Geology of Warren County

Open-File Data

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2 - Geomorphology - H. W. Webb

3 - Engineering Geology - R. Murphy & H. Freeland

Stratigraphy of Warren County

The Precambrian to Silurian age rocks found in Warren County can be divided into seventeen formations, fifteen of which are described. The Swift Run Formation, metasedimentary rocks associated with the basal Catoctin Formation, and the layer gneiss near Linden are not described. (Refer to Bull. 86 and R. I. 44) for a description of these units. Three types of dikes, amphibolite, metabasalt, and mica peridotite, are described. Colluvial, terrace, and flood plain deposits are described.

Pedlar Formation

West of Matthews Arm an elliptical shaped area of the Pedlar Formation is exposed (Plate 1). The main Pedlar exposures (Plate 1) occur in a roughly elliptical shaped area extending from northeast of Dungadin Heights for 9.5 miles (15 km) south to Hogback Mountain and west from Compton Gap 6.9 miles (11 km). A linear northeast extension of the main area extends from Carson Mountain to Moore Run. Good exposures occurs along Gooney Run, in Fox Hollow, near Boyds Mill, and in Brown Hollow. Scattered exposures occurs along State Road 649 from the junction with State Road 607 south to Browntown.

The contact with overlying formations is unconformable. Locally metasediment of the Swift Run Formation overlies the Pedlar. However, throughtout most of the area metabasalts or metasediments of the Catoctin Formation overlie the Pedlar. This contact is commonly marked by a zone of unakite and a sharp break in slope. A good exposure occurs 0.3 mile (0.5 km) southeast of the entrance to Skyline Caverns on State Road 649. The lower contact with the layered gneiss does not occur in Warren County. A discussion of this contact can be found in Lukert and Nuckols (1976).

The Pedlar is an assemblage of meta-igneous rocks consisting of quartzo feldspathic granulite (R-4372, R-4373) and altered quartz monzonite. The granulite is composed of quartz, perthite, epidote, garnet, rutile, ilmenite, and leucoxene. The granulite is associated with the Front Royal fault and small shear zones. Where Gooney Run crosses the Front Royal fault is the best area to observe the granulite facies of the Pedlar. The greenish-gray quartz monzonite is composed of quartz, microcline, plagioclase, pyroxene altered to pyrite and chlorite, biotie, muscovite, specular hematite, pyrite and chalcopyrite. Several greenstone dikes intrude the Pedlar (Plate 1) and are described in the section on dikes. Radiometric age determinations from zircons in the quartz monzonite near Marys Rock tunnel (about 10 miles, 16 km, south-southwest of Warren County) provide a date of 1,100 million years (Davis, and others, 1958).

Catoctin Formation

Exposures of the Catoctin Fomration extend in a broad belt southwestward from the Clarke County boundary to Dickey Hill and Carson Mountain. Along the southeastern boundary of the county the Catoctin underlies Mount Marshall. Southeast of Bentonville exposures of the fomration occur in Thompson Hollow, Matthews Arm, Gimlet Ridge and along Overall Run. Good exposures of the purple rhyolitic metatuffs occurs along State Road 630, 0.6 mile (0.97 km) south of its junction with State Road 613. Basaltic flows with columnar jointing occur 0.6 mile (0.97 km) south of the junction of U. S. Highway 340 and 522, along 522. The basal Catoctin contact with the Pedlar is unconformable. However, locally the Swift Run Formation occurs between the Pedlar and Catoctin and in these areas the basal Catoctin contact is conformable. Along State Road 649, 0.3 mile (0.5 km) southeast of Skyline Caversn the basal Catoctin contact is exposed. Here unakite of the underlying Pedlar Formation is in contact with grayish-green metabasalt.

Due south about 0.5 mile (0.8 km) the unakite is overlain by a thin purple meta-arkose and rhyolitic metatuff. The upper contact with the Weverton is unconformable is placed at the top of the youngest metabasalts and purple slate.

The most common rock type in the Catoctin is greenstone. The greenstone is the product of a low-grade regional metamorphism of a basalt flow. "Individual basalt-flow thickness range from 75 to 150 feet (23 to 46 m)".

The mineral composition of the greenstone is albite, epidote, chlorite, actinolite, and minor quartz, magnetite, specular hematite, sphene and pyroxene (R-5050, R-5604, R-5699, Lukert, and Nuckols, 1975, p. 31). Amygdule fillings consist of white albite, quartz, calcite, green epidote, chlorite, and red jasper. Porphyritic greenstone with plagioclase phenocrysts in a matrix of fine-grained albite, epidote, magnetite and pyroxene is exposed about 1.0 mile 1.6 km) south of Front Royal along U. S. Highway 522. Commonly, the top of a flow is marked by a zone of breccia consisting of amygdaloidal greenstone, phyllite and red argillite (R-5603). "The epidote-amygdaloid breccia is composed of angular or irregularly rounded fragments of purple red, and bluish- gray amygdaloidal greenstone in a matrix of fine-grained greenstone, quartz, and epidote" (Reed, 1969). "The occurrence of epidosite, a pale yellow-green, fine-grained rock, is fairly common throughout the formation. This early chemical-alteration product of meta-basalt (Reed and Morgan, 1971) occurs as vein fillings and a cementing agent in flow breccia and interbedded quartoze sandstone. In thin section the composition is a fine-grained, equigranular, subhedral epidote with small aggregates of anhedral quartz. Where the basalt has been altered to epidosite, a relict basaltic texture may be preserved with little alteration of the amygdules (Gathright and Nystrom, 1974)" (Lukert and Nuckols, 1975, p. 32). Epidosite is very common in breccia zones (R-4369, R-4370, R-5600, R-5601, R-5605). Mud-lump breccias consisting of angular to subangular fragments of reddish-brown argillite in a matrix of fine-grained schistose greenstone occur locally at the base of flows. Columnar jointing is common in the flows and the columns are often replaced by epidote and quartz. Purple metatuffs (R-5602, R-5607) composed of very fine-grained sericite and microylline quartz and feldspar with a phyllitic texture and green-smeared epidote, quartz, feldspar and slate blebs are common at or near the top of the Catoctin.

Metasedimentary rocks interbedded with the Catoctin flows are of three types: meta-arkose, metalithic sandstone (R-5608), and phyllite. The meta-arkose is composed of angular to subrounded quartz and feldspar in a matrix of sericite and epidote. A conglomeratic texture is locally common with granules and pebbles of quartz, gneiss, phyllite, and greenstone. The metalithic sandstone is composed of poorly sorted quartz, feldspar and rock fragments of gneiss, phyllite and greenstone in a matrix of chlorite and sericite. The matrix constitutes 20 to 50 percent of the rock. Granules and pebbles of quartz, gneiss, phyllite, and greenstone locally give the rock a conglomeratic texture. The phyllites and slates are composed of sericite with scattered quartz grains and may be altered volcanic ash layers.

The thickness of the Catoctin is difficult to determine because the upper and lower contacts are not exposed on the same fault block. Estimates of 2,000 to 2,500 feet (610 to 762 m) based on the outcrop width and the general structural configuration are compatible with thicknesses reported to the north by Gathright and Nystrom (1974). A late Precambrian age of 820 million years has been reported for the lower Catoctin of Pennsylvania (Rankin and others, 1969).

Cambrian System

Weverton Formation

The Weverton Formation occurs in a sinous northeastward -trending belt from State Highway 55 south of Green Hill to Rock Spring Branch near the northeast corner of the county. 1.6 miles (2.6 km) east of Overall a narrow north trending belt of Weverton is exposed. A small area of Weverton occurs about 1 mile (1.6 km) east of the junction of U. S. Highway 340 and State Highway 55, on the south side of State Highway 55. Good exposures of the basal Weverton occur along Overall Run east of Overall. The remainder of the formation may be seen along the entrance road to Camp Wamava and along the Southern Railway 2.4 miles (3.9 km) west-northwest of Linden.

The lower contact with the Catoctin may be an angular unconformity with coarse clastic sediments of the Weverton overlying metabasalt and metasediments of the Weverton over-lying metabasalt and metasediments of the Catoctin. The contact is gradation and is placed at the top of the youngest conglomeratic bed of the Weverton below phyllite of the lower Harpers Formation.

Three lithologic subdivisions with an aggregate thickness of approximately 500 feet (152 m) are recongized within the Weverton. The lower unit corresponds to the basal conglomerate and laminated phyllite member of Rader and Biggs (1975, p. 11). The basal beds of the lower unit are locally conglomeratic being composed of subangular to rounded quartz and flat clay clasts in a matrix of quartz and lithic fragment sand cemented by quartz, sericite, and chlorite. The remainder of the unit is light gray to tan and purplish gray, locally conglomeratic quartzite with thin interbeds of olive-gray to dark greenish-gray sandy phyllite. The cross-bedded quartzites are composed of medium- to coarse-grained, poor- to well-sorted, well-rounded quartz grains in a sparse sericite-chlorite matrix. Pink and white quartz pebbles up to 8 mm in diameter are interspersed throughout. The lower unit is about 150 feet (46 m) thick.

Two rock types form the relatively non-resistant middle unit: sandy phyllite and quartz sandstone. Both rocks are composed of angular to subrounded fine- to medium-grained quartz in a matrix of sericite-chlorite. Overgrowths are common on the quartz grains and commonly sericite partially replaces the quartz. When the sericite-chlorite content exceeds 40 percent of the rock the term sandy phyllite is used. Sandstone is used if sericite-chlorite comprise less than 40 percent of the rock. Locally the unit is conglomeratic. The middle unit is about 200 feet (61 m) thick. This unit corresponds to the silty phyllite and subarkose members of the Weverton of Rader and Biggs (1975, p. 11 - 12).

The upper unit is composed of resistant quartz-pebble conglomerate and sericitic- chloritic sandstone. Scour and fill structure and cross-bedding, often marked by discontinuous purple ferruginous bands, are common. The quartz pebbles, up to 1 cm in diameter, are subrounded to rounded in a quartz-feldspar sand matrix cemented by quartz, sericite and chlorite. The sandstone are medium- to coarse-grained quartz and feldspar in a matrix of sericite-chlorite with minor quartz cement. Magnetite and ilmenite are common in these rocks. This unit is about 150 feet (46 m) thick and corresponds to the quartz-pebble conglomerate member of Rader and Biggs (1975, p. 12-13.

Harpers Formation

The Harpers Formation, divided into two members, is composed predominantly of pelitic phyllite and silty to sandy, fine-grained phyllite. In the upper member quartzite, sandstone, and meta-arkose are present. In the northern part of the county the Harpers extends northeasterly from the southeast slope of Green Hill 9 miles (14 km) to the county boundary. South of Bentonville the formation occurs along the eastern slope of Brush Mountain. Two smaller areas of exposure occur east of Front Royal and south of State Highway 55. Contacts with the underlying Weverton and the overlying Antietam are conformable and gradational. The total thickness of the Harpers is approximately 2,500 feet (763 m). Along Brush Mountain the Harpers is not divided into member because of lack of outcrops and the increase in ferruginous sandstones.

Lower member: The basal contact is placed at the top of the youngest quartz-pebble conglomerate bed in the Weverton. A ferruginous meta sandstone in the base of the upper member marks the upper contact. The member is about 1500 feet thick. Two rock types, phyllite and metalithic sandstone, are the dominant lithologies. The lower 300 to 400 feet (91-122 m) are predominantly light bluish-gray, brick-red, tan, and pink phyllite that weathers to bronze-colored chips. The basal 40 feet (12 m) have thin, purple, sandy phyllite interbedded with phyllite and metalithic sandstone. The upper 1100 to 1200 feet (335-366) of the lower member consist of olive-gray, sandy and silty, locally feldspathic phyllite and metalithic sandstone (R-4206). Many grains have been partially replaced by the matrix which consists of fine-grained sericite and chlorite. Good exposures occur east of Howellsville near State Road 638; in a southeastward-trending draw on the southeast slope of Green Hill; and in roadcuts on the west side of Leach Run just north of where it flows under State Highway 55.

