GEOLOGIC MAP OF THE ROUND HILL QUADRANGLE, CLARKE AND LOUDOUN COUNTIES, VIRGINIA, AND JEFFERSON COUNTY, WEST VIRGINIA

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INTRODUCTION

The Round Hill quadrangle, an area of about 71 square miles, is located in Clarke and Loudoun Counties, northern Virginia, and Jefferson County, easternmost West Virginia (fig. 1). The quadrangle lies across the Blue Ridge front, the boundary between the Valley and Ridge and Blue Ridge geologic provinces of the Appalachian orogen (fig. 2), and is underlain by rocks ranging in age from Middle Proterozoic to Middle Cambrian. The main ridge of the Blue Ridge Mountains bisects the quadrangle from southwest to northeast; the highest point, just south of Wilson Gap, is 1,713 ft in elevation. The Shenandoah River flows northward out of the map area at an elevation of about 330 ft.

Bedrock in the quadrangle includes granitic basement rocks of Middle Proterozoic (Grenville) age and a cover rock sequence composed of Late Proterozoic rift facies basaltic flows and associated sediments, Lower Cambrian drift facies sandstones and siltstones, and overlying Lower to Middle Cambrian carbonate rocks of a succeeding passive margin. All of these rocks, including the previously tectonized basement rocks, were deformed during the Alleghanian orogeny and, in the Round Hill area, now lie on the west flank of the Blue Ridge - South Mountain anticlinorium and east flank of the Massanutten synclinorium (fig. 2).

PREVIOUS WORK

The Round Hill quadrangle lies within the area of the Harpers Ferry folio (Keith, 1894a), which is the earliest geologic map of the area that uses modern terminology. The West Virginia portion of the quadrangle was mapped by Grimsley (1916) in his report on

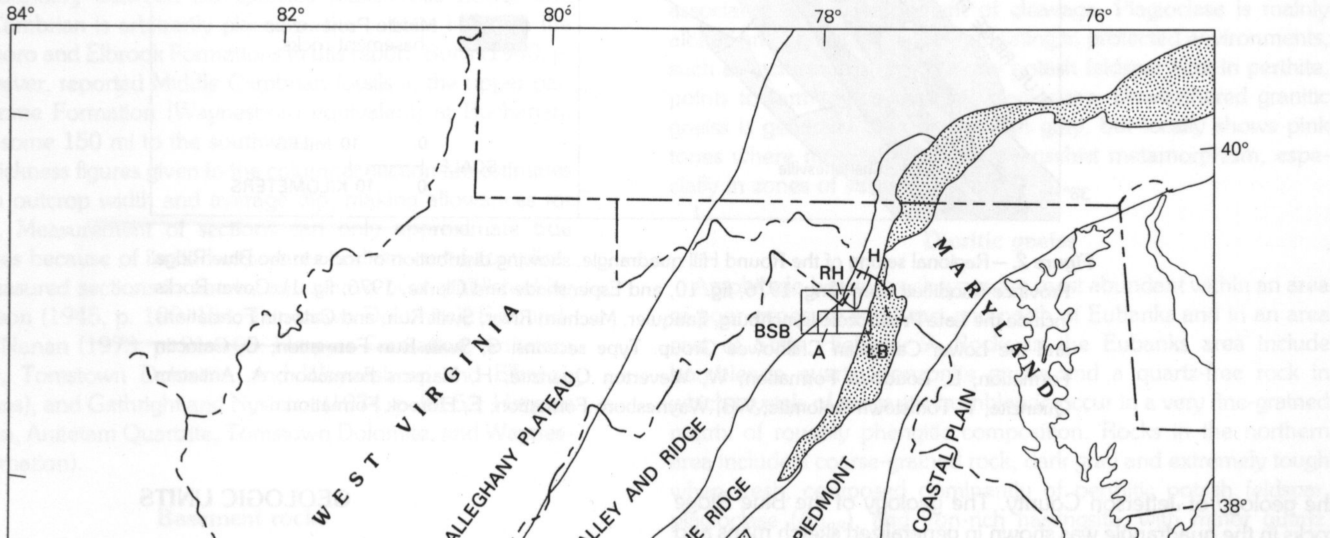

Figure 1.—Generalized geological province map showing the location of the Round Hill quadrangle (RH). Published detailed geologic maps in the area: A, Ashby Gap quadrangle (Gathright and Nystrom, 1974); BSB, Berryville, Stephenson, and Boyce quadrangles (Edmundson and Nunan, 1973); LB, Lincoln and Bluemont quadrangles (Parker, 1968); H, Harpers Ferry area (Nickelsen, 1956). Stippled areas are Early Mesozoic basins.

