks. Contour interval is 100 ft. Datum is sea level.

Boreholes

Altitude (ft) of the top of Pre-Cretaceous basement rocks. Datum is sea level. (Andreasen, et al., 2013)

Sample locations

Geochronology sample

Base Map Symbols

Topography

Topographic index contour (100-ft interval)

Topographic intermediate contour (40-ft interval)

Hydrography

Stream

Water body (e.g. lakes, ponds, rivers)

Transportation

Expressway | Local Connector
Secondary Hwy | Local Road
Ramp | 4WD

Interstate Route | US Route | State Route

1. Structural symbols on alluvium represent bedrock exposures in stream valleys. In areas where bedrock outcrops are restricted to within stream channels, alluvium is omitted from the map to show the approximate extent of the bedrock unit outcrops.

2. Contacts are generally inferred or approximate. Distribution and concentration of structural symbols are a general indication of the confidence of the location and identity of any contact.

3. Depth to bedrock contours are adapted from figure 2 of Hansen and Edwards (1986) and figure 47 of Andreasen et al. (2013) and well data therein, with minor changes to contours made based on the elevations of bedrock outcrops located as part of this study.

Figure 1. Traces of contacts separating Cretaceous and younger units (except Quaternary alluvium and select portions of terrace and upland deposits; see note 1) adapted from the following map data sources:

1. Unpublished field mapping of Baltimore County and Baltimore City Coastal Plain sediments by J. Reinhardt and E. T. Cleaves, 1970s, scale 1:24,000
2. Unpublished field mapping of Howard County Coastal Plain sediments by J. Reinhardt, 1973-1975, scale 1:24,000
3. Glaser, J. D., 1976, Geologic Map of Anne Arundel County: Maryland Geological Survey, scale 1:62,500

Version: RELAY2021.1.1 | MD DNR Publication No: DNR 12-032822-308

Map available as printable PDF from the website: http://www.mgs.md.gov/

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Lieutenant Governor

Department of Natural Resources
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Secretary
Allan Fisher
Deputy Secretary

Maryland Geological Survey
Richard A. Ortt, Jr.
Director

Introduction

The Relay Quadrangle is contained within portions of Anne Arundel, Howard, and Baltimore Counties, as well as a small portion of Baltimore City in the northeast corner of the quadrangle. Most of the quadrangle is urban and suburban. A portion of the northwest corner occupied by Patapsco Valley State Park is relatively undeveloped.

The geology of the Relay Quadrangle has been mapped previously at various scales. Knopf and Jonas (1925) and Cloos and Broedel (1940) mapped portions of the Relay Quadrangle as part of their 1:62,500 scale geologic maps of Baltimore and Howard Counties, respectively. Cohen (1937) produced a regional structural map that includes data gathered from Relay Quadrangle bedrock. Mapping of bedrock units by W.P. Crowley was compiled into multiple county-scale maps (Crowley et al., 1976; Edwards Jr., 1993) that together include all the exposed bedrock of Relay Quadrangle, although W.P. Crowley never produced a geologic map of the Relay Quadrangle at 1:24,000 scale. Most recently, mapping of the Relay Quadrangle and adjacent Savage Quadrangle bedrock units was undertaken by Drake (1998) as part of his investigations into regional-scale tectonic problems. Mapping of Coastal Plain units at 1:24,000 scale by J. Reinhardt and E. T. Cleaves was compiled into 1:62,500 scale geologic maps of Howard County (Edwards Jr., 1993) and Baltimore County and City (Crowley et al., 1976). Within Anne Arundel County, Coastal Plain units were mapped at 1:62,500 scale by Glaser (1976).