Upper member: The basal contact of the upper member is placed beneath the ferruginous metasandstone overlying phyllite of the lower member. The gradation upper contact is picked at the base of the oldest Skolithos- bearing, vitreous quartzite of the Antietam Formation. The upper member is distinguished from the lower by its lighter color and the presence of quartzites. Rock types in the upper member include bluish-gray, sandy phyllie (R-4217), light-gray and tan quartzite (R-4216), vitreous, white quartzite, subarkosic quartzite (R-4215), metaarkose, and ferruginous sandstone. Skolithos and Arenicolites (trace fossils) were the only fossil found. Good exposures of the gradational Harpers-Antietam contact can be observed about 1.0 mile (1.6 km) northeast of Wildcat Knob along State Road 603. Additional good exposures of the upper member are present along State Road 647 in Dismal Hollow and along the Southern Railway about 0.8 mile (1.3 km) southeast of the community of Happy Creek.

Antietam Formation

The main outcrop belt of the Antietam Formation extends northeastward from the northeastward from the southwest slope of Green Hill to the northern boundary of the county north of Venus Run. Another large area of Antietam occurs south of Bentonville along Brush Mountain. Small areas of Antietam occurs east-northeast of Bentonville, north of Dungardin Heights, and south of Woodland Park. Good exposures occur along Venus Run, Venus Hill, Wildcat Knob, and Brush Mountain. The best exposures are along the Southern Railway at the north end of Green Hill. The lower contact is placed at the base of ridge-forming, vietreous, Skolithos-bearing quartzite overlying sandy phyllite of the upper Harpers Formation. Because Antietam rocks have been thrust over the Waynesboro and Shady formations in Warren County, the stratigraphy of the upper part of the formation and its stratigraphic relationship to younger rocks in the county is unknown.

"The Antietam Formation consists of fine- to coarse-grained, silica-cemented, vitreous quartzite and subarkose; phyllite partings are common. The silica cement occurs as overgrowths on the detrital grains and makes up as much as 15 percent of the rock. Sericitic matrix material occurs commonly in less persistent layers that accentuate the bedding. The quartz content ranges from 80 to 95 percent; feldspar, 5 to 20 percent; sericite 1 to 10 percent; and opaque minerals 1 to 2 percent. Skolithos tubes are abundant in most of the quartzite beds, and their shapeis often outlined by iron oxide (goethite or hematite) stains" (Lukert and Nuckols, 1976, p. 42-43). Thin quartz-granule and -pebble conglomerate beds are present. The thickness of the Antietam is 400 to

600 feet (122 to 183 m).

The fault breccia between the Antietam and the younger Waynesboro and Shady Formation is mapped as a separate unit (Plate 1). Exposures and float by breccia occur from the abandoned iron mines (Plate 1, numbers   and   ) at the southwest end of Green Hill and along the northwest slope to Manassas Run. The best exposures are between the Southern Railway and Interstate Highway 66 at the north end of Green Hill and in the abandoned iron mines. Also good exposures occur 4,000 feet (1,219 m) west of Venus Hill and along State Road 603 (Plate 1). The angular fragments of quartzite cemented by iron oxide (goethite and hematite range from 0.25 inch to 3 feet (0.64 to 91 cm) in longest dimension (R-4225, R-4381, R-5614).

Shady Formation

The following description of the Shady Formation is taken from Lukert and Nuckols (1976, p. 44-45). " The Shady Formation is a high-magnesium dolomite poorly exposed in a narrow belt west of the Antietam quartzite with which it is in fault contact. Only the upper few ten of feet of light- to dark-gray, fine- to coarse-grained, medium- to thick-bedded, laminated dolomite is present because of the faulting and determination of structural, lithologic, and stratigraphic relationships are further hindered by a thick residuum and local terrace, alluvial, and colluvial deposits. A few small outcrops occur 4,000 feet (1,219 m) east of Morgan Ford, 3,000 feet (914 m) west of Howellsville, and 4,000 feet (1,219 m) west-southwest of Venus Hill. Chert rosettes and nodules were observed in the upper dolomite 1.8 miles (2.9 km) south of Milldale on the west bank of the Shenandoah River."

Only the uppermost 70 feet (21 m) of the Shady is exposed. To the northeast in Clark County Edmundson and Nunam (1973, p. 20) and Gathright and Nystrom (1974, p. 4)estimate the thickness of the Shady as 1,200 feet (366 m).

Waynesboro (Rome) Formation

The Waynesboro Formation occupies a folded belt averaging 3,500 feet (1067 m) wide extending northeastward from Morgan Ford to Hardin Island. Southeast of Morgan Ford to near Woodland Park the outcrop belt is about 2,500 feet (762 m) wide. A third poorly exposed belt extends from about 0.5 mile (0.8 km) east of Bentonville southwestward to Overall Run along the southern boundary of the country. Good exposures occur in the bluff along the west side of Manassas Run, on the crest of the ridge extending from the Southern Railway northeast of Happy Creek community to the Shenandoah River, on the low ridges 400 to 600 feet (122 to 183 m) east of the Front Royal town limits near Woodland Park, along Border Marsh Run southeast of Milldale, and in Sandbank Hollow south of Bentonville. The lower contact is placed at the top of the very dark-gray, fine-grained shady dolomite overlain by shale and sandstone of the Waynesboro. The upper contact is placed at the top of the youngest maroon shale beds of the Waynesboro below the green dolomite and dolomitic shale of the Elbrook.

Lithologically, the Waynesboro is divided into lower clastic, middle carbonate and upper clastic units. The lower unit about 500 feet (152 m) thick is characterized by maroon, olive, and dark-gray shale and maroon and yellowish-tan, fine- to medium-grained sandstone. Dark bluish-gray, saccharoidal dolomite and bluish-gray, fine-grained limestone characterize the middle unit. This unit is about 400 feet (122 m) thick.

The upper unit about 300 feet (91 m) thick is composed of maroon and green shale and maroon to pale orange sandstone. The bulk of the sandstone are in the lower half of the unit. A total thickness of 1,200 feet (365 m) is estimated for the Waynesboro.

Elbrook Formation

The Elbrook Formation is exposed in a broad, folded belt extending from northeast of Milldale southwestward to Woodland Park (Plate 1). A small area of the formation is exposed as a fault slice south of Dungadin Heights. Good exposures of the upper part of the formation occur in the valley east of Shenandoah Valley Golf Club. The middle part of the formation is exposed along the Shenandoah River across from Shenandoah Shores and east of the abandoned powerplant. The lower part of the formation is exposed on both sides of the valley parallel to State Road 606 south of Shenandoah Shores.

The lower contact is conformable with the Waynesboro and is placed at the upper, thick maroon shale of the Waynesboro and the lower, green to greenish-gray dolomite and dolomitic shale of the Elbrook. The upper contact is at the base of the lowest sandstone in the Conococheague and is also conformable. The thickness of the Elbrook is about 2,000 feet (610 m).

The lower 300 to 400 feet (91 to 122 m) of the Elbrook is composed of green to greenish-gray, fine-grained dolomite

(R-5612), dolomitic limestone, and shale. A thin, rusty brown weathering, calcareous siltstone marks the top of this unit. The bulk of the formation is composed of dark- to medium-gray, fine- to medium-grained limestone, dolomitic limestone, dolomite, and dolomitic shale. Bedding thickness vary from 0.5 inch (1.3 cm) to 2 feet (61 cm). The thicker beds weather ribbon-banded and on complete decalcification the dark argillaceous bands yield ocherous, shale-like chips. The thickness of this unit is about 1,200 to 1,300 feet (366 to 396 m). The upper 300-400 feet (91-122 m) of the formation is characterized by interbedded yellow-weathering, light-gray, laminated dolomite and blue, algal limestone.

Conococheague Formation

The Conococheague Formation crops out in a belt averaging 0.5 mile (0.8 km) wide extending from White Oak Level in the northeastern part of the county southwestward through Front Royal to the entrance to the Shenandoah National Park. Two additional areas of Conococheague occur in the southern part of the county; one east of Limeton and a small area east of Overall. Good exposures of the formation may be seen along the bluffs of the Shenandoah River east of Willow Brook, south of Horseshoe Bend, west of the abandoned power plant and in the fields northeast of Front Royal Junction.

In Warren County the Conococheague can be divided into four broad lithologic units of unequal thickness. The lower 200 feet (61 m) of the formation is designated the Big Spring Station Member (Wilson, 1952, p. 307-308); sandstone, dolomite, and dolomitic limestone similar to the member as described by Edmundson and Nunan (1973) to the northeast in Clarke County are present. The lower contact with the Elbrook is mapped at top of the interbedded laminated dolomite and algal limestone of the upper Elbrook. The upper contact of the Big Spring Station is gradational with other overlying limestone of the Conococheague. Lithologically, the member is composed of rusty-weathering, coarse-grained, calcareous sandstone (R-5909); bluish-gray, fine-grained, laminated limestone; dark gray, dolomitic limestone; light-gray fine-grained dolomite; and intra-formational conglomerate. The intraformational conglomerate contains flat, plate like limestone clasts in a fine- to medium-grained limestone matrix with algae and oolites.

Overlying the Big Spring Station Member is a unit about 600 feet (183 m) thick composed mostly of ribbon-banded limestone. The medium gray beds are composed of fine-grained limestone (R-5908). Dark-gray, silty dolomite bands stand out in marked contrast to the medium-gray limestone giving the rock a ribbon-banded appearance. Interbedded with the ribbon-banded limestone are edgewise conglomerate and limestone containing distinct siliceous laminae.

Limestone with abundant siliceous crinkly laminae forms the third unit which is about 800 feet (244 m) thick. The limestone is dark to medium gray and fine grained; siliceous laminae are readily apparent only on weathered surface. Thin intraformational conglomerate, ribbon-banded limestone, and medium-gray, medium- to fine-grained dolomite are present.

The bulk of the upper unit is composed of fine-grained, light gray, laminated dolomite with thin sandstone beds near the top. Interbedded with the dolomite is limestone with siliceous laminae and conglomerate. The upper contact of the Conococheague is placed at the top of the youngest sandstone or dolomite beneath the fossiliferous black limestone of the Stonehenge Formation. The estimated thickness of the Concocheague is 2,300 feet (701 m).

Ordovician System

Stonehenge Formation

The lower part of the Stonehenge Formation is exposed west of Rockdale near the junction of State Roads 658 and 661 in the hanging wall of a reverse fault that parallels Willow Brook. The upper part of the Stonehenge is exposed along State Road 661 beginning at Success and extending 0.5 mile (0.8 km) southeasterly along the road. A small elliptical are of uppermost Stonehenge is exposed 0.4 mile (0.6 km) west of where State Road 658 crosses Willow Brook. East of U. S. Highway 340 in the southern portion of the county a thin belt of poorly exposed Stonehenge occurs. A discussion of the Concocheague - Stonehenge contact is given with the Concocheague. The upper contact is placed at the base of the first thick, yellow-weathering dolomite of the Rockdale Run Formation. Interbedded with the dolomite are 4- to 6-inch (10- to 15- cm) thick beds of gray to white chert.

The lower 100 to 150 feet (30 to 46 m) of the Stonehenge has been termed the Stoufferstown Member (Sando, 1958). Lithologically, it consists of fine- to medium-grained, dark-gray to black limestone with thin, sheet like partings. The partings are crinkly due to cleavage where the beds have been folded. Thin, coarse-grained, bioclastic limestone is also present.

Above the Stoufferstown Members there is about 500 feet (152 m) of medium- to dark-gray and black, fine- to medium-grained limestone. Near the top of the unit siliceous laminae and algal structures are common.

Good fossils are not common in the Stoufferstown; however, thin beds of macerated fossil debris are common. The following were identified from the upper portion of the Stonehenge: *Finkelnburgia* sp. (brachiopod), *Dakeoceras* sp. (cephalopod), and *?Eccyliomphalus* sp. (gastropod) (F-892, F-896). Several additional gastropod species were present but were not identifiable. The total thickness is 600 to 650 feet (183 to 198 m) in the northern portion of the county. To the south along Overall Run the thickness is estimate not to exceed 350 feet (107 m).

Rockdale Run Formation

The Rockdale Run Formation occurs in a belt beginning 1.2 miles (2.9 km) north of Ashby and extending southwestward through Front Royal to Overall. North of Front Royal the belt averages about 1 mile (1.6 km) wide; south of Front the belt is narrower, averaging about 0.5 mile (0.8 km) wide. The upper part of the Rockdale Run is best exposed along Willow Brook 0.5 mile (0.8 km) southeast of Rockland; along the ridge east of Riverton Junction, and in the quarries of the Riverton Corporation (active quarry number ,; abandoned quarry numbers , ,). A good section of the formation is exposed on the Shenandoah River east of the Potomac Edison powerplant. Additional good exposures occur along the east side of the South Fork of the Shenandoah River at Camp Skymont, west of Dungadin Heights, and northwest and southwest of karo.