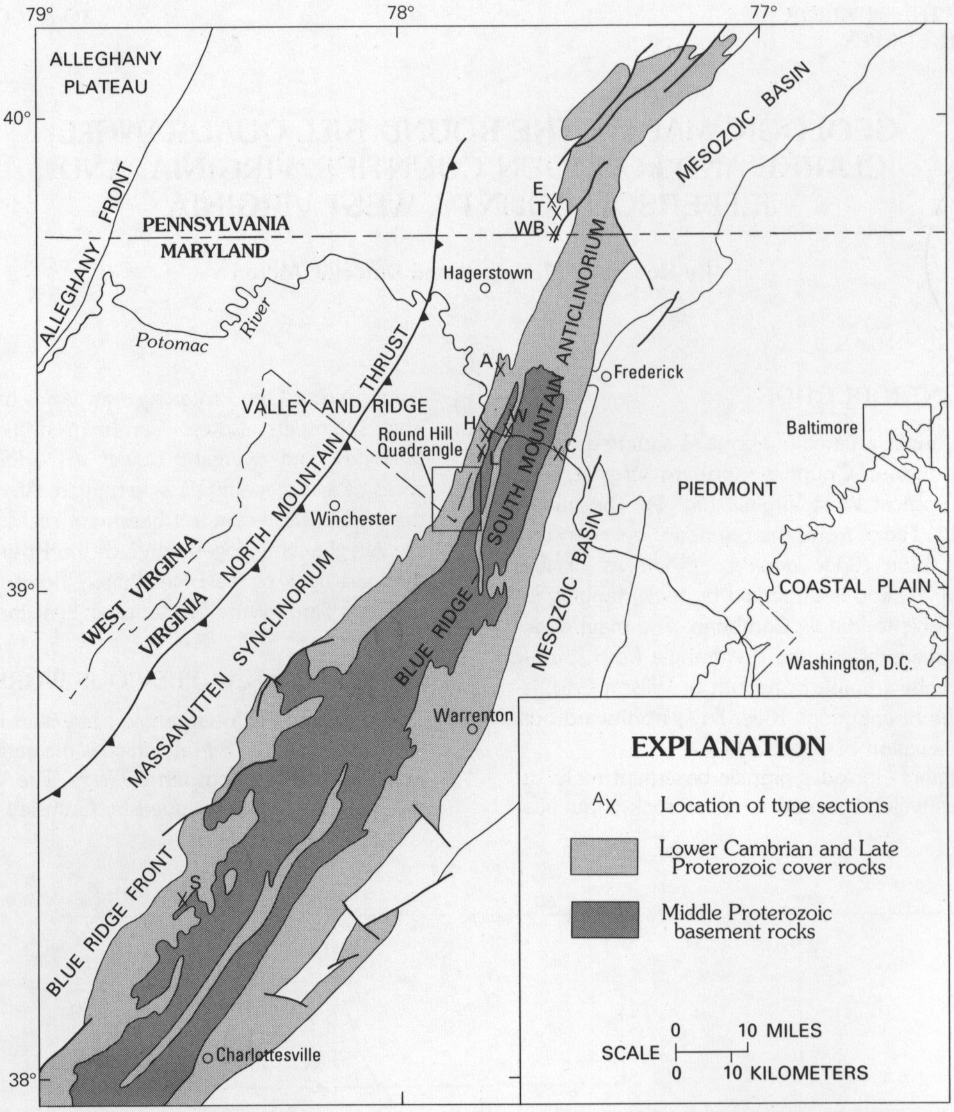

Figure 2.—Regional setting of the Round Hill quadrangle, showing distribution of rocks in the Blue Ridge Province (modified from King, 1976, fig. 10, and Espenshade and Clarke, 1976, fig. 1). Cover Rocks include the Late Proterozoic Lynchburg, Fauquier, Mechum River, Swift Run, and Catoctin Formations and the Lower Cambrian Chilhowee Group. Type sections: S, Swift Run Formation; C, Catoctin Formation; L, Loudoun Formation; W, Weverton Quartzite; H, Harpers Formation; A, Antietam Quartzite; T, Tomstown Dolomite; WB, Waynesboro Formation; E, Elbrook Formation.