The majority of the Relay Quadrangle exposes Cretaceous and younger unconsolidated and poorly consolidated sediments deposited atop crystalline bedrock. The unconsolidated sediments occur as a thin veneer draped along the Mid-Atlantic Fall Line (approximate boundary between the Coastal Plain and Piedmont physiographic provinces) in the northwest of the quadrangle, and gradually thicken to the southeast, reaching over 700 ft in thickness in the southeast corner of the quadrangle (Hansen and Edwards, 1986). Alluvium occurs in most stream valleys. Alluvial terrace gravels occur along the banks and floodplains of the Patapsco River and its major tributaries. Extensive outcrops of metamorphic and plutonic bedrock occur within portions of the northwest corner of the quadrangle. The oldest unit present is the Mt. Washington Amphibolite (Crowley, 1976), a group of amphibolite and subordinate ultramafic rocks metamorphosed to greenschist and amphibolite facies. The Mt. Washington Amphibolite hosts several varieties of felsic gneiss, at least some of which clearly intrudes the mafic rocks of the unit. The Mt. Washington Amphibolite is a part of the Baltimore Mafic Complex (BMC), a regionally extensive unit of mafic and ultramafic rocks thought to represent either a dismembered ophiolite (Crowley, 1976; Morgan, 1977; Muller and Chapin, 1984; Wagner and Srogi, 1987; Horton et al., 1989; Guice et al., 2021), a layered igneous intrusion (Williams, 1886; Leonard, 1901; Jonas and Knopf, 1921; Herz, 1951; Hopson, 1964; Southwick, 1970; Higgins, 1972; Gates et al., 1991; Shank et al., 2015), or an obducted portion of an island-arc or backarc complex (Hanan and Sinha, 1989; Sinha et al., 1997). Within the Relay Quadrangle, the Mt. Washington Amphibolite is in contact to the east with interlayered amphibolite and subordinate felsic gneiss of the Druid Hill Amphibolite, which grade eastward into felsic gneiss of the Relay Felsite (formerly the Druid Hill Amphibolite Member and Relay Gneiss Member, respectively, of the James Run Formation (Crowley, 1976), updated to formational status by Drake (1998)). Both the Druid Hill Amphibolite and Relay Felsite are thought to be metamorphosed volcanic, volcaniclastic, and hypabyssal arc-products (Higgins, 1972; Crowley, 1976). Felsic gneiss of the Cold Spring Gneiss injection complex (Crowley, 1976; formerly the Leakin Park Gneiss and Ilchester Gneiss of Hopson, 1964) intrudes the Mt. Washington Amphibolite and Druid Hill Amphibolite and possibly the Relay Felsite) throughout the quadrangle; at several locations forming map-scale bodies. In one area a lens of quartzite with at least a partial metasedimentary component appears to be in contact with felsic gneiss of the Druid Hill Amphibolite. Sparse outcrops of Ellicott City Granodiorite (Hopson, 1964) intrude Mt. Washington Amphibolite at the western edge of the quadrangle adjacent along the Patapsco River. Swarms of anastomosing tabular bodies of granitic gneiss, possibly genetically related to Ellicott City Granodiorite (Drake, 1998), intrude Mt. Washington Amphibolite extensively and cut all the other crystalline rock units at various locations.

As part of this study, the bedrock geology of the Relay Quadrangle was mapped at 1:24,000 scale using traditional field techniques as well as GPS with approximately 15 ft accuracy. 19 samples were collected for major element geochemistry analysis to aid in distinguishing between units that appear similar to one another in the field. In addition, 12 previously analyzed samples from the Relay Quadrangle are included in the following discussion and associated figures. U-Pb data were obtained for zircon populations from a total of three samples analyzed by LA-ICP-MS.

Geochemistry

Rocks analyzed from the Relay Quadrangle are generally of a bimodal chemical distribution with respect to SiO_2. Plotted on a total alkali vs. silica diagram (LeBas et al., 1986), rock compositions range widely from 37 to 80 weight percent silica content. Assuming present compositions reflect those of the protoliths, the samples have silica and total alkali contents consistent with picro-basalt, basalt, trachy-basalt, basaltic-andesite, dacite, and rhyolite, with most samples plotting in the basalt and rhyolite fields. One sample plots left of the picro-basalt field (Fig. 3).

The chemistry of the mafic rocks generally follows a tholeiitic trend of increasing TiO_2 with increasing $Fe_2O_3/(Fe_2O_3+MgO)$ (Fig. 4) (Miyashiro, 1973); mafic rock compositions generally plot within tholeiitic fields on K_2O vs. SiO_2 (Fig. 5) (Peccerillo and Taylor, 1976) and MgO vs. Fe_2O_3 vs. Na_2O+K_2O plots (Fig. 6) (Irvine and Baragar, 1971). Analyzed mafic rocks from the Mt. Washington Amphibolite are not distinguishable in terms of major element composition from mafic rocks analyzed from the Druid Hill Amphibolite.