The lower contact of the Rockdale Run is placed at the base of oldest yellow-weathering dolomite underlain by dark-gray to black limestone of the Stonehenge Formation. The upper contact of the Rockdale Run in unconformable and is placed at the youngest massive dolomite overlain New Market or Lincolnshire lithologies.

The formation is composed of bluish- to dove-gray, fine-grained limestone; mottled and laminated dolomitic limestone; and medium- to light- gray; fine- to medium-grained dolomite. The mottled beds appear to be anastomosing networks of irregular rodlike bodies of dolomite in fine-grained darker colored limestone. Dove-gray mictritic limestone similar to the upper New Market is abundant in the upper 300 to 400 feet (91 to 122 m) of the Rockdale Run north of Front Royal. South of Front Royal the amount of dolomite in the formation increases (Edmundson, 1945; Rader and Biggs, 1975, 1976). Thin lenses of coarse-grained, dolomitic sandstone are found 1,200 feet (366 m) east of the Potomac Edison power-plant and on the ridge north of Rockland and west of Willow Brook. Thin lenses of chert are common near the base of the formation (R-5615).

The thickness of the Rockdale Run is estimated to be 2,400 feet (732 m). Locally fossils are abundant in lime-stone beds. They are rare in dolomite beds. Ceratopea sp, Eccyliomphalus sp., Hormotoma sp. (F-895, F-898), Lecanospira sp. (F-889, F-894), Ophileta (F-899), Orospira sp. (gastropods), and large coiled cephalopods (F-893, F-897) were found.

New Market Limestone

The New Market Limestone and overlying Lincolnshire Formation are mapped as a single unit because their outcrop widths are too narrow to be shown separately on Plate 1. They outline a major anticline and ossociated synclines and anticline parallel to U. S. Highway 340/522 north of Interstate Highway 66. Another major anticline outlined by the forma-tions extends from Kendrick Lane in Front Royal northward to about 0.9 mile (1.4 km) north of the Front Royal Country Club. A third belt of New Market and Lincolnshire extends to the southwest from west of the Skyline Caversn entrance to west of Overall. In the Limeton area this belt is repeated by faulting. The lower part of the New Market is well exposed near the farm pond on the west side of the South Fork of the Shenandoah River at Kings Eddy and in the draw across the river to the northeast. Two sections are exposed in an anticline 2.4 miles (3.9 km) south of Cedarville along U. S. Highway 340/522. The thickest New Market is exposed 0.3 mile (0.5 km) east on State Road 675 from the junction with U. S. Highway 340/522. Another thick section is exposed in the bluffs 0.7 miles (1.1 km) northwest of Karo.

The New Market unconformably overlies the Rockdale Run. A carbonate-pebble and -cobble conglomerate marks the basal contact of the New Market (Figure 9). A paleosinkhole is exposed 2,000 feet (610 m) N.60°E. of the junction of U. S. Highway 340/522 and State Road 658 at 150 feet (46 m) south of a farm pond. The upper contact is placed at the youngest dove-gray, micritic limestone below dark, medium-grained limestone of the Lincolnshire Formation.

Throughout most of the area the New Market Limestone can be separated into an upper high-calcium limestone and a lower impure limestone and conglomerate. The lower unit is composed of carbonate-pebble, -cobble, and -boulder conglomerate. The clasts are limestone and dolomite in a coarse sparry calcite matrix. The thickness of the conglomerate varies from 0 to 20 feet (6 m). Overlying the conglomerate is a series of thin-bedded, argillaceous, gray, fine-grained to aphanic, often bioturbated Limestone; the thickness varies from 0 to about 20 feet (6 m).

The upper unit is the high-calcium quarry stone of the Shenandoah Valley. This unit is composed of compact, thick-bedded, bluish- to dove-gray, micritic limestone that breaks with a distinct conchoidal fracture and weathers with a chalklike coating. Small, clear, rhomboid-shaped crystals of calcite are common, giving the limestone a bird's-eye appearance. Northwest of kara interbedded with the micritic limestone is a coarse-grained, gray, fossiliferous limestone (biopelsparite, R-6136). Bryozoan, ostracode, brachiopod, and gastropod fragments and pellets with a micrite rim comprise the framework grains. The cement is sparry calcite. The biopelsparite comprise only a very minor portion of the upper unit. Generally this unit contains 97 to 98 percent calcium carbonate (see Economic Geology section for chemical analyses). The thickness of the unit varies from 0 to 40 feet (12 m).

Because of the unconformable relationship with the Rockdale Run, the thickness of the New Market is highly variable. In the field behind the General Lee Motel, 0.8 mile (1.3 km) north of Cedarville, the New Market is locally less than 5.0 feet (1.5 m) thick. Along State Road 675, 0.3 mile

(0.5 km) west of Zion Church, the formation is about 60 feet (18 m) thick. North of Overall the New Market is locally absent. Gastropods resembling the genera Trechonemella and Lophospira and the small coral Tetradium syringoporiodes were found in several localities.

Lincolnshire Formation

The outcrop areas of the Lincolnshire are the same as those outlined for the New Market. The Lincolnshire is well exposed in quarries of the Riverton Corporation (Plate 1, active quarry number , abandoned quarry numbers); in the field east of the General Lee Motel, 0.8 mile (1.3 km) north of Cedarville; in the bluffs 0.7 mile (1.1 km) northwest of Karo; and in the small stream 0.7 mile north of Overall.

The lower contact with the New Market is placed at the top of the youngest, dove-gray, micritic limestone of the New Market and below the oldest, dark-gray, medium-grained limestone of the Lincolnshire. South of Front Royal the New Market is locally absent and the Lincolnshire unconformably overlies the Rockdale Run Formation. This stratigraphic sequence is well displayed at the locality north of Overall. In some areas the Lincolnshire is overlain by black, fissile shale and in other areas by interbedded black argillaceous limestone with only minor black shale. The top of the Lincolnshire is mapped at the base of either of the above lithologies. The upper contact is exposed on the east side of the north bound lane of U. S. Highway 340/522 0.4 mile (0.6 km) south of Cedarville.

The principal lithology of the formation is dark- to medium-gray, medium-grained limestone, (R-5616). Black and dark-gray, blàcky chert nodules and stringers are locally abundant. Interbedded with the dark limestones are thin beds of light-gray, coarse-grained, bioclastic limestone. The thickness of the Lincolnshire varies from about 25 to 100 feet (8-30 m).

Fossils are common to abundant in the Lincolnshire. Ramose bryozoans (F-891), ostracodes, trilobites, crinoid columnals, brachiopods, cephalopods, and algae have been found. Girvanella (algae) is so abundant in some beds that they comprise as much as 75 percent of the rock. The brachiopod _Dinorthis_ _atavoides_ is a good index fossil for the formation. In the upper 5 to 10 feet (1 to 3 m) of the Lincolnshire large straight cephalopods (?_Orthoceras_ spp.) are found; one specimen is about 3 inches (8 cm) in diameter and at least 1 foot (30 cm) long.

Edinburg Formation

Along the east limb of the Massanutten synclinorium the Edinburg Formation occurs in a northeastward-trending belt parallel to U. S. Highway 340 from the southwestern part of the county to the north center part. In the Limeton area the formation is repeated by faulting and north of Riverton and east of U. S. Highway 340/522 it is present in a long, narrow syncline. In the northwest corner of the county, along U. S. Highway 11 and in the adjacent fields the upper Edinburg is exposed. The most complete section of the Edinburg is exposed north of Riverton along the State Road 655 leading to the Riverton Corporation plant. Another good exposure occurs along the farm road 4,000 feet (1219 m) east of the end of State Road 673, about 1.1 mile (1.8 km) north-northeast of Limeton. In the valley north of Camp Skymont is a third locality of good exposures in the eastern belt. The Edinburg of the western belt occurs along U. S. Highway 11 and adjacent fields.

The lower contact is discussed with the Lincolnshire. The top of the Edinburg is placed at the base of the Oranda calcareous siltstone in the western belt and in the eastern belt north of Riverton. South of Riverton the top of the Edinburg is placed at the top of the youngest granular limestone loverlain by the a thick sequence of black Martinsburg shale.

In Warren County the bulk of the Edinburg is composed of two principal lithologies to which Cooper and Cooper (1946, p. 78-86) applied the names Liberty Hall and Lantz Mills. Nodular weathering dark-gray to black, fine-grained, argillaceous limestone of the Lantz Mill is the principal lithology in the western belt. Several metabentonite beds were noted in adjacent sections in Shenandoah County.

The upper 50 to 75 feet (15-23 m) of the formation in the western belt is composed of medium- to dark-gray, medium- to coarse-grained limestone and several thin beds of dove-gray micritic limestone. Cooper and Cooper (1946, p. 81) applied the name St. Luke Member to this unit. Small sink-holes are common in the St. Luke and serve as a distinctive marker where outcrops are sparse.

In the eastern black, fine-grained to aphanic, shaly limestone and black shale of the Liberty Hall are the principal lithologies. North of Riverton Lantz Mills lithology is interbedded with the Liberty Hall. The entire Edinburg south of Riverton is Liberty Hall lithology (Cooper and Cooper, 1946, p. 78). The St. Luke Member is not present in the eastern belt.

East of U. S. Highway 340/522 along State Road 655 leading to the Riverton Corporation plant and along Crooked Run, Cooper and Cooper (1946, p. 94) measured 435 feet (133 m) of Edinburg limestone and shale. This composite section appears to represent a reasonable thickness for the eastern belt. A complete section does not occur in the western belt in Warren County. However, in the adjacent Strasburg and Toms Brook quadrangle (Rader and Biggs, 1976) the Edinburg is somewhat thicker, averaging 500 feet (152 m).

Fossils are common to locally abundant. The Lantz Mill is abundantly, fossiliferous, the Liberty Hall less so, and the St. Luke sparsely fossiliferous. The forms most useful for identification of the Edinburg are Echinosphaerites aurantium (cystoid), Mastopora pyriformis (algae), and species of Resserella, christiania, and Sowerbyella (brachiopods).

Oranda Formation

The thickest development of the Oranda Formation occurs along U. S. Highway 11 east of Cedar Creek in the northwestern corner of the county. Along the east limb of the Massanutten synclinorium the Oranda is thin north of Front Royal. South of Front Royal a few thin beds similar to the Oranda are interbedded with the upper limestone beds of the Edinburg Formation. The best exposure of the Oranda is along U. S. Highway 11 east of Cedar Creek. Small outcrops of the formation occur 0.3 mile (0.5 km) north of the junction of Interstate Highway 66 and U. S. Highway 340/522 and along a farm road 0.8 mile (1.3 km) north of the junction.

The lower contact is discussed with the Edinburg. The upper contact is placed at the top of the youngest gray siltstone overlain by black argillaceous limestone and calcareous shale of the Martinsburg Formation.

The Oranda is composed of gray to brownish-gray calcareous siltstone; black, silty shale; dark-gray, calcareous mudstone; cobbly weathering, gray, fossiliferous and argillaceous limestone; and tan to brown metabentonites. The thicker metabentonites have thin silicified zones at the base which often contain trilobites, bryozoans, brachiopods, and cephalopods. North of Front Royal the Oranda consists of thin, coarse-grained, decalcified siltstone that weathers rusty brown and shaly.

Along the west limb of the Massanutten synclinorium the Oranda ranges from 50 to 60 feet (15 - 18 m) thick. North of Front Royal on the east limb the thickness does not exceed 15 feet (5 m).

Martinsburg Formation

The Martinsburg Formation occupies a broad northeastward trending belt east of Massanutten Mountain and west of the South Fork of the Shenandoah River and Crooked Run (Plate 1). Good exposures of the lower part of the formation occur along U. S. Highways 340-522 north of Riverton, in the shale quarry just north of Interstate Highway 66 (active Quarry No.), and along the north side of the South Fork of the Shenandoah River in the southern part of the County. Typical flysch deposits of the middle Martinsburg are exposured in the bluff along the North Fork and along State Highway 55 between Buckton and Waterlick. The upper fossiliferous sandstone is exposed along State Road 678 at the county boundary and along the Signal Knob trail. The lower contact is discussed with the Oranda. The upper contact is unconformable and is placed at the top of the medium-grained, brown, unfossiliferous sandstone that underlies the white sandstone and conglomerate of the Massanutten Sandstone.