the geology of Jefferson County. The geology of the Blue Ridge rocks in the quadrangle was shown in generalized sketch maps and discussed by Jonas and Stose (1939) and Stose and Stose (1946, 1949). These rocks were later mapped in detail by Nickelsen (1956) in an area stretching from Wilson Gap and Round Hill northward to the Potomac River (see fig. 1); in contrast to the previous studies, all of which show major thrust faults within the Chilhowee Group rocks, Nickelsen showed a continuous but highly folded section from the basement rocks to the Lower Cambrian carbonates. Rocks of the Great Valley in Virginia have been mapped at small scales and described by Butts (1933, 1940) and Edmundson (1945). In more recent years, a number of adjacent quadrangles have been mapped in detail (see fig. 1): Lincoln and Bluemont (Parker, 1968), Ashby Gap (Gathright and Nystrom, 1974), and Berryville (Edmundson and Nunan, 1973).

GEOLOGIC UNITS

Stratigraphic nomenclature

The stratigraphic nomenclature used in the Round Hill quadrangle is shown on the columnar section. The type localities of all of the formally named units lie within 60 miles of the quadrangle, most within 35 miles (see fig. 2). The names used for the Lower Cambrian formations in Virginia change at some arbitrary location, generally near the boundary between the Central and Southern Appalachians at Roanoke (table 1). The exact correlation of these units has been problematic because of difficulty in assigning consistent formational contacts. As a result of such problems in correlating with type areas, the names Shady Formation and Rome Formation have been used in the adjacent Berryville (Edmundson and Nunan, 1973) and Ashby Gap (Gathright and Nystrom, 1974) quadrangles. Although those names have precedence, their type sections are quite distant, and it is unlikely that they will be accepted throughout the Central Appalachians. Accordingly, the names Tomstown Dolomite and Waynesboro Formation are used herein.

Age and thickness assignments

No isotopic age dates have been obtained for basement rocks in the Round Hill quadrangle, but radiometric dating of zircons in similar rocks in central Virginia yield ages of 1000 to 1150 Ma (Grenvillian) (Sinha and Bartholomew, 1984, p. 182–183, and references therein). These dates may reflect a metamorphic episode rather than primary crystallization.

The assignment of the base of the Cambrian is problematic and ultimately arbitrary. Most workers now agree that the Catoctin Formation is Late Proterozoic in age, based on isotopic dating (Rankin and others, 1969; Badger and Sinha, 1988; see Catoctin Formation below), and that the fossiliferous Antietam Quartzite is Early Cambrian in age (Resser, 1938, p.4–6). Because of their lack of fossils, the Harpers Formation, Weverton Quartzite, and Loudoun Formation have been arbitrarily referred by some workers to the Precambrian (for example, Resser, 1938; Mitra, 1989) or have been assigned a Cambrian(?) or latest Precambrian age. Early Cambrian fossils have recently been reported from the Hampton and Unicoi Formations of southwestern Virginia (Simpson and Sundberg, 1987), suggesting that all or most of the Chilhowee Group is Early Cambrian in age. This report follows the common usage of placing all of the formations of the Chilhowee Group in the Lower Cambrian.

The boundary between the sparsely fossiliferous Lower and Middle Cambrian is arbitrarily placed at the contact between the Waynesboro and Elbrook Formations in this report. Butts (1940, p. 66), however, reported Middle Cambrian fossils in the upper part of the Rome Formation (Waynesboro equivalent) at Buchanan, Virginia, some 150 mi to the southwest.

The thickness figures given in the columnar section are estimates based on outcrop width and average dip, making allowances for structure. Measurement of sections can only approximate true thicknesses because of limited exposures and structural complications. Measured sections in nearby areas have been published by Edmundson (1945, p. 180–184; Tomstown Dolomite), Edmundson and Nunan (1973, p. 91–105; Harpers Formation, Antietam Quartzite, Tomstown Dolomite, and Waynesboro and Elbrook Formations), and Gathright and Nystrom (1974, p. 50-52; Harpers Formation, Antietam Quartzite, Tomstown Dolomite, and Waynesboro Formation).