Two groups of felsic rocks are distinguishable on the basis of major element composition (Fig. 4). Rocks from the first group, which contain high silica, low K, and high Na, are chemically similar to felsic rocks previously analyzed from the Relay Felsite (Hopson, 1964; Higgins, 1972), the Carroll Gneiss of Baltimore City (Hopson, 1964), the Churchville Gneiss of Harford County (Southwick, 1970), and various members of the James Run Formation in northern Maryland (Higgins and Conant, 1990; Plank, 2001). Samples from the second group of felsic rocks contain high K and generally low Na relative to the first group, and are chemically and texturally similar to outcrops of Cold Spring Gneiss in Baltimore City (Crowley, 1976; Daniel Viete, personal communication, 2019).

Geochronology

Previous geochronology

Tilton et al. (1970) proposed a Cambrian age for the James Run Gneiss on the basis of discordant ages of zircon grains separated from (1) a sample collected at the Gatch Quarry at Churchville in southern Harford County, Maryland, type locality of the James Run Gneiss (Southwick and Fisher, 1967) (Churchville Gneiss Member of the James Run Formation (Higgins, 1972; Horton et al., 2010)), and (2) a felsic gneiss sample from the Campbell Quarry in Baltimore, later assigned to the Carroll Gneiss Member of the James Run Formation (Crowley, 1976). Sinha et al. (2012) obtained a SIMS U-Pb age of 479 ± 4 Ma for the same split of zircons from the Gatch Quarry analyzed by Tilton et al. (1970). Horton et al. (2010) obtained a number of SHRIMP U-Pb ages from the James Run including 458 ± 4 Ma for a felsic gneiss outcrop from the Gatch Quarry (Churchville Gneiss Member of the James Run Formation), 462 ± 4 Ma for the Carroll Gneiss Member, and 458 ± 4 Ma for a sample of felsic gneiss from an outcrop of Relay Felsite located within the Relay Quadrangle approximately 300 ft east of the Druid Hill Amphibolite-Relay Felsite contact as mapped herein.

To determine a best estimate age for the Baltimore Mafic Complex (BMC), Sinha et al., 1997 analyzed two zircon fractions separated from a plagiogranite and two from a quartz gabbro and obtained a TIMS U-Pb upper intercept age of 489 ± 7 Ma. This age is in agreement with a 490 ± 20 Ma Sm-Nd model age reported by Shaw and Wasserburg (1984) based on three rock samples. U-Pb geochronology by SIMS on zircons extracted from two Ellicott City Granodiorite samples yielded ages of 363 ± 10 Ma and 369 ± 4 Ma, respectively (Sinha et al., 2012).

Samples and analytical methods

The locations of each of the three samples analyzed for U-Pb data can be found on the Geologic Map of the Relay Quadrangle. U-Pb geochronology of zircon was performed on the Laser Ablation-Inductively Coupled Plasma-Mass Spectrometer (LA-ICP-MS) at the Tectonics, Metamorphic Petrology & Orogeny (TeMPO) Laboratory at Johns Hopkins University. Typical 2σ uncertainty of $^{238}U/^{206}Pb$ for each measurement is ~3% (±12-15 Myr), which should be considered the accuracy of these age data (individual analyses), because excess variance in a population cannot be identified at a level finer than the analytical precision (Horstwood et al., 2016). Analyses from each sample are plotted on Tera-Wasserburg Concordia diagrams and constitute kernel density estimate and histogram plots in Figure 2. Analyses that do not overlap within 2σ covaried uncertainty of Concordia are considered discordant. For each of the three analyzed samples, the MSWD (Mean Square Weighted Deviation) of $^{238}U/^{206}Pb$ ages suggests the age do not form a single statistical population (Spencer et al., 2016).

Results

19-WJ-MD-1388

This sample was collected from an outcrop of quartzite interlayered with subordinate (up to 15%), thin layers of garnet-chlorite-muscovite schist. The outcrop is heavily fractured, sheared, and veined. The rock is interpreted as metasedimentary based on its mineralogy. The sampled unit appears to be in contact with felsic gneiss of the Druid Hill Amphibolite located along Soapstone Branch, although the contact is not exposed.

The sample yielded a statistical peak around 480 Ma; in addition, the sample yielded younger concordant ages ranging as young as 419 ± 13 Ma (Fig. 2A). As this sample is interpreted as metasedimentary, these younger ages could represent detrital zircons derived from younger source rocks, thus placing the depositional age of the sampled rock significantly younger than the various maximum depositional ages and crystallization ages for Relay Quadrangle units and correlative rocks suggested by this and previous studies (e.g. Horton et al., 2010; Sinha et al., 2012). Alternatively, the younger population of ages may represent a metamorphic event or be due to Pb loss along cracks or during hydrothermal alteration. The presence of a negatively skewed age probability curve is consistent with Pb loss (Spencer et al., 2016), and the outcrop from which this sample was collected is highly fractured and heavily intruded by quartz veins.