The Martinsburg in Warren County may be divided into three lithologic units (in ascending order): black shale (slate) and limestone, sandstone and shale, and sandstone. The lower unit consists of 200 to 250 feet (61-76 m) of black, aphanic, argillaceous limestone; black, calcareous shale (slate); and thin, tan metabentonites. The bulk of the formation in the Massanutten synclinorium is a typical flysch sequence (Unit 2) of alternating shale and sandstone. The shale is olive green, brown, and greenish gray and silty in units ranging from 1 inch to 5 feet (2.5 cm - 1.5 m) thick. The lithic sandstone is olive green to gray, rusty weathering and fine to medium grained. Thin-section examination reveals quartz (monocrystalline), chlorite, sericite, calcite, dolomite, chert, limonite, and rock fragments (siltstone, polycrystalline quartz, and chert). The framework grains are subangular to subrounded. Graded bedding, flute casts, and current ripple laminated layers are common. Because of complex structure and the lack of marker beds, the thickness of this unit is estimated at more than 2,800 feet (835 m). Overlying the flysch sequence is a sandstone (Unit 3) about 170 feet (51m) thick. The lithic sandstone is brown, medium grained, rusty weathering and the lower 100 feet (30 m) is fossiliferous. The upper 70 feet (21 m) is unfossiliferous and thought to be nonmarine by Secrist and Evitt (1943). The total thickness of the Martinsburg is estimated to be more than 3,200 feet (975 m).

The lower unit is moderately fossiliferous containing trilobites (*Cryptolithus* and *Isotelus*), gastropods (Sinuites), and graptolites. The flysch sequence is sparsely fossiliferous containing trilobites, bryozoans, gastropods, and brachipods. Along Passage Creek at the county boundar, Secrist and Evitt (1943) described a Maysville age fauna above the flysch sequence which they called the Passage Creek faunal zone.

Included in this zone are graptolites, bryozoans, brachiopods, pelecypods, gastropods, cephalopods, and trilobites.

Silurian System

Massanutten Sandstone

The Massanutten Sandstone forms the northeastward-trending mountains of the Massanutten synclinorium along the western boundary of the county (Plate 1). Good exposures are present along the crest of Massanutten Mountain and along State Road 678 and Passage Creek just across the county boundary in Shenandoah County.

The basal contact with the Martinsburg is unconformable. It is placed at the top of a medium-grained, brown, unfossiliferous sandstone that underlies the white sandstones and conglomerates of the Massanutten. The upper contact is not exposed in Warren County. To the west along Passage Creek in Shenandoah County the Bloomsburg overlies the Massanutten (Rader and Biggs, 1976).

White quartz sandstones and quartzites that are locally conglomerate are the major rock types. Cross beds are intermediate- to high-angle. Subangular to angular framework grains range from 0.5 to 1 mm. Quartz cement comprises less than 10 percent of the rock. The interlocking grain boundaries indicate that the grains have been pressure welded. Thin, black, organic-appearing, sandy shales are present at the top of the many of the fining- upward sequences. Neamatophytes (plants) from 13 horizons along Passage Creek (Shenandoah County) have been reported (Pratt and others, 1975). Only the lower 200 feet (61 m) of the Massanutten Sandstone occurs in Warren County. This portion of the formation is roughly equivalent to the lower Tuscarora Formation of the western Valley and Ridge.

Dikes

Igneous intrusives with dike-like form of three distinct compositions occur in Warren County: (1) amphibolite dike; (2) metabasalt and (3) mica peridotite.

Three amphibolite dikes intrude the Precambrian layered gneiss south of Linden. The amphibolite is composed of actinolite with or without plagioclase and accessory chlorite, epidote, and sphene. Lukert and Nuckols (1976, p. 26) report that the enclosing rock has not been altered by the dike intrusion.

Two metabasalt dikes are mapped south of Linden where they intrude the layered gneiss. West of the Blue Ridge in the Browntown area several metabasalt dikes intrude the Pedlar. These dark-grayish green aphanitic dikes are composed of lath-shaped plagioclase with chlorite and magnetite. Phenocrysts of plagioclase are common in some of the dikes. Zonal alteration of the enclosing rock was observed at Boyds Mill. The dike at this locality is a porphyritic metabasalt (R-). Zone 1 (closest to the dike) is a light gray to white, coarse-grained, pegmatitic-appearing rock composed of microcline, quartz, plagioclase, garnet and graphite (R-). Zone 2 is gray, medium- to coarse-grained rock composed of plagioclase, quartz, titanium-rich biotite, garnet and magnetite (R-). Zone 3 is a greenish-gray, coarse-grained rock composed of plagioclase, microcline, quartz, titanium-rich biotite, and magnetite (R-).

Beyond zone 3 the enclosing rock is the typical quartz monzonite of the Pedlar.

Mica peridotite intrudes the Martinsburg Formation 2.8 miles (3.5 km) S. 11 E. of the junction of State Highway 55 and State Road 678 at Waterlick. The following minerals were reported by Young and Bailey (1955) and Rader and Biggs (1976): chlorite, phlogopite, hydorbiotite pseudomorphs after olivine and pyroxene, pyrite perovskite, leucoxene, apatite, dolomite, ankerite, ilmenite, magnetite, epidote, quartz, serpentine (?), garnet, rutile, talc, and calcite (R-6137, R-6184, R-6185). Soil samples collected over the highly magnetitic portion of the dike were analysed for zinc, lead, copper, chromium, nickel, calcium, and magnesium by atomic absorption (Rader and Biggs, 1976).

Quaternary System

Surficial deposits mapped (Plate 1) include flood plain alluvium and terraces. Alluvial fans adjacent to valley streams are included with terraces; those on hill and mountain sides with colluvium. Colluvial deposits interpreted from aerial photographs and those mapped in the Front Royal and Strasburg quadrangles are shown diagrammatically on Figure ______.

Colluvial Deposits

Continuous to scattered deposits of rock and soil with rock fragments moved downhill mainly by gravity occur along the sides of the Blue Ridge, Dickey Ridge, Massanutten Mountain and foothills of the Blue Ridge such as Brush Mountain and Green Hill. These mostly consist of angular cobbles and boulders (64-256 mm+). Along the Blue Ridge the slopes are covered with fragments of greenstone, unakite, epidote, and flow breccia derived from the Catoctin and some granite from the Pedlar formation. Massanutten Mountain has numerous talus deposits of white quartz sandstone, quartzite, and quartz-pebble conglomerate, many of which because of their sparse tree cover are quite visible to the west from U. S. Highway 340. These talus deposits often merge downslope into alluvial fans which have a similar composition but with the interstices being sand and soil filled. Green Hill and Brush Mountain have fragments of quartzite and quartz sandstone.

Some colluvial material appears to have been moved downslope during times of heavy rainfall as debris avalanches. There are three of these on Gimlet Ridge to the west side of State Road 631 about 4000-feet (1.2 km) southwest of its intersection with State Road 613. Colluvial deposits vary in thickness from 0-25 (0-7.5 m).

Terraces

Adjacent to the North and South Forks of the Shenandoah River are numerous occurrences of fluvial terrace deposits. These usually produce flat-topped landforms. Deposits are more continuous adjacent to the river; scattered areas occur on hills and ridges up to 1.5 miles (2.4 km) from the river. As many as three levels of terraces may be present; the higher terraces are considered to be the oldest. Deposits range from as high as 450' (135 m) above river level in the Bentonville area downstream to as high as about 200' (60 m) near Milldale. Scattered terraces occur adjacent to Manassas Run, Happy Creek, Passage Creek, and Flint Run.

The surface layer usually consists of scattered pebbles to cobbles size round stones of quartzite and quartz sandstone. Terraces adjacent to igneous rocks also have some igneous and metamorphic materials. In some areas such as The Point West of Karo deposits are thin and discontinuous but as the landform is suggestive of a terrace they may have been removed by erosion. In general the higher terraces have larger size roundstones, up to 3 feet (0.9 m) in diameter, than the lower. Deposits range in thickness from 0-25 feet (0-7.5 m).

Between Dungadin Heights and Limeton there are three main areas of ironstone breccia consisting of angular fragments from 0.2 to 10 inches (0.5 to 25 cm) of silica and iron oxide (Plate 1). In the southern-most area the breccia consists of cryptocrystalline orange and red jasper. Scattered occurrences are also found between Limeton and Overall mostly associated with terrace deposits.

Good exposures of terraces can be seen along State Road 638 adjacent to Shenandoah Farms, State Road 619 west of the South Fork Shenandoah River, and U. S. Highway 340 between Limeton and Bentonville. Multiple terrace levels occur along State Road 624 between Morgans Ford and the underpass with Interstate Highway 66.

Alluvium

Flood-plain deposits occur in broad areas along the Shenandoah River and all its major tributaries. These consist mainly of fine-grained, dark-brown quartz sand and silty clay; pebble-size fragments of quartzite and sandstone are scattered through the deposits indicating former stream channels. Roundstones are common in the present channels ranging up to boulder size near mountainous portions of the county. Cobbles and silty clays are preserved in cut-off meanders northwest of Waterlick. Drill holes at Bentonville Landing, Riverton, boat ramp, and Morgans Ford indicated from 15-20' (4.5-6.0 m) of alluvium along the Shenandoah. Tributaries have thickness of 0-15' (0-4.5 m).

Geomorphology

Warren County is bounded on three sides mainly by rugged ridges and foothills of the Blue Ridge and Massanutten mountains. South of Front Royal the South Fork of the Shenandoah River and its tributaries have eroded hills and mountains of diverse orientations and shapes. To the north in areas drained by the Shenandoah Rivers and its North Fork northeast-southwest direction. The county is located in two physiographic provinces, the Blue Ridge and to the west of it the Valley and Ridge. Within these six separate topographic areas have been delineated to describe the landforms there (Figure). Major drainage basins of the Shenandoah River, which drains the entire county, include those of Flint Run, Gooney Run, Happy Creek, Manassas Run, Crooked Run, and Passage Creek. Elevations range from 3474 feet on Hogback Mountain at the southern limit of the county, generally becoming less northeastward, to 420 feet along the Shenandoah River at the northern limit near Treasure Island. The greatest amount of relief is along the Blue Ridge and Massanutten Mountain. Flatter areas occur in the floodplain and along tops of terraces of the Shenandoah River and its forks and in the area roughly bounded by the communities of Front Royal, Milldale, and Nineveh. Scenic natural features of the county include Greasy Falls, overlooks along Skyline Drive in Shenandoah National Park in the Blue Ridge, Skyline Caverns, Signal Knob, Buzzard Rock and Passage Creek water-gap in Massanutten Mountain, and bluffs and meanders of the Shenandoah River. Mans use of the land as influenced by the type and location of landforms is shown by the position of Front Royal at the confluence of the forks of the Shenandoah and by the location of major highways in gaps in the mountains.