Basement rocks

Granitic and dioritic gneisses, the oldest rocks exposed in the Round Hill quadrangle, show no bedding or other sedimentary features; all have compositions consistent with igneous protoliths, and an areal uniformity suggestive of a plutonic origin. Primary textures and mineral phase compositions, however, have been partially to nearly completely altered by metamorphism. Where not completely overprinted by or transposed into the NNE-SSW Appalachian trend, the rocks of the basement generally show an E-W, steeply dipping foliation and a nearly horizontal lineation, presumably produced during the Grenville orogeny. Exposures are insufficient to determine the mutual structural or temporal relations of the granitic and dioritic gneisses. The basement rocks appear to bear the greatest affinity to types found in the northwestern and

Table 1.—**Stratigraphic nomenclature of Lower Cambrian Rocks north and south of Roanoke, Virginia**

South		North	
	Rome Formation		Waynesboro Formation
	Shady Dolomite		Tomstown Dolomite
Chilhowee Group	Erwin Quartzite	Chilhowee Group	Antietam Quartzite
	Hampton Shale		Harpers Formation
	Unicoi Formation		Weverton Quartzite
			Loudoun Formation

central belts of the Blue Ridge farther southwest in Virginia and variously denominated as parts of the Pedlar Formation of Bloomer and Werner (1955), the augen-bearing gneiss of Lukert and Halladay (1980), and the porphyroblastic granite gneiss of Clarke (1984).

Granitic gneiss

The most abundant basement rock type is medium-grained, leucocratic granitic gneiss, composed of subequal quantities of perthitic potash feldspar, plagioclase, and quartz, with or without minor biotite, garnet, and ilmenite. The rocks were apparently subjected to a high temperature and pressure, dry metamorphism during the Middle Proterozoic Grenville orogeny, at which time the garnets grew and the foliation and layering formed. Effects of greenschist facies metamorphism during the Paleozoic Era range from minor to profound and include albitization, sericitization, and saussuritization of plagioclase, replacement of garnet and biotite by chlorite, and ilmenite by leucoxene, as well as the textural changes associated with development of cleavage. Plagioclase is mainly albite (An_{1-5}), but oligoclase remaining in protected environments, such as inclusions isolated by the potash feldspar host in perthite, points to formerly more calcic plagioclase. Unweathered granitic gneiss is generally gray or greenish gray, but locally shows pink tones where more affected by greenschist metamorphism, especially in zones of strong shearing.

Dioritic gneiss

Amphibole-bearing rock types are most abundant within an area of poor exposure southeast and north of Eubanks and in an area east of State Highway 9. Rocks in the Eubanks area include hornblende quartz monzonite gneiss and a quartz-free rock in which crystals of pargasitic hornblende occur in a very fine-grained matrix of roughly phengitic composition. Rocks in the northern area include a coarse-grained rock, dark gray and extremely tough when fresh, composed dominantly of perthitic potash feldspar, plagioclase (An_{28}), and iron-rich hastingsite, with minor quartz. The hastingsite is commonly poikilitic with quartz inclusions, and may have replaced a pyroxene, presumably during Grenville metamorphism. In addition to the coarsely crystalline phases, the rock contains patches of an extremely fine-grained mixture of stilpnomelane and quartz that probably replaced a different pyroxene, presumably during Paleozoic metamorphism. Associated with this rock is leucocratic quartz syenite, coarser and better foliated than rocks of the granitic gneiss unit.

Swift Run Formation

A relatively thin and locally discontinuous sequence of metasedimentary rocks, dominantly phyllites and quartzites, nonconformably overlying basement rocks, extends through the quadrangle at the eastern base of the Blue Ridge. The unit was named the Swift Run tuff by Stose and Stose (1944) for exposures at Swift Run Gap in the Blue Ridge, about 60 mi southwest of the Round Hill quadrangle (fig. 2). The outcrop belt in the Round Hill quadrangle locally reaches a width of almost 3,000 ft but is more commonly about 1,000 ft wide, probably two or three times the formation thickness. The outcrop belt narrows and the formation may even pinch out locally in areas of poor exposure near the north edge of the quadrangle. A separate small lens lies below the Catoctin Formation in the southeast corner of the quadrangle. Where exposed, the base of the Swift Run is sharply defined or is indefinite over a few feet where the basement underwent weathering prior to deposition of the Swift Run. The contact with the overlying Catoctin Formation is placed at the base of the lowest metabasalt.