19-WJ-MD-17

This sample is a felsic gneiss collected on the south bank of the Patapsco River ca. 140 m up section from the approximate trace of the gradational contact separating the Druid Hill Amphibolite and Relay Felsite. The sample is a well foliated, pale gray, medium-grained, leucocratic quartz-plagioclase-gneiss containing minor muscovite and chlorite.

Results for this sample include one anomalously young analysis and three discordant analyses. The remaining analyses, which do not constitute a single age population (MSWD 7.1 for weighted mean of $^{238}U/^{206}Pb$ ages not excluded as discordant or anomalous), form a statistical peak at 496 Ma (Fig. 2B).

19-WJ-MD-18

This sample was collected from an approximately 10 foot-thick body of felsic gneiss located on the north bank of Bull Run near its confluence with Soapstone Branch. The sampled body is fine- to coarse-grained pinkish-orange gneiss consisting predominantly of orthoclase and plagioclase feldspar and quartz, with subordinate muscovite, biotite, and accessory garnet. The approximate trace of the Druid Hill Amphibolite-Mt. Washington Amphibolite contact is mapped along the western edge of the sampled gneiss body, although the nature and exact location of this contact remain unclear.

Results for this sample include one anomalously young age with large uncertainty, and 17 discordant analyses. The remaining analyses, which do not constitute a single age population (MSWD 10.3 for weighted mean of $^{238}U/^{206}Pb$ ages not excluded as discordant or anomalous), form a statistical peak at 482 Ma (Fig. 2C).

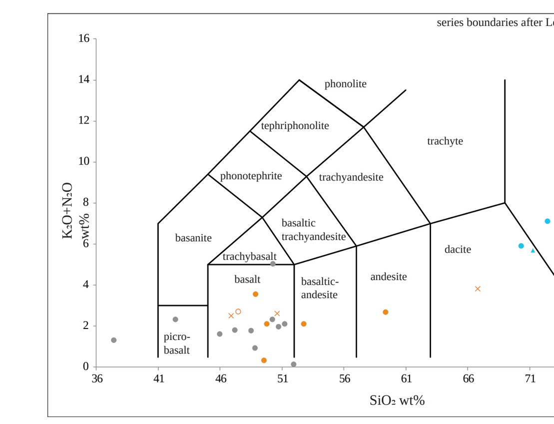

Figure 3. Total alkalis vs. silica plot of samples from the Relay Quadrangle.