Characteristics of Landforms	Bedrock Lithology	Average Slope*	Drainage	Comments
1 Mountains with long linear, steep-sided, high flat-topped ridges oriented mainly north-south, north-east-southwest, northwest-southeast; valleys narrow and "V-shaped", broader along perennial streams	Green, gray greenstone; purple phyllite; green epidosite; interbedded metasediments; greenish-gray granodiorite in Compton Gap area	steep; sloping near top of some ridges; some perennial streams with nearly level wide, flood-plains	Compton Gap south area numerous, straight steep-gradient intermittent streams flowing into tributaries of south Fork Shenandoah River; Compton Gap north area: scattered meandering, low-gradient, perennial streams with tributary intermittents flowing into Shenandoah River Mostly boulders and cobbles in channels in both areas	Area in Blue Ridge and foothills, mostly wooded; rough country to traverse except along perennial stream courses; slopes usually quite rocky with some steep cliffs; with scattered springs
2 Hills with long rather continous linear, steep-sided, medium-height ridges oriented mostly northeast-southwest; separated into different lenght segments by cross-cutting streams; valleys aligned either parallel or perpendicular to ridges	white, gray quartzite; gray phyllite; gray quartz-pebble conglomerate	steep, sloping near bottom of some ridges	Bentonville area: numerous straight, low-gradient, intermittent streams flowing into tributaries of South Fork Shenandoah River Front Royal area and northeastward: scattered, low-gradient perennial and intermittent streams often with right angle bends in channel direction which flow into Shenandoah River;	Rugged, wooded country; where present are western-most foothills of Blue Ridge; easiest route of traverse is through watergaps in ridges

	Characteristics of Landforms	Bedrock Lithology	*Average Slopes	Drainage Features	Comments
				channels with boulders cobbles and sand in both areas	
3	Hills, long to short, linear to non-oriented, rolling with broad valleys; adjacent to Shenandoh River and its forks are scattered broad, flat-topped, steep-sided hills	gray limestone with gray to tan dolomite and some gray sandstone and black, red, and green shale	Gently sloping, near streams may range up to steep; broad floodplains of major streams almost level	Front Royal north: mostly drained by meandering low-gradient (except near rivers) intermittent streams which flow into Shenandoah River Front Royal south: mostly drained by meandering, low-gradient, perennial streams and tributary intermittents streams which flow into South Fork Shenandoah River; some rapids in Shenandoah River from resistive bedrock channel content of both areas mostly sand	Mostly cleared land used for farming; with scattered linear rock outcrops; with scattered sinkholes, numerous near Shenandoah River and its South Fork; long, broad valley of interior drainage east of Rockland
4	Hills, relatively short linear to arcuate, oriented mostly north-east south-east, highly dissected, with broad "U-shaped" vallleys; along South Fork Shenandoah River and west of Flint Run are scattered, broad, flat-topped, steep-sided hills	Greenish to gray shale and sandstone	Steep to sloping sides with nearly level tops; broad flood-plains of major streams almost level	Straight to arcuate low-gradient perennial streams with numerous intermittent tributaries; channel content mostly sand except for streams draining mountains which have cobbles, boulders & sand; numerous rapids in Shenandoah River forks from resistive bedrock	Partially cleared land use for farming

Characteristics of Landforms	Bedrocks Lithology	*Average Slope	Drainage	Comments
5 Mountain, long, high crest with numerous long, linear steep-sided ridges oriented mainly at right angles to crest with "V-shaped" intervening valleys	Greenish to gray shale and sandstone; gray quartzite and sandstone	Steep near crest and along drainages; along ridges varies from steep near mountain crest to gently sloping near end of ridge	Numerous branching intermittent streams with steep gradients which flow either into the Shenandoah River or its tributaries; channels with boulders and cobbles; usually with alluvial fans at confluence with tributaries and in lower parts of streams where gradients are lower	Almost entirely wooded; slopes usually quite rocky, especially in higher elevations; rugged terrain with traverse limited mainly to gaps; many, steep, rocky cliffs near crest which grade downslope into talus deposits and alluvial fans
6 Hills high, linear to diversely oriented, steep-sided and mountains with broad "bowl-shaped" valleys and narrow long steep-sided hollows and ridges	Greenish-gray granodiorite with some greenstone dikes	Steep; some low ridges gently sloping; broad floodplains almost level	Browntown area: drained entirely by Gooney Run which has numerous meandering perennial tributaries of low-gradient in the valleys but steeper in their mountainous headwaters; lower part of Gooney Run deeply incised. Bentonville area: perennial and intermittent streams of low gradient which drain into Flint Run. Dungadin Heights area: linear intermittent streams with moderate	Lower elevations cleared for farming and housing; limited amount of bedrock exposed

Characteristics of Landforms	Bedrock Lithology	*Average Slope	Drainage	Comments
			gradient which flow into South Fork Shenandoah River. channel deposits of all areas mostly sand except in headwaters which have boulders and cobbles	

Engineering Geology of Warren County

by

Roy Murphy and Howard Freeland

Introduction

Engineering Geology, or Geological Engineering, is the science of applying geologic knowledge of the earth to the everyday construction efforts of mankind. The profession utilizes principles from soil and rock mechanics, civil engineering, agronomy, economic geology, mining, geophysics, geodesy, cartography, hydrology, chemistry and environmental science. Knowledge from these disciplines are used to evaluate problems and make subsequent recommendations in the areas of resource development, industrial growth, land use planning, agriculture, recreation, housing, water procurement and storage, solid and liquid waste disposal, transportation and environmental hazards. The last twenty years, in particular, have seen much geologic input in the accelerated highway construction program. Now, more than ever, Federal, state, and local governments, as well as private industry, need to utilize persons trained in such a multi-disciplinary field. The expense and difficulties involved in construction today dictate being right on the first effort. Future efforts in building construction, sanitation, raw materials procurement and benifaction, land use planning, and even civil defense, should receive geologic consideration.

Despite all the uses of geologic information flexibility in application should be the rule. The parameters of geologic data are usually fairly wide and variable. Agronomy students are taught in the study of soils that they are dynamic systems. This is also true of rocks and other natural bodies. Though the parameters of a rock unit may change slowly with time, these characteristics may vary greatly along the strike and across the dip. Local areas of different deposition, non-deposition and weathering can also be noted. If the environment has remained essentially constant a geologic unit may change character in terms of thousands, or even millions of years. On the other hand, an environmental change can produce different characteristics in as short a period as one to three. For example, a fresh sample of rock may be very sound and durable; but after exposure to several freeze-thaw cycles, mild acidic waters or mechanical manipulation, the resulting product may be a loose, easily fragmented rubble or a reduced load-bearing clay. This one type problems has caused great expense to Virginia taxpayers and corporations in the western region of Virginia.

Such awareness of the parameters of geologic units is required in slope design and foundation work. Many articial rock-soil slopes and foundations of structures have experienced distress, and even failure, due to unexpected weathering and a loss of upward lift by buoyancy forces. The former can be characterized by raveling, block-failures, soil flows, and even cataclismic landslides. The latter is produced by a drop in the local watertable, subsidence of a hidden solution cavity, gradual dissolution of a clay-bearing rock, or plastic flow of a clay. In contrast, the raising of the watertable can also cause problems and damage if a structure is not constructed to allow for it. The least serious problem would be simple flooding of a basement. There are numerous cases in the literature of the watertable rising through the elevation of septic fields and causing not only odorous, annoying overland flow, but pollution of lower elevation surface and subsurface water supplies and, therefore, a threat to regional health.

Even in apparently solid rock, as is found in some highway cuts, a knowledge of the geologic unit, the orientation of the unit to the roadway, the desired steepness and the degree of internal strength of the rock are needed items of information. This information is essential not only because of construction design, but in order to make economic calculations for the amount and type of drilling required, the type of explosive and powder factor, and the play-off of costs involved in construction, right-of-way acquisition and maintenance. Even if all factors, except the power factor, are controlled, heavier powder loads than necessary will produce a ragged, weakened slope. Sometimes, on the other hand, a geologic investigation can eliminate the need for drilling and blasting completely. This can be important in urban areas and near such sensitive structures as hospitals, nurseries, old buildings, museums, poultry farms, etc.

When constructing a road cut, or any other artifical slope, the greatest chance of producing a stable surface occurs if the drill holes are oriented as near to perpendicular to the bedding as possible, except in cases where the natural bedding angle to the horizontal is compatible with design. In other words, for a roadway cut through an area where bedrock dips 60°SE, the northwest side should be drilled and cut parallel to bedding; whereas, the other side should be designed within 30° to 60° of the horizontal or 90° to 60° with the bedding plane. The actual degree chosen would depend on the continuity of the rock, weathering characteristics, and expertise of the builder. Remember though that even the best design can be ruined by overblasting. Slope maintenance cost approximately $5,400 in Warren County during the year 1975.

In addition to data concerning rocks, a presentation of data concerning the overburden is helpful. Such characteristics of a soil as its liquid limit, plastic limit, plasticity index and california bearing ratio are subject to change with chemical effects and long time duration; but for the immediate future, they are valid. The parameters presented in the section on engineering characteristics are indicators of the suitability of an area for roads, parking lots, building sites, resevoirs and other purposes. For purposes of borrow material, or even ceramic clay procurement, the liquid limit, and plasticity indexes are particularly helpful. The educated evaluation of the data yields indications of places where soil benifaction, for strength, is required. The classification alone, though here primarily intended for engineering guidelines, also indicates soils where septic fields, sewage lagoons, or farm ponds would be difficult, or impractical, to construct and maintain.

The depth to bedrock and nature of the overburden is further helpful in selecting safe foundations and building sites. Even a natural slope which has been stable for 100 years can be treacherous in periods of excessive rainfall. During the floods of August, 1969, in Nelson County, many structures built on hillsides, as well as those in the flood plains, were destroyed. Thick deposits of broken rock and soil upslope from homesites were activated by the unusual rainfall. Several bridges and culverts with inadequate foundations were total losses not due to flood debris, but due to being washed away.

Where small structures are concerned, knowing the overburdern conditions aids in the cost predictions of deep construction for permanence versus replacement. This is becoming increasingly important in cases where structures must be built in a flood plain.

The data presented in the section on engineering characteristics are extracted from the Virginia Department of Highways and Transportation Materials records accumulated over a twenty-year period. Therefore, specific data relative to any one type problem may not be found in the information. Also, as the testing was done relative to many projects over the years, some test results are pertinent to 1950 standards and others valid for the 1970's. As mentioned previously, flexibility in interpretation should be used in applying the data. Though the writers have attempted to collect as much information as possible, the full series of tests were not performed on all units. Despite the information that is available, there is not substitute for current study and testing dedicated to each modern situation. As a small example, a tested sandstone unit may be very hard one place and contain a weathered carbonate cement another place, therefore, being much weaker. Today's creations need to be built with today's research.

DEFINITIONS

CBR - California Bearing Ratio. A unit of measurement based on a materials soaked strength as a subgrade material. Test procedure and discussion to be found in AASHTO Specifications, Part II, T 191-72, 11th Ed., 1974, pp. 640 to 645.

AASHTO - American Association of State Highway and Transportation Officials. Used in this context is the title for a classification of highway subgrade materials based on gradation, liquid limit, plastic limit and plasticity index. Refer to Highway Materials, Krebs, R. D. and Walker, R. D., 1971, McGraw-Hill, Inc., pp. 109 to 116.

Overburden - In this context overburden includes all the rock or soil material overlying bedrock including any saprolite or $<$ 50 hammer blow SPT material. Fifty blow plus material may also be considered as overburden if bedrock does not underlie it.

SPT - Standard Penetration Test. Procedure and details found in T 206-74, AASHTO Specifications, Part II, 11th Ed., 1974, pp. 694 to 696, or any engineering field manual. Test is used to determine an indication of the support strength of a soil strattum based on its resistance to penetration.

Los Angeles Abrasion (LA) - An aggregate test for quality found in T 96-74, AASHTO Specifications, Part II, 11th ed., 1974, pp. 287 to 290.

Soundness Loss - An aggregate quality test using chemicals and wet-dry cycles in order to determine a rock's resistance to weathering. T 104-74, pp. 317 to 321.

Liquid Limit
Plastic Limit - Two soil characteristics determined as part of the Atterburg Limits. Complete description of test procedure found in Lambe, T. W., 1951, Soil Testing for Engineers, John Wiley & Sons, New York, or T-89-68 and T-90-70.

Drill data is based on the use of a skid-mounted, medium weight, rotary drill with a down pressure of approximately 450 psi.

Acid Insoluble Residue (AIR) - A test used on carbonate rocks to determine the percentage of non-carbonate material present, the test is an indicator of the skid resistance of a surface course aggregate for highway construction. See D 3042-72, American Standard Test Method, for details.

Strike - The trend of an inclined rock unit or a level surface.

Dip - The angle between a rock layer or bed and a horizontal plane.

Pre-split Slope - Rock cuts that are drilled at regular spacing and proper attitude before a relatively light explosive charge breaks away the rock into an excavation. A smooth, uniform slope should be produced.

Pinnacles - An irregular rock-soil contact where towers of relatively fresh rock protrude into overburden.

Drilling Rates - The time needed to penetrate a rock unit using a skid-mounted rotary drill with a tri-cone roller bit. This rate has been determined by a combination of drilling experience and estimated drilling rates as given by T. N. Williamson in Surface Mining, The Maple Press Company, York, Pennsylvania, 1972, pp. 320 to 321.