Quartzite occurs in the lower part of the formation, most abundantly in the lenses mapped as the lower member of the Swift Run, but also as a minor component in the dominantly phyllitic upper member. The quartzite is characterized by the dominance of clastic grains of quartz, mostly in the coarse and very coarse sand sizes, but locally with scattered pebbles or rarely cobbles. Clastic grains of feldspar are scarce and clastic grains of mafic minerals are absent, but clots of sericite or epidote probably represent the former and clots of chlorite and opaque minerals the latter, altered during Paleozoic metamorphism. Detrital apatite, zircon, tourmaline, and opaque minerals are very minor constituents. Quartzite grades from grain-supported metasediment with thin sericite and chlorite films between grains to a phyllitic quartzite dominated by the sericite (or sericite and chlorite) matrix.

At some localities, the basal exposures of the Swift Run apparently represent an ancient regolith developed on the basement gneiss. The rocks in these exposures are characterized by angular, irregular quartz grains that could not have undergone any significant transport. Rocks with such grains in a matrix of sericite and chlorite, in some cases mimicking the textures of the basement gneiss, appear to represent a quartz-rich lag deposit. These rocks grade within thirty or forty feet into normal bedded quartzite with rounded quartz grains. The major areas of quartzite coincide with embayments in the basement contact that may represent lows in the sub-Swift Run paleorelief.

The phyllitic upper member of the Swift Run comprises a variety of lithologies, the interrelations of which are obscure because of generally poor exposure. Quartzite grades into quartzose phyllite, with scattered clastic grains. Phyllites free of evident clastic grains occur as massive beds or are thinly interbedded with fine-grained quartzites. In the upper part of the member other rock types appear, including hematite-rich phyllite and phyllite with sericite-chlorite layers and very fine grained quartz-feldspar layers irregularly alternating on a scale of millimeters or less. The composition and variability of these phyllites, which are similar to those interbedded with metabasalt in the overlying Catoctin Formation, suggest they have a considerable content of volcanic material mixed with clastic sediment, or may even be rhyolitic and intermediate ash beds or flows. Fine-grained pinkish-white dolomitic marble was found at a single locality 2 miles south of the north boundary of the quadrangle.

The Swift Run Formation in this area is interpreted as dominantly sedimentary deposits of small streams flowing over an eroded surface of low relief underlain by gneissic bedrock or its regolith. As the volcanic episode represented by the Catoctin Formation began, increasing amounts of volcanic material entered the depositional system, until effusions of basalt marked the local termination of the Swift Run. The thin marble beds, better exposed in nearby quadrangles, occuring at or close to the top of the Swift Run, may represent limestones deposited in lakes or ponds formed as volcanic activity disrupted the drainage network.

Quartz grains in the Swift Run have been variably affected by pressure solution and plastic flow; in zones of greater deformation, they are strongly flattened parallel to the cleavage. The only porphyroblastic metamorphic mineral is magnetite, which forms octahedra several millimeters in size, abundant in some phyllite beds.

Sedimentary units occur between the basement gneisses and the Catoctin volcanics over a large area in northern Virginia and have been given several names, including Lynchburg Group, Fauquier Formation, and Swift Run Formation. The Swift Run Formation of this quadrangle lies on strike with and is similar to the tuffaceous and arkosic sediments at Swift Run Gap (Stose and Stose, 1944) and to the Swift Run Formation of King (1950).

Catoctin Formation

The name Catoctin was first used by Geiger and Keith (1891) for rocks exposed on Catoctin Mountain, a few miles east of the Round Hill quadrangle. In northern Virginia, the formation crops out on both flanks of the Blue Ridge anticlinorium; it has been studied in detail on the northwest flank by Reed (1955) and Reed and Morgan (1971), and it has been described by Nickelsen (1956) in the Round Hill area and by Gathright and Nystrom (1974) in the Ashby Gap quadrangle. In the Round Hill quadrangle, the Catoctin consists of metabasalts and minor interbedded metatuffs and associated metasedimentary rocks. Reed (1955) described the metabasalt as composed of albite, chlorite, epidote, actinolite, and sphene, with minor amounts of pyroxene, magnetite, hematite, and ilmenite. Irregular epidosite masses a few inches to several feet across are common within the metabasalt; they are essentially epidote and quartz with minor amounts of actinolite (Reed and Morgan, 1971). Rhyolite metatuff, forming a thin layer (about 10 to 25 ft thick) at the top of the lower Catoctin, consists of quartz, potassium feldspar, plagioclase, sericite, and minor opaque minerals. Metasedimentary beds, most common in the lower Catoctin, are generally composed of silt-sized or smaller grains, mostly quartz; these beds may include tuff.