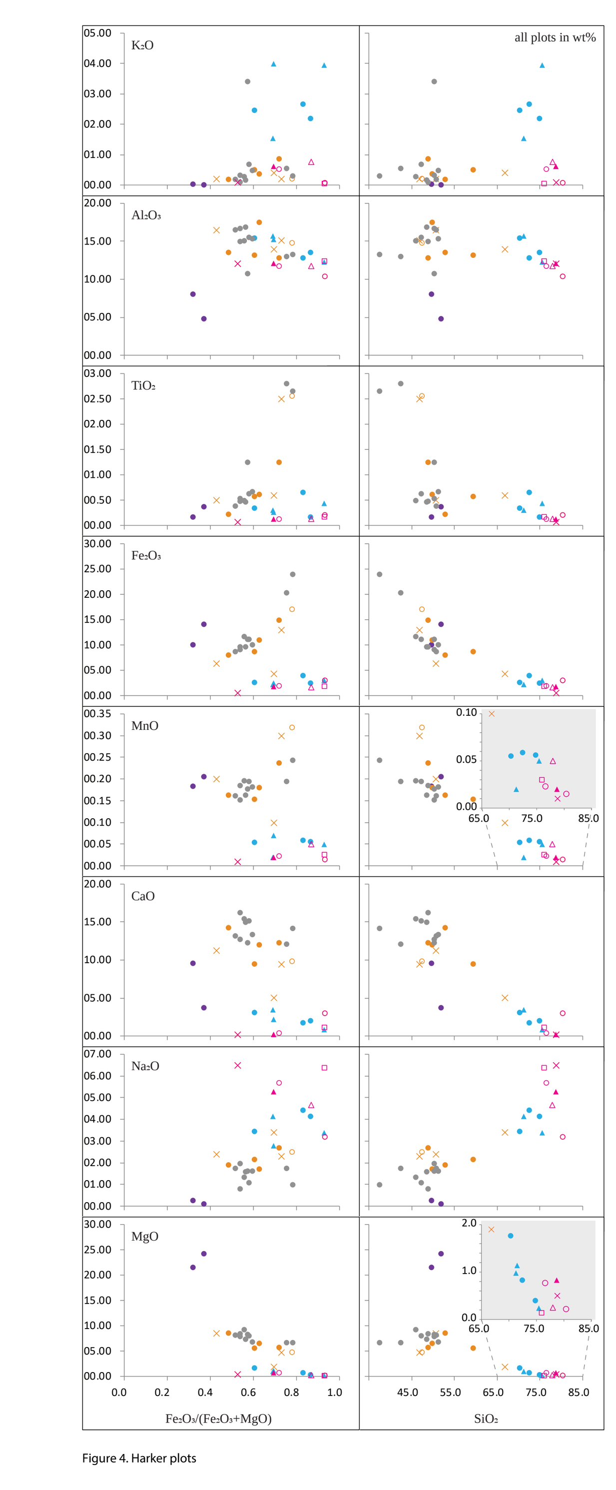

Figure 4. Harker plots

Legend for Figs. 3-6

● this study

○ Robert Smith, personal communication

▲ Daniel Viete, personal communication

△ Hopson, 1964

× Drake, 1998

□ Hanan and Sinha, 1989

Relay Felsite

Druid Hill Amphibolite

Mt. Washington Amphibolite

Cold Spring Gneiss

chlorite schist (Druid Hill Amphibolite)