Aquifer - A unit of rock or soil that contains enough ground water to supply either domestic or commercial needs.

Kaolinite - A two-layered clay mineral family which are usually fairly unreactive with the addition of water though they possess a high shrinkage ratio. They are platy and have a low base exchange capacity.

Illite - A commonly used name for a group of three-layered clays which are bonded together by potassium ions. These clays do possess a moderate base exchange capacity and are known to be expansive when wet. The liquid limit and plastic limit are usually only moderate though sodium, potassium and calcium species can be higher. The shrinkage ratio is usually approximately 15 percent in a pure clay. (Lambe and Whitman, 1969)

Montmorillonite - A group of clay minerals having a three-layered structure and a thickness of 10 .

These minerals have the ability to expand greatly with the addition of water. They further possess high liquid limits and plasticity indexes.

Vermiculite - A three layer structured clay with layers bonded by magnesium ions. This clay expands greatly when heated.

Chlorite - A group of clay minerals which are approximately 14 thick and possess three layers and occurs as either an expansive or inexpansive variety.

Breccia - A rock that is composed of cemented, angular fragments.

Dolomite - A sedimentary rock composed of calcium-magnesium carbonates.

Joint - A rock fracture that has not experienced movement.

Powder factor - The percentage of weight of explosives vs. weight of rock needed to excavate a particular rock. The ratio varies according to rock internal strength.

Water Table - The upper surface of a zone of saturation within the earth.

Bedding Thickness

Laminated	- Less than 1/2"
Thin	- 1/2" to 2"
Medium	- 2" to 2'
Thick	- 2' to 4'
Massive	- Greater than 4'

Dip Attitude

Gentle	- 1° to 20°
Moderate	- 20° to 45°
Steep	- 45° to 90°

Criteria for Cut Slope Stability

Gentle (Soil Slope)	- 2:1 to 3:1*
Moderate	- 2:1 to 3/4:1
Steep	- 3/4:1 to 1/4:1
Pre-split	- Vertical

*Measured 2 units along X axis and 1 unit along Y axis.

Depth of Overburden

Shallow	- Less than 2'
Moderate	- 2' to 10'
Deep	- Over 10'

Engineering Characteristics

Name: Pedlar formation

Description: Commonly consists of quartzo feldspathic granulite and altered greenish, or bluish, hypersthene granodiorite.

Bedding: Normally thick to massive

Fracturing:

Weathering: Highly resistant, usually weathers to a shallow depth except on the leading edge of thrust faults. The loose material will consist of large rectangular blocks with a thin overburden.

Topography: The formation forms steep escarpments and foothills.

Ease of Excavation: Always requires explosives. Drilling rates are slow and bit life short. Expected rate as low as 0.2 ft./hr with EW or AW bit.

Cut Slope Stability: Good, except in areas of open or soil filled joints where cleavage and/or fracturing is toward the open cut.

Foundation Stability: Usually excellent, should be excavated to fresh material. Exceptions are on the leading edges of over thrust faults.

Construction Usage: Excellent for all highway use but prohibitive due to severe crusher jaw wear and abrasiveness. Excellent for rip-rap, building stone and fill material.

Rock Test Data:	L. A.:	22.1 - 28.9	(7 tests)
	S. G.:	2.66 - 2.81	(7 tests)
	Soundness:	3.8 - 12.6	(5 tests)
	Absorption:	0.4 - 1.25	(5 tests)

Overburden Data: None available

Geologic Hazards: None reported

Name: Catoctin formation

Description: Fine grained, greenish gray metabasalt with sporadic beds of metasediment, usually phyllite.

Bedding: No bedding as such, however cleavage due to tectonics has strong local development moderate to steeply dipping. Metasediment layers usually thin to flaggy.

Fracturing: Cleavage and jointing produce plates and irregular blocks. Locally such features are highly abundant, closely spaced and irregular, usually steeply dipping and may or may not be mineral filled. Common filling materials are quartz, epidote, chrysotile asbestoform, and actinolite-tremolite. Local instances of columnar jointing are encountered. Common joint sets are N75°E and N45°-55°W.

Weathering: Highly resistant, moderate weathering producing shallow overburden of hackly, broken fragments of rock. The metasediment beds weather more deeply, up to 70 ft.

Topography: Rough steep sided mountains with high relief, farily stable slopes when undisturbed.

Ease of Excavation: Requires explosives. Slow drilling rates and low bit life with rotary equipment. Normal bit life 100-200 ft., but as low as 3 ft. in quartz or epidosite veins.

Cut Slope Stability: Variable depending on orientation of the cut relative to regional trend and cleavage. Moderate slopes may be necessary. Full field study required.

Foundation Stability: Excellent for heavy structures so long as fresh material is encountered.

Construction Usage: Road stones, both base and surface course aggregate; rip-rap and fill. It has been used for dimension stone.

Rock Test Data: a. Los Angeles Abrasion, $\frac{\text{A } 15.1}{13.6}$ $\frac{\text{Grade B } 12.0}{18.0 - 18.8}$ $\frac{\text{Grade C } 13.3}{17.8\ 14.9\ 14.5}$

b. Specific gravity - 2.75 to 3.31 depending on local mineralization (25 tests)

c. Acid insoluble residue - 99 - 100%

d. $Mg\ SO_4$ 0.73 - 3.14, 6.6, 7.6

e. Compressive shear 9,800 psi - 62,100 psi (25 tests)

f. Shear angle 44° to vertical (25 tests)

g. tensile strength 250 psi to 1930 psi (25 tests)

h. absorption 0.21 to 4.09, 0.3 (25 tests)

Overburden Data: a. depth 5 - 19 ft.

b. Standard Penetration test - 12 to 50 far less than 1' (50 tests)

c. Optimum moisture range - 12% to 22% (6 tests

Overburden Data: (continued)

d. CBR range - 1.3 to 18.8 (6 tests)

AASHTO

e. Class range - A-6 (4) to A-7-6 (18) clay soils (6 tests)

f. Liquid Limit - 28.3% to 46.5%

g. Plastic Limit - 20.1% to 30.3%

h. expansion index - 0.6% to 4.6%

Geologic Hazards: Rockfalls, variable competence of horizons

Name: Weverton formation

Description: Five (5) separate units ranging upward through clayey, sandy, quartz pebble conglomerate; laminated phyllite and conglomerate phyllite; olive-gray sub-arkose; silty phyllite with lithic sandstone and quartz-pebble conglomerate. Units are frequently gray to purplish- gray and constitutents are poorly sorted.

Bedding: Usually thick and irregular.

Fracturing: Highly abundant; moderately to closely spaced, with one irregular; moderately to closely spaced , with an irregular pattern. Often the fracturing is more pronounced than bedding.

Weathering: The phyllites and conglomerates tend to be moderately resistant particularly to aerial weathering. The clayey conglomerates and feldspathic sandstone units are less resistant particularly when frequently wetted. Soil ~~month~~ is generally thin.

Topography:

Ease of Excavation: Blasting required in siliceous cemented portions of quartz pebble conglomerate and occasionally in other members. Usually heavy equipment is sufficient. Rotary drilling rates should range 1.5 to 20 fph in softer units and 0.2 to 1.0 ft. in very hard layers.

Cut Slope Stability: 3:1 to 1:1 slopes usually required due to rapid weathering. Each area should be checked before final design is established.

Foundation Stability: Generally good, though weathered portions should be excavated due to the frequent presence of hydrous micas.

Construction Usage: All the units may be used for fill. Only the more siliceous units are suitable for rip-rap.

Rock Test Data: a. L. A.

b. S. G.

c. A. I. R. - non-calcareous

d. Mg SO_4

e. Compressive shear

f. Shear Angle

g. Tensile Strength

h. Absorption

Overburden Data: a. SPT

b. OM 13.8 - 24.7 (3 tests)

c. CBR 18.2 - 52.6 (3 tests)

d. AA SHTO A-4 (1) or A-4 (4) (3tests)

e. LL 22.8 - 47.0 (3 tests)

f. PL 0-32.4 (3 tests)

g. exp. index 0.1 (1 test)

Geologic Hazards: If cut on too steep a slope the unit is unstable due to the high percentage of clay minerals in the matrix. These same minerals also cause foundation problems and dust control problems during construction.

Name: Harpers Formation

Description: Pelitic phyllite and silty to sandy, fine grained phyllite overlain by quartzite, sandstone and meta-arkose. Lower member contains light bluish-gray, brick-red, tan and pink phyllite that weathers to bronze-colored chips. Upper member contains sandstone, quartzite and ferruginous metasandstone.

Bedding: Fissile to massive depending on lithology.

Fracturing: Unit often possesses a southeast dipping fracture cleavage and jointing; such a system is disturbed but well developed, and locally and irregularly. Such fracturing is usually open producing a rovelling slope.

Weathering:

Topography:

Ease of Excavation: Moderately easy with heavy power equipment, especially in areas of high sericite and chlorite mineralization. Unweathered sections generally require blasting as do the quartzite beds and conglomerates. Drilling rates from 0.15 to 20 ft./hr. should be expected, based on the lithology penetrated.

Cut Slope Stability: 3:1 to 1:1 slopes generally acceptable depending on lithology and local structure. Some rovelling and fall-out to be expected with steeper slopes.

Foundation Stability: Good quality foundation material. In fills soil specifications should be used. Sometimes difficulty will arise in obtaining proper density due to mineralization.

Construction Usage: Good for fill and road material. Sandstone units could be a potential source of non-polishing aggregate.

Rock Test Data:

Overburden Data: a. SPT

b. OM 14.1 - 29.6 (8)

c. CBR 0.3 - 23.8 (8)

d. AASHTO A-4 (1), A-7-5 & A-7-6 (8)

e. LL 22.8 - 62.0 (8)

f. PL 0 - 40 (8)

g. Exp. index 0 - 9.5 (8)

Name: Tomstown formation

Description: A high magnesium unit, of light to bluish, fine to medium grained dense dolomite constitutes the upper 2/3's whereas an impure blue limestone with yellow shale partings occupies the lower portion.

Bedding: From 0.5 in. in the yellow shaley zone to moderately thick bedded, or massive.

Fracturing: Usually moderately to well developed joints steeply to vertically dipping; moderately abundant but frequently irregularly spaced.

Weathering: Moderately resistant, particularly in the high magnesium upper portion. Mantle is usually thin and the mantle-bedrock interface is irregular with occasional prehistoric sinks.

Topography:

Ease of Excavation: Requires blasting, pinnacles present special problems. In the harden upper units drill rates of 0.5 to 1 ft./hr. can be expected.

Cut Slope Stability: Stable if cut is perpendicular to structure.

Foundation Stability: Good quality for heavy structures if solid rock is encountered. The presence of sinkholes and pinnacles makes a foundation investigation necessary.

Construction Usage: Excellent for fill material, road material, rip-rap, concrete aggregate. Hardness of high magnesium dolostone units causes high crusher wear.

Rock Test Data: a. L. A. 18.4, 28.1, 20.0, 29.9, 21.2

(7 tests another Co. 14.9 - 21.6)

2.64 (1) 2.82

b. S. G. 2.85 - 2.74, 2.71 (13 tests in Fred. Co. 2.83 - 2.85)

c. AIR 4.83 - 5.08 another Co.

d. $MgSO_4$ (13 tests other Co. 0.49 - 3.97)

e. Compressive Shear

f. Shear Angle

g. Tensile strength

h. Absorption 0.38, 0.35

0.18 - 0.24, 0.65 (13 test other co. 0.05 - 0.67)

Overburden Data: a. SPT

b. OM

c. CBR

d. AASHTO class

e. LL

f. PL

g. Exp. index

Geologic Hazards: Sinkholes

Name: Waynesboro Formation

Description: Lithologically divided into three units. The lower unit consists of maroon, olive, or dark-gray shale; maroon to pale-orange, fine to medium-grained lithic sandstone and quartz sandstone; and oolitic chert. All units possess greater or lesser quartzites of carbonate. The middle unit is dolomite or limestone, fine to coarse-grained. The upper unit is much like the lower. The upper half can contain maroon or green shales, whereas the lower portion contains more sandstone.