The Catoctin Formation is as much as 3000 ft thick in the Ashby Gap quadrangle to the southwest (Gathright and Nystrom, 1974, p. 10), but thins northeastward and is no more than a few tens of feet in thickness along State Highway 9 in the northern Round Hill quadrangle; apparently it is locally absent in the Purcell Knob area, just to the north of the quadrangle (Nickelsen, 1956, p. 247). Thickness variations of the Catoctin have been attributed to post-Catoctin erosion (Stose and Stose, 1946, p. 28–29; King, 1950, p. 13) or to uneven deposition, perhaps on a pre-Catoctin basement surface of high relief (Cloos, 1951, p. 25-28; Reed, 1955, p. 877). The distribution of the Catoctin in the Round Hill quadrangle suggests the presence of a pre-Catoctin basement high north of the quadrangle.

Reed (1955, p. 893), citing the mineralogy, chemical composition, extent, and primary structures such as flow breccia, amygdular layers, and columnar jointing, characterized the Catoctin lavas as tholeiitic basalts that formed subaerial flows. On the other hand, Kline and others (1987) have recently suggested, on the basis of hyaloclastite textures and pillow structures in exposures from Fauquier to Albemarle Counties, Virginia, south of the Round Hill quadrangle, that the Catoctin on the east limb of the anticlinorium was deposited in a submarine environment. Rankin and others

(1969) reported a zircon age of 820 Ma (810 using revised constants) for five Blue Ridge rhyolites, including a sample from the Catoctin Formation on South Mountain in Pennsylvania, but Badger and Sinha (1988) obtained a Rb-Sr whole-rock and pyroxene age of 570±36 Ma for the Catoctin in central Virginia. The older date appears to be flawed by the use of samples from different formations and perhaps by the presence in the samples of xenocrystic zircons inherited from older rocks (Rankin and others, 1989, p. 42). Samples of rhyolite metatuff collected recently from along State Highway 7 at Bluemont, just south of the Round Hill quadrangle, have yielded a discordant U/Pb zircon date of about 600 Ma (Aleinikoff and others, 1991).

The Catoctin is a resistant unit and where thick holds up the backbone of the Blue Ridge. It forms the crest of the Blue Ridge from the common point of the three counties, near the southern boundary of the quadrangle, southward into central Virginia. In the Round Hill quadrangle, outcrops of the Catoctin Formation are sparse and irregularly distributed, but float blocks are common on mountain slopes. Very good exposures of the unit can be seen in cuts along State Highway 7 across the Blue Ridge just south of the quadrangle boundary. Large boulders of epidosite are common on the ridge crest along County Road 601 in the southern part of the area.

Metadiabase

Metadiabase (greenstone) is compositionally similar to the metabasalt of the Catoctin Formation, but texturally more uniform, with rare epidosite masses. Dikes, with thicknesses usually on a scale of feet, are nearly ubiquitous in areas of basement gneiss, less abundant in areas of Swift Run Formation, and are probably present but not distinguishable in areas of Catoctin Formation. Resistance to weathering varies considerably, and can be greater or less than that of the basement gneiss. Estimates of the abundance of metadiabase from natural exposures are thus difficult. Espenshade's (1986, p. 25) measurements showing that metadiabase dikes in the basement make up 15–20% of the section in a pipeline trench in the Rectortown quadrangle, about 10 mi to the south, probably applies to the Round Hill quadrangle as well. The one area of metadiabase distinguished on the map is characterized by exceptionally abundant metadiabase float and no evident gneiss. It may represent a sill-like body or it may be merely a complex of dikes particularly resistant to weathering.

The volume of metadiabase dikes reflects spreading during breakup of Grenvillian North America and incipient opening of the Iapetus Ocean (or associated precursor rifts). Attitudes of the dikes are generally not evident; most that could be measured show northeast strikes, which may be the result of rotation during Paleozoic deformation rather than original attitudes. The Catoctin volcanics were presumably erupted from vents where dikes reached the surface; an occurrence of agglomeratic metabasalt at the base of the Catoctin Formation east of the Round Hill reservoir may mark an eruptive center.

Chilhowee Group

The Chilhowee Group was named by Safford (1856, p. 152–153) for a thick sequence of sandstones and shales on Chilhowee Mountain, Tennessee, and the name has come to be used throughout the southern and central Appalachians for basal Cambrian siliciclastic rocks that overlie Precambrian igneous or sedimentary rocks and are overlain by Cambrian and Ordovician platform carbonate rocks.