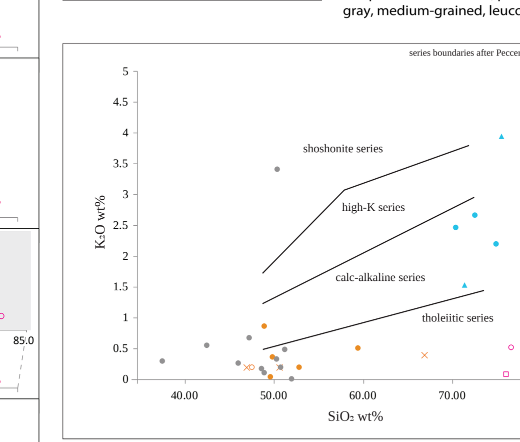

Figure 5. K_2O vs. SiO_2 plot

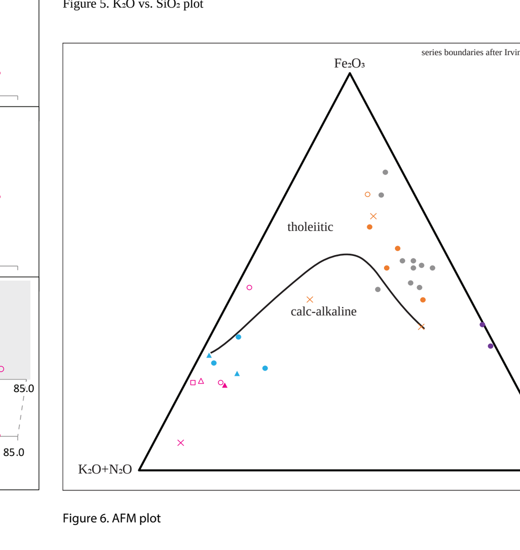

Figure 6. AFM plot

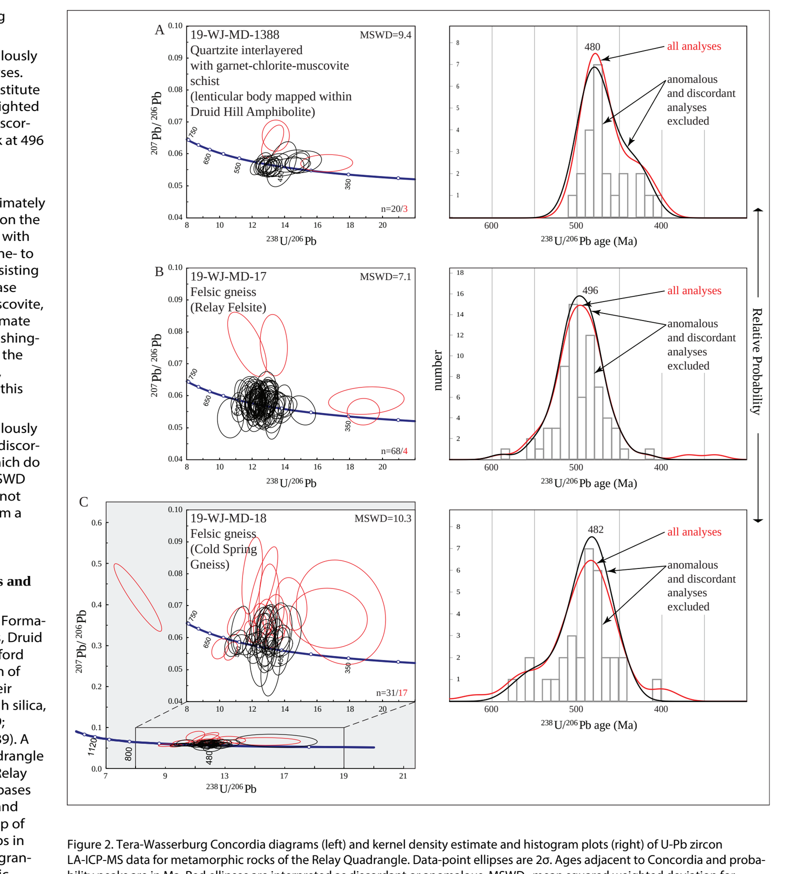

Figure 2. Tera-Wasserburg Concordia diagrams (left) and kernel density estimate and histogram plots (right) of U-Pb zircon LA-ICP-MS data for metamorphic rocks of the Relay Quadrangle. Data-point ellipses are 2σ. Ages adjacent to Concordia and probability peaks are in Ma. Red ellipses are interpreted as discordant or anomalous. MSWD=mean squared weighted deviation for weighted mean of $^{238}U/^{206}Pb$ ages not excluded as discordant or anomalous.

Discussion

Relationship between Cold Spring Gneiss and other bedrock units

Rocks formerly grouped as the James Run Formation (including Relay Felsite, Carroll Gneiss, Druid Hill Amphibolite, James Run Gneiss of Harford County, MD, and the James Run Formation of Cecil County, MD) have been noted for their common chemistry: relatively high Na, high silica, and low K (Hopson, 1964; Southwick, 1969; Higgins, 1972, 1990; Hanan and Sinha, 1989). A group of felsic rocks within the Relay Quadrangle is distinguishable from felsic rocks of the Relay Felsite and Druid Hill Amphibolite on the bases of abundant K-feldspar, relatively high K, and relatively low Na (Fig. 4). This distinct group of felsic rocks resembles felsic gneiss outcrops in the Baltimore area first referred to as the "granodiorite gneiss of Leakin Park" and "granitic gneiss east of Ilchester" by Hopson (1964), and subsequently expanded into the Cold Spring Gneiss by Crowley (1976). The nomenclature of Crowley (1976) is adopted here. The K-feldspar-bearing gneiss crops out in abundance along the Druid Hill Amphibolite-Mt. Washington Amphibolite contact within the Relay Quadrangle, consistent with the common occurrence of K-feldspar-bearing gneiss mapped as Cold Spring Gneiss along the same contact in western Baltimore (Crowley, 1979). Drake (1998) did not include Cold Spring Gneiss on his geologic map of the Relay and Savage quadrangles but mapped two bodies of felsic gneiss as "plagiogranite (Omp)"; both bodies have been reassigned to the Cold Spring Gneiss on the basis of abundant K-feldspar and relatively high K content analyzed in samples from each body (Fig 4). Field and geochronology data collected as part of this study indicate the Cold Spring Gneiss is distinct from the younger Ellicott City Granodiorite and the various swarms and masses of pegmatitic granite that cut all other bedrock units in the area.

The relationship between the rocks mapped as Cold Spring Gneiss and the other felsic rocks occurring within the Druid Hill Amphibolite and Relay Felsite remains unclear. One possibility is that the Cold Spring Gneiss represents an intrusive source for Relay Felsite and felsic rocks occurring within the Druid Hill Amphibolite. This cogenetic interpretation is consistent with the broad similarity between the respective distributions of U-Pb zircon ages yielded from the Cold Spring Gneiss, Relay Felsite, and a quartzite body within the Druid Hill Amphibolite (Fig. 2), although significant uncertainty (12-15 Myr) is associated with each age. A cogenetic relationship requires subsequent alteration on the part of the Cold Spring Gneiss or the Druid Hill Amphibolite and Relay Felsite to account for analyzed chemical differences. Hopson (1964), Southwick (1969), and Higgins and Conant (1990) provided evidence for various mechanisms by which exposure to seawater followed by diagenesis and metamorphism could result in the depletion of K and enrichment of Na observed in the Relay Felsite, Druid Hill Amphibolite, and correlative units in Baltimore City and Baltimore, Harford, and Cecil Counties. A cogenetic relationship between the Relay Felsite and Cold Spring Gneiss also requires an explanation for the difference in silica content observed between the two rock groups.