Bedding: Ranges from thin (shales) to moderately thick (dolomites) with locally thick carbonate sections.

Fracturing: Shales are highly fractured and are often the site of bedding faults; the carbonates more frequently posses block-jointing.

Weathering: Shale sections weather deeply to a characteristic dark red soil; whereas the carbonate frequently contain solution pockets and recrystallized zones.

Topography: Usually occupies low ridges and low, open, valleys with small hills.

Ease of Excavation: Variable depending on lithology and bedding, though generally it is rippable with heavy equipment. Thicker sandstone and carbonate units may need blasting. Drill rates should range 0.2 to 20.0 fph.

Cut slope stability: Stability should be good if slope design is compatible with dip of beds and orientation

Cut Slope Stability: (continued) of joints. If highly weathered shales or solutioned areas are encountered a soil cut design should be used.

Foundation Stability: Due to differential weathering a deep and irregular bedrock form may be encountered. Once equitable pressure points are assumed material is satisfactory for nearly all structures.

Construction Usage: Variable depending on lithology; has been used for road and concrete aggregate, dimension stone, brick and tile manufacture and agri-lime.

Rock Test Data: Another Co.

a. L. A. 15.5 - 24.1 (19 tests) carbonates only

b. S. G. 2.71 - 2.82 (8 tests carbonates only; 7 tests
2.55 - 2.69 calcareous shale

c. AIR

d. Mg SO_4 11.1 - 100.0 - 7 tests ave. 38.0 - non-carbonate
1.13 - 13.42 5 tests carbonates only

e. Compressive Shear

f. Angle

g. Tensile

h. Absorption 0.60 - 3.32 7 tests non-carbonate
0.13 - 1.29 8 tests, carbonates only

Overburden Data:

a. depth

b. SPT

c. OM range 19.9 - 28.8 (10 tests)

d. CBR 2.7 - 21.0 (10 tests)

e. AASHTO A-5 (8) - A-7-6 (20) (10 tests)

Overburden data:

f. LL 41 - 66

g. PL 19 - 37

h. exp. index

Geologic Hazards: Solution cavities, and plastic residuum.

Name: Elbrook formation

Description: The lower portion is composed of green to greenish-gray, fine grained dolomite, dolomitic limestone and shale with an overlying bed of calcareous siltstone. Above the siltstone is a thick section of dark to medium gray, fine to medium grained limestone, dolomitic limestone, pure dolomite and dolomitic shale. The upper portion is composed of interbedded yellow-weathering, light-gray, laminated dolomite and blue, algal limestone.

Bedding: Bedding thickness vary from 1.3 cm. to 61 cm. thick.

Fracturing: Generally steeply dipping, irregular and moderately developed. Spacing varies with geographic location though is generally wide to moderate.

Weathering: Thicker beds usually weather with a ribbon-banded appearance due to siliceous layers. Upon decalcification the beds produce shale like chips. The dolomitic shales and mixed mineralogy beds usually produce "punky" slab beds less than 2.4 cm. thick.

Topography:

Ease of Excavation: The thicker and more competent bed will require drilling and blasting. Normal drill rates should range 0.5 to 2.0 ft./hr. The weathered beds and highly argillaceous beds are rippable. Bedrock pinnacles frequently present problems.

Cut Slope Stability: Depending on the attitudes the formation is acceptable for pre-splitting and is usually stable. If the thinner beds are near a vertical inclination a reduced slope design should be used.

Foundation Stability: Stability is excellent in solid rock. Exploration should always be conducted, however, due to weathered pockets and sinkholes being present.

Construction Usage: Generally excellent for rip-rap, dimension stone, fill material and aggregate. Some areas of 50-50 calcite-dolomite stone may be expansive in alkaline concrete mixes.

Rock Test Data:

a. A 14.24 to 30.44 (9 tests)

b. SG 2.69 to 2.83 (10 tests)

c. AIR

d. $MgSO_4$

e. Cc

f. Angle

g. Tensile

h. Absorption 0.23 to 1.49 (9 tests)

Overburden Data:

a. depth 2' - 36'

b. SPT

c. OM 16.8% - 31.2% (9 tests)

d. CBR 3.3 - 12.5 (9tests)

e. AASHTO A-4 (8) to A-7-6 (19) (9 tests)

f. LL 36 - 79 (9 tests)

g. PL 19 - 35 (9 tests)

h. Exp. index 0.1 - 1.93 (9 tests)

Geologic Hazards: Unit frequently possesses sinkholes and/or voids. Due to subsurface solution channels contamination sources should not be located in the Elbrook as many local springs and wells draw from it.

Name: Conococheague formation

Description: Unit is predominately composed of limestones and dolomites with interbedded sandstones. Frequently the exposures posses a wavy liminar appearance due to thin interbeds of silica and/or clay material. The sandstone are often coarse grained and partially friable. Also found is an intraformational conglomerate.

Bedding: The carbonates are moderately to thickly bedded. Sandstones range from 1 - 100 ft.

Fracturing: Usually, the unit is broken into rectangular blocks. The joints are usually open and irregular.

Weathering: As the unit weathers differentially the characteristic wavy pattern is observed on outcrops. Subaerially the unit also decomposes differentially producing cavities and pinnacles. The sandstone units will weather producing a cobbly sandy soil whereas the carbonates produce a saprolitic to highly plastic clay.

Topography: Because of solubility the terrain of the Conococheague is usually gently rolling valleys. The sandstones will create low, long ridges if thick enough.

Ease of Excavation: Explosives will always be required in fresh rock situations. Drilling rates are approximately 3-5 ft. per hour. The erratic subground profile frequently produces problems.

Cut Slope Stability: Due to the local topography cut-slopes in the Conococheague are relatively low. Generally the unit may be pre-split.

Foundation Stability : Due to the variable lithology a thorough study should be made for foundations in order to avoid hidden clay seams, caverns and weak crumbly sandstone units.

Construction Usage: The formation has been used for many years as road aggregate, railroad ballast and fill material with success.

Rock Test Data:

L. A. - 10.8 - 18.6 (8 tests)

S. G. - 2.68 - 2.77 (8 tests)

Soundness loss 0.16 - 4.12 (8 tests)

Absorption - 0.48 - 1.27 (8 tests)

Overburden Data:

Depth range - 0 to 35.0 ft.

Standard Penetration test - 0 - 24 blows

Optimum Moisture - 20.8 - 26.7 (10 tests)

CBR - 2.0 - 11.7 (10 tests)

AASHTO Class - A-7-5 (16) to A-7-6 (19)

Liquid Limit - 69.0 - 79.0 (10 tests)

Plastic Limit - 21.0 - 32.0 (10 tests)

Expansion Index - 0.07 - 4.25 (10 tests)

Geologic Hazards: The characteristic of differential solubility causes the greatest hazards in the farms of sinkholes, caverns, mud voids and clay seams.

Name: Stonehenge formation

Description: Fine to medium grained, dark-gray to black limestone with thin, sheet like partings. Also thin, coarse-grained, bioclastic limestone is present. The upper portion consists of medium to dark gray and black fine to medium grained limestone with siliceous laminae and algal structures.

Bedding:

Fracturing:

Weathering: Moderately resistant, outcrops frequently protrude 1-3 ft. above surface. Slightly weathers to a shallow depth. Mantle thickness varies due to pinnacle structures.

Topography:

Ease of excavation: Unit requires blasting. The pinnacles require special treatment. Drill rates 1.6 to 6.0 ft/hr.

Cut Slope Stability: Variable depending on pinnacles and inclination of partings with cuts.

Foundation Stability: Thorough foundation studies are required to outline solution cavities, caverns, or pinnacles. If solid rock is encountered bearing is excellent for heavy structures.

Construction Usage: Good for fill, rip-rap, road material, ballast, etc.

Rock Test Data: a. L. A. 16.6, 19.0, 26.5, 24.2

b. S. G.

c. AIR

d. $MgSO_4$ 0.66

e. Compressive shear

f. Shear angle

g. Tensile strength

h. Absorption

Overburden Data: 2 tests

a. SPT

b. OM

c. CBR N. A.

d. AASHTO

e. LL

f. PL

g. Exp. Index

Geologic Hazards: Pinnacles and solution cavities.

Name: New Market formation

Description: The formation consists of an upper section of compact, thick bedded, bluish to dove gray, fine grained high calcium limestone over thin bedded shaly, dolomitic, buff limestones and carbonate-pebble conglomerate.

Bedding: As stated, bedding is thick to thin from top of section downward.

Fracturing:

Weathering:

Topography:

Ease of Excavation: Formation requires drilling and blasting. The extremely compact upper units must be carefully drilled in order to avoid conchoidal overbreakage. Drill-ability rates should range between 2.0 - 6.0 fph.

Cut Slope Stability: Unless the unit is steeply dipping toward the cut and/or distorted and fractured it is usually stable. The lower units are prone to fall-outs and "popping" in tunnels.

Foundation Stability: Excellent for all classes of structures.

Construction Usage: The formation has been used for road materials of all types, steel flux stone, dimension stone, railroad ballast, fill, concrete stone and the glass industry.

Rock Test Data:

L. A. - 27 - 32 (18 tests)

S. G. - 2.55 - 2.61 (18 tests)

Soundness - 1.31 - 8.30 (18 tests)

Absorption - 0.71 - 1.12 (18 tests)

Overburden Data: Formation too thin to have been tested.

Geologic Hazards: As with any carbonate rock the possibility of sinkholes and solution cavities exists.

Name: Lincolnshire formation

Description: Dark to medium gray, medium grained limestone containing black and dark-gray chert nodules and stringers locally. Frequently contains interbeds of light-gray, coarse grained bioclastic limestone with predominance of bryzoan debris.

Bedding:

Fracturing: Very little to highly fractured depending on closeness to the dege of thrust faults.

Weathering: Irregular weathering surface, residual boulders and characteristic dark red clay soil.

Topography:

Ease of Excavation: Unit requires drilling and blasting. Residual boulders may be larger than can be handled by conventional loaders, thus requiring special drilling and shooting. Drill rates normally 2.0 - 6.0 ft. per hour.

Cut Slope Stability: Generally stable, though if the cut parallels the strike and the dip is toward the cut at a steep angle some instability could exist.

Foundation Stability: Excellent for any size structure once solid rock is encountered. However, there must be a certainly that structure does not overlie solution cavities, or is not built on residual boulders.

Construction Usage: Road materials of all types, steel industry, railroad ballast and fill. The chert makes the stone questionable for concrete.

Rock Test Data:

a. LA

b. SG

c. AIR

d. Mg SO_4

e. Compressive Shear

f. Shear Angle

g. Tensile Strength

h. Absorption

Overburden Data:

a. Depth		
b. SPT	15 - 40 ft.	
c. OM	17.8 - 2.5	2 tests
d. CBR	1.8 - 2.5	2 tests
e. AA SHTO	A - 7-5 to A-7-6	2 tests
f. LL	56.2 - 105.0	2 tests
g. PL	16.7 - 32.0	2 tests
h. exp. index	1.17 - 3.05	2 tests

Geologic Hazards: Solution cavities, residual boulders, deep weathering.

Name: Edinburg formation

Description: p. 25, RI 40, para. 2.

Bedding: Ranges from a laminated fissile argillaceous limestone to a medium (2" - 2') bedded cobbley, platey dark gray limestone.

Fracturing: Locally and well developed joints, high degree of fracturing. Joints usually open or soil filled.

Weathering: Moderately resistant, moderately to highly weathered locally to a moderate depth; shaly flakes, jagged fragments up to medium size elongate plates and blocks. Mantle varies thin to moderate.

Topography:

Ease of Excavation: Moderately easy with heavy equipment particularly in the Liberty Hall Facies. The Lantz Mills section could require blasting in fresh sections. Drill rates range from 1 to 25 ft/hr. with light rotary equipment.

Cut Slope Stability: Depending upon local cut vs. bedding orientation and facies encountered slope should range from 1:1 to 2:1. In L. H. facies slope design may have to be reduced.

Foundation Stability: Good for light and medium structures if excavated to fresh material. Local mineralization (argillaceous weathering products) can cause swelling. Thorough investigation required also due to sinkholes.

Construction Usage: Liberty Hall facies suitable after study for fill material. Lantz Mill usually suitable for fill material and road aggregate.