Alternatively, the Relay Felsite and felsic components of the Druid Hill Formation may have been derived from intrusive sources distinct from the Cold Spring Gneiss. These intrusive sources may have been distal, or removed by faulting along the Mt. Washington Amphibolite-Druid Hill Amphibolite contact, or they may be buried beneath Coastal Plain sediments to the east, implying the Druid Hill Amphibolite is stratigraphically above the Relay Felsite. Alternatively, the various low-K felsic rocks intruding the Mt. Washington Amphibolite and Druid Hill Amphibolite may represent an intrusive source for the Relay Felsite and felsic components of the Druid Hill Formation.

Additional geochemistry and geochronology work is required to fully characterize the various felsic rock units that occur within the Relay Quadrangle and nearby areas, particularly the poorly understood Cold Spring Gneiss. Field observations and geochemical data (Figs. 3-6) suggest Cold Spring Gneiss underlies a larger area of the Relay Quadrangle than previously mapped, and it is possible that areas in the Relay Quadrangle and elsewhere mapped as Relay Felsite or correlative felsic units such as Carroll Gneiss may yet contain a significant proportion of rocks more similar to Cold Spring Gneiss.

Age and origin of the Relay Felsite and Druid Hill Amphibolite

The Druid Hill Amphibolite and Relay Felsite appear to comprise a stratigraphic sequence consisting of supracrustal deposits that have been metamorphosed and cut by numerous shallow felsic intrusions. Previous evidence for supracrustal deposition comes from the Relay Quadrangle and from correlative units to the northeast in Baltimore City and Harford and Cecil Counties, and includes geochemical affinities to rocks of known volcanic/volcaniclastic origin (Hopson, 1964; Southwick, 1969; Higgins, 1972); relict pillow basalts (Higgins, 1990) and amygdules (Southwick, 1970; Crowley, 1976); stretched polygranular quartz blebs suggestive of recrystallized pumice fragments (Hanan and Sinha, 1989); and the presence of interlayered mafic and felsic layers with sharp contacts, uniform thickness, and lateral continuity, consistent with volcaniclastic sedimentation (Knopf and Jonas, 1929; Hopson, 1964; Crowley, 1976; Horton et al., 2010). The discovery within the Druid Hill Amphibolite of a lenticular body of quartz-rich rock including quartzite interlayered with garnet-chlorite-muscovite schist supports a supracrustal origin for the Druid Hill Amphibolite and the Relay Felsite into which it grades, although it should be noted that the contacts bounding the lenticular body or quartz-rich rock are not exposed and may be faults.

Geochronology results support a complex history for the Relay Felsite. U-Pb ages of zircons collected from a sample of Relay Felsite do not define a single age population and may include inherited and/or detrital components (Fig. 2B). Significantly, the majority of U-Pb zircon ages yielded by the Relay Felsite sample do not agree with the 458 ± 4 Ma SHRIMP U-Pb age determined by Horton et al. (2010) for a sample of the same unit collected roughly along strike less than 400 yards to the northwest. A possible explanation for the apparent difference in the age data is that the Relay Felsite is a polygenetic group of compositionally similar rocks including older (ca. 495 ± 12-15 Ma) supracrustal and hypabyssal rocks cut by younger (458 ± 4 Ma) intrusions. Zircon grains that yielded the 458 ± 4 Ma SHRIMP U-Pb age were interpreted to have derived from a shallow intrusion based on oscillatory zoning and external grain characteristics (Horton et al., 2010). An alternative explanation for the disagreement in ages analyzed as part of this study and by Horton et al. (2010) is that the samples are both ca 460 Ma and that the older zircon ages (ca. 495 ± 12-15 Ma) from the sample dated as part of this study represent detrital or inherited ages. However, given the documented robust arc activity ca. 460 Ma (Aleinikoff et al., 2002; Horton et al., 2010; Sinha et al., 2012) and the interpretation of the Druid Hill Amphibolite and Relay Felsite as hypabyssal, volcanic and volcaniclastic, it seems unlikely that the sample analyzed in this study could have been deposited or emplaced at ca. 460 Ma without accruing abundant zircon grains of this age.