Rock Test Data:
- a. L. A. (B) 21.3 - 23.7
- b. S. G. 2.70 - 2.74, 2.66, 2.71 (out of CO. 2.81 - 2.84)
- c. AIR 14.8 to 16.0 (3) in CO, 7.2 - 19.1
- d. $MgSO_4$ 1.02 - 4.22
- e. Compressive shear
- f. angle
- g. Tensile

  Not available (e.–g.)
- h. Absorption 0.12 - 0.64 - 0.76

Overburden Data:
- a. Depth 0 - 28 ft.
- b. STP 3 - 36
- c. OM range 22.0 - 23.0 (4)
- d. CBR range 1 - 3 (4) other areas generally low seldom > 4.0
- e. AASHTO A - 7-6 (20) clay (4)
- f. Liquid Limit 52 - 81
- g. PL 19 - 24
- h. Expansion Index 0.1 - 2.5 (4) usually higher > 4%

Geologic Hazards: Rockfalls, slope slumping, expansive subgrades, frequent solution channels and joints. The clay weathering product generally contains illite, kaolinite and chlorite family clays in a 6-3-1 ratio. Ocassionally there is significant 5% - 7% montmorillonite.

Name: Martinsburg formation

Description: Formation mainly consists of a Flysch sequence of alternating olive-green to gray locally siliceous shale and greenish-gray, fine to medium grained lithic sandstone. The lower portion contains black, silty calcareous shale and scattered thin beds of dense, black argillaceous limestone.

Bedding: Beds range from thin to thick with individual units easily observable in cuts. Locally there is a well developed cleavage which as obscured the bedding. Tectonism has also caused much local disturbance.

Fracturing: Formation is usually high fractured with moderately abundant joints and well developed cleavage.

Weathering: Usually resistant the formation produces a shallow silty or sandy overburden.

Topography: The formation usually underlies areas of rolling hills and rounded shallow valleys.

Ease of Excavation: Based on local lithologies the unit may have to be blasted though if the seismic velocity is less than 3000 fps it may be ripped. Drill rates could range as much as 1.0 - 20.0 fph.

Cut Slope Stability: Depending on the orientation of the cut versus the bedding angle and deformation the stability can be good to poor.

Foundation Stability: If excavation to fresh material is assured the formation should be adequate for all classes of structures.

Foundation Stability: If excavation to fresh material is assured the formation should be adequate for all classes of structures.

Construction Usage: Formation has been used for fill material and rip-rap and locally for brick and tile manufacturing.

Rock Test Data: none available

Overburden Data:

Depth - 0 - 10 ft.

Optimum Moisture - 11.2 - 19.8 (40 tests)

CBR - 0.8 - 36.0 (40 tests)

AASHTO - A-2-4 (a) - A-6 (12) (40 tests)

LL - 22.0 -40.0 (40 tests)

PL - 4.0 - 25.0 (40 tests)

Expansion Index - 0.03 - 3.0 (40 tests)

Geologic Hazards - In some local area the strata weather to a bentonitic clay producing a poor foundation material. Due to the varying lithologies and deformation local, deep, odd-shaped pockets of weathered rock may be encountered. This material may be weak bearing or water soaked. In most places the unit is considered impervious and septic fields are placed with difficulty.

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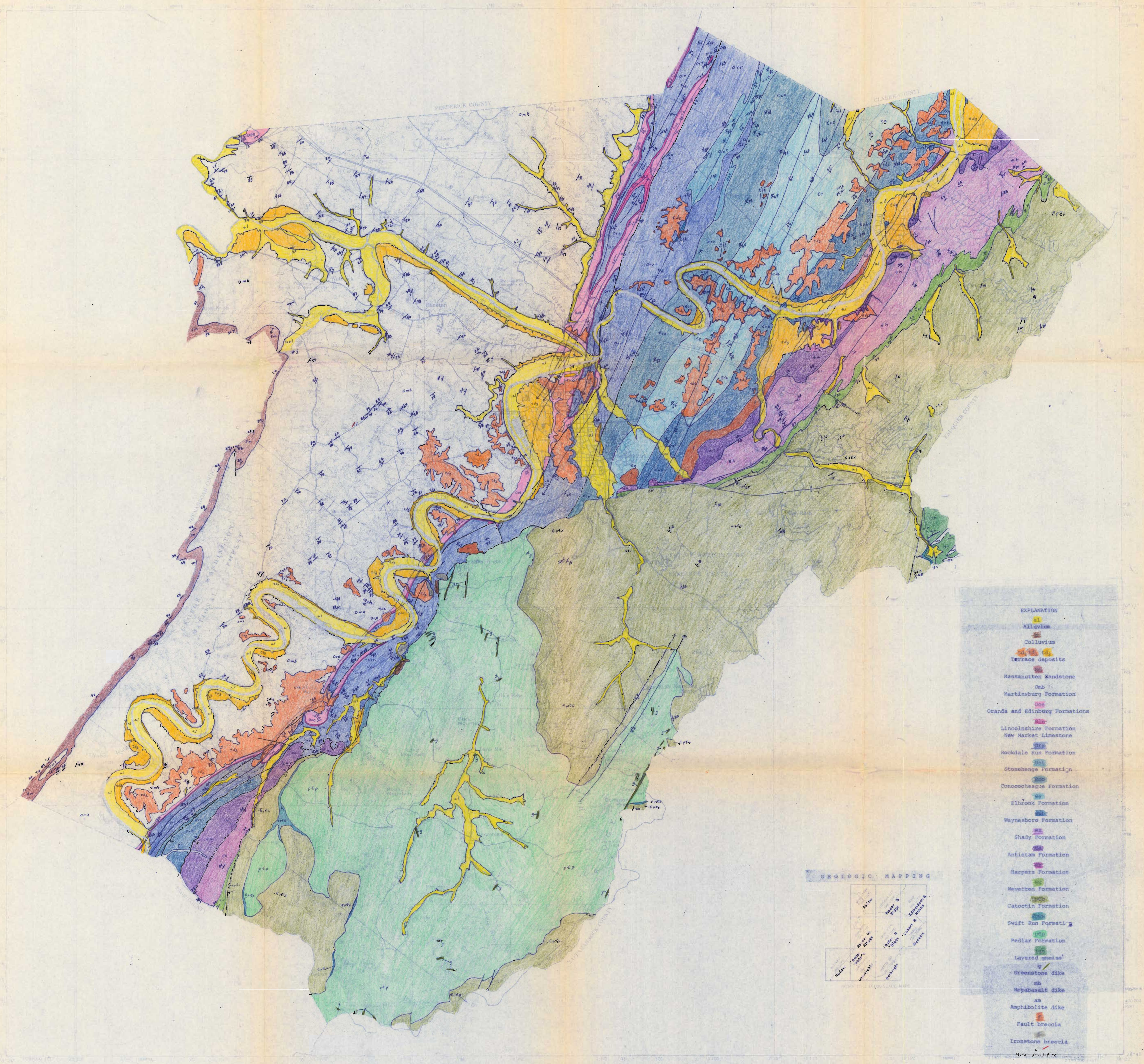
COMMONWEALTH OF VIRGINIA
DIVISION OF MINERAL RESOURCES
JAMES L. CALVER, STATE GEOLOGIST

WARREN COUNTY
VIRGINIA
COUNTY MAP SERIES (TOPOGRAPHIC)



Mapped, edited, and published by the Geological Survey

ROAD CLASSIFICATION

CONTOUR INTERVAL 50 FEET

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY, RESTON, VIRGINIA 22092
AND VIRGINIA DIVISION OF MINERAL RESOURCES, CHARLOTTESVILLE, VIRGINIA 22903
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

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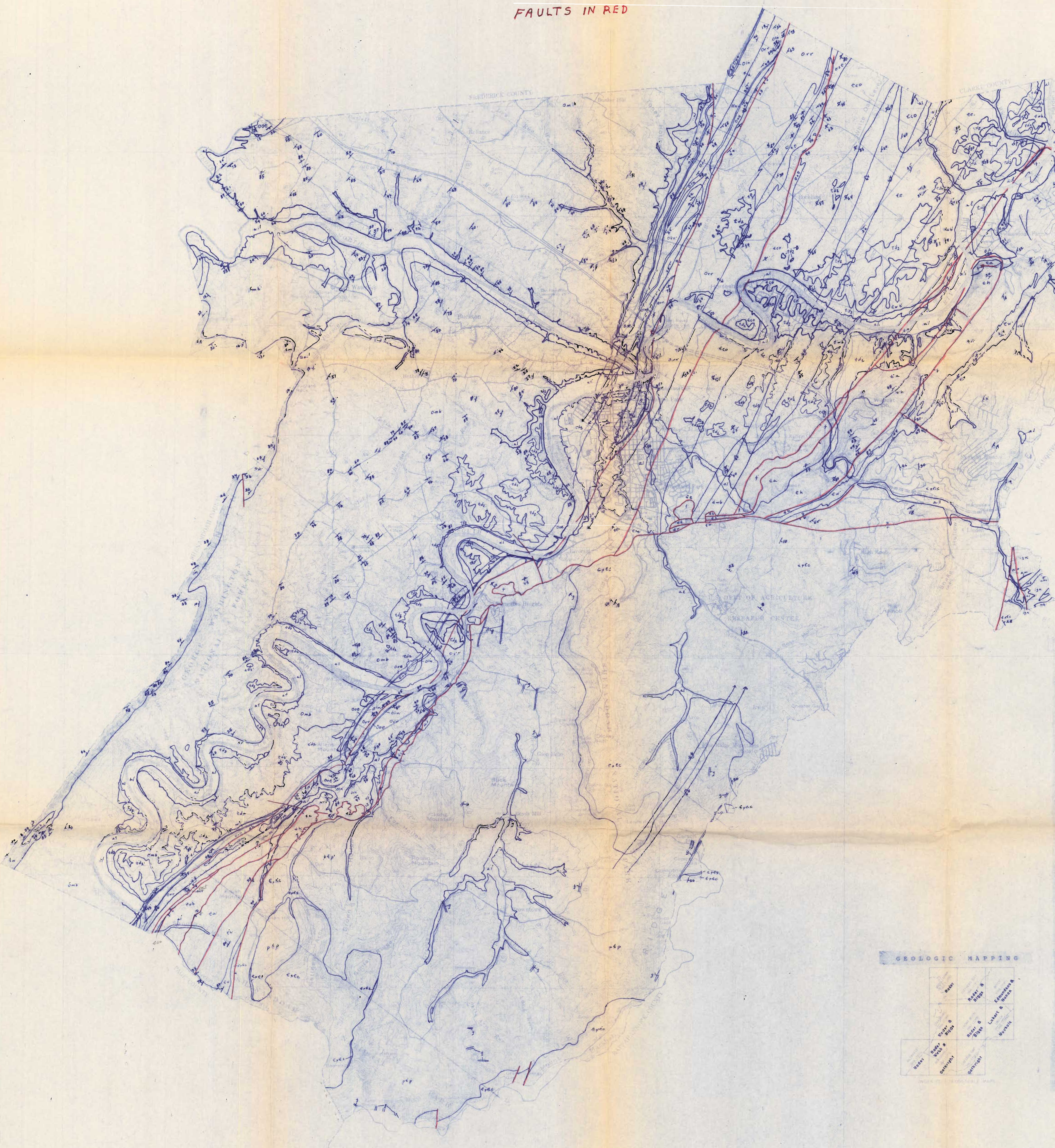
FAULTS IN RED



EXPLANATION

al
Alluvium

c
Colluvium

td₁ td₂ td₃
Terrace deposits

Sm
Massanutten Sandstone

Omb
Martinsburg Formation

Ooe
Oranda and Edinburg Formations

Oln
Lincolnshire Formation
New Market Limestone

Orr
Rockdale Run Formation

Ost
Stonehenge Formation

Єco
Conococheague Formation

Єe
Elbrook Formation

Єwb
Waynesboro Formation

Єs
Shady Formation

Єa
Antietam Formation

Єh
Harpers Formation

Єw
Weverton Formation

ЄpЄc
Catoctin Formation

ЄpЄs
Swift Run Formation

pЄp
Pedlar Formation

lgn
Layered gneiss

g
Greenstone dike

mb
Metabasalt dike

am
Amphibolite dike

f
Fault breccia

I
Ironstone breccia

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1975