Relationship of Relay Felsite and Druid Hill Amphibolite to Baltimore Mafic Complex (BMC)

The relationship between the Mt. Washington Amphibolite (and larger Baltimore Mafic Complex (BMC)) and the stratigraphic sequence represented by the Druid Hill Amphibolite and Relay Felsite remains an outstanding question. Geochronology results support a broad age correlation between the BMC and the Druid Hill Amphibolite and Relay Felsite. Except for a handful of younger ages, the majority of zircon ages from the Relay Felsite (Fig. 2B) agree within uncertainty with ages reported for the BMC (Sinha et al., 1997; Shaw and Wasserburg 1984). Crowley (1976, p. 29) interpreted the base of the Druid Hill Amphibolite in the Baltimore area as either a low-angle thrust fault or an unconformity, arguing it truncates an anticline within the BMC the existence of which he determined from the distribution of sparse ultramafic and mafic outcrops. Within the Relay and Savage quadrangles, Drake (1998) mapped the Mt. Washington Amphibolite-Druid Hill Amphibolite contact as the Soapstone Branch thrust fault, citing evidence for a thrust fault presented by Crowley (1976) while leaving the possibility of an unconformity unaddressed. Drake (1998) mapped the location of the proposed fault based on the presence of mylonitic foliation and the relative sparsity of pegmatitic granite within the Druid Hill Amphibolite as compared to the Mt. Washington Amphibolite to the west.

During this study, limited evidence was observed for a fault separating the Mt. Washington Amphibolite and Druid Hill Amphibolite. Mylonitic foliation was observed throughout the Mt. Washington Amphibolite, Druid Hill Amphibolite, Relay Felsite, and Cold Spring Gneiss, but not in any notable concentration along the Mt. Washington Amphibolite-Druid Hill Amphibolite contact as mapped here or as mapped by Drake (1998). At one location along the east bank of Bull Branch just north of its confluence with Soapstone Branch, the foliation within the Mt. Washington Amphibolite appears to be truncated by the western contact of a large body of Cold Spring Gneiss and the foliation of the gneiss, although the contact is not exposed and the observed orientations could be explained by folds. In general the patchy distribution of outcrops and the homogeneity of the mafic rocks of the Relay Quadrangle—in terms of geochemistry and outcrop appearance—makes the identification of structures in the field difficult. More detailed petrology and geochemistry work is required to fully characterize the relationship between the Mt. Washington Amphibolite and Druid Hill Amphibolite, as well as the nature and exact location of any contact separating them.

Acknowledgements

This map was funded by the United States Geological Survey (USGS) under award number G19AC000251. The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

The author appreciates the map reviews by D.K. Brezinski and R. Kavage-Adams. I am especially grateful to Avery A. Drake and William P. Crowley for their previous work mapping in the Relay Quadrangle. The map units and contacts in their field notes and published maps do not in every case agree with the results of this work, and in some cases it is clear these authors made observations on outcrops I was unable to locate. However, the notes and maps of these two investigators were essential in helping me locate the most interesting and important outcrops. I am grateful to Juergen Reinhardt, Emery Cleaves, and John Glaser for their maps of unconsolidated sediments of the Coastal Plain which were incorporated into this map. I am grateful to Robert C. Smith II and Gloria J. Smith for graciously allowing me to present their unpublished geochemical data as part of this map and accompanying text. I wish to thank George L. Guice, Michael Ackerson, and the Smithsonian National Museum of Natural History Department of Mineral Science for access to and assistance with various sample preparation and analytical facilities. I thank Dionysus I. Foustoukos and Carnegie Science Geophysical Laboratory for allowing me use of their XRF facilities. I express my appreciation to numerous members of the Johns Hopkins Department of Earth and Planetary Sciences: Daniel R. Viete for inviting me to use the mineral separation and LA-ICP-MS facilities; Robert M. Holder, Freya R. George, and Daniel Viete for a variety of technical assistance with analytical work and for permitting the use of some of his unpublished whole-rock geochemistry data; Joseph F. Browning-Hanson and Naomi Becker for assistance with mineral separation facilities; and all members of the Tectonics, Metamorphic Petrology & Orogeny Laboratory (along with frequent visitor George Guice) for numerous invaluable and stimulating discussions on the nature and origins of the various bedrock units of the Baltimore, MD area.

The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government. Geological field mapping was conducted in 2018-2020.

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