Loudoun Formation

The distinctive phyllite or slate (and locally conglomerate) that occur above metabasalts of the Catoctin Formation were named the Loudoun Formation by Keith (1894b) and have generally been considered the basal unit of the Chilhowee Group (Butts, 1933; King, 1950; Nickelsen, 1956). Beds in central Virginia described by Furcron and Woodward (1936) as a basal Cambrian lava flow unconformable on the Catoctin are probably equivalent to the Loudoun (King, 1950, p. 16). Reed (1955, p. 892–3), however, has suggested that these beds represent metamorphosed saprolite at the top of the Catoctin metabasalts, and should be included within the Catoctin Formation. This interpretation has been followed in the adjacent Ashby Gap quadrangle (Gathright and Nystrom, 1974, p. 15). Elsewhere, particularly where the slate appears to be a metatuff or where it is overlain by a conglomerate member, the name Loudoun has been retained in more or less the original sense of Keith (1894b) for a mappable unit between the Catoctin metabasalts and Weverton quartzites (Nickelsen, 1956); this is the usage herein. As recognized in the Round Hill quadrangle, the Loudoun is a gray to purple phyllite with a well developed foliation. A few beds of conglomeratic phyllite, consisting of quartz granules and grains and flattened, light-gray phyllite clasts as much as 8 in. across, were found near State Highway 9 and just north of Sunny Ridge.

The stratigraphic relationship between the Chilhowee Group and the Catoctin Formation is not clear. Furcron and Woodward (1936) interpreted the base of the Loudoun as an angular unconformity. King (1950, p. 17) suggested that the Loudoun lies unconformably on Catoctin and older rocks. Cloos (1951) and Reed (1955, p. 879) found no evidence of a major unconformity, and Nickelsen (1956, p. 248) considered the Loudoun to be transitional between the Catoctin Formation and Weverton Quartzite. No significant break in the section was recognized by the authors in the Round Hill quadrangle.

The Loudoun Formation in the Round Hill quadrangle is thin and poorly exposed. Small outcrops can be found along and just south of State Highway 9, where the unit is thickest; elsewhere, to the south, its presence is known only from a distinctive topographic bench or swale and from phyllite chips in the soil. South of State Highway 7, in the Bluemont quadrangle, it is very thin and possibly absent.

Weverton Quartzite

The Weverton was named by Keith (1894b, p. 329) for outcrops on South Mountain near Weverton, Maryland, in the Harpers Ferry quadrangle. In the Round Hill area, the Weverton is a ridge-forming unit, mostly quartzite and conglomeratic quartzite; phyllite is a very minor constituent. There is an overall trend of increasing grain size upward through the formation, with the coarsest beds at the top. The three informal members mapped separately in the Round Hill quadrangle appear to correspond closely to those used by Nickelsen (1956), but differ from those used by Gathright and Nystrom (1974), whose lower member includes the lower two members used herein. The three members generally form distinct ridges with abundant outcropping ledges, which can be easily traced on the ground and, where the structure is less complex, south of Wilson Gap, can be readily distinguished on the topographic base or on aerial photographs. The lower two ledges are similar in character and generally must be identified by stratigraphic position, but the upper member is distinctive and can be recognized by its dark color, coarse grain size, and large-scale crossbedding or massive appearance. Topographically low intervals between ledges are poorly exposed but are also mostly quartzite, apparently in thinner beds and with more numerous thin phyllite interbeds. The quartzite ledges occur on the west slopes of the Blue Ridge south of the junction of the three counties, and on both west and east slopes and the crest north of this point. The ledges produce abundant float that ranges in size from gravel to blocks tens of feet across; this float forms thick block fields that occur along the base of ledges and choke many of the small first-order hollows on the ridge slopes. Float blocks also form a veneer of colluvium on much of the lower slopes of the mountain.

The sediments forming the Weverton have been characterized by Schwab (1986, p. 126) as alluvial fan and coastal floodplain deposits. The correlative Unicoi Formation in southwest and central Virginia has been subdivided by Simpson and Eriksson (1989) into five facies associations representing alluvial fan, proximal to distal braid plain, and upper to lower shoreface environments.

The ledge-forming quartzites of the Weverton are well exposed throughout the outcrop belt. The lowest ledge is best exposed at Raven Rocks in the southernmost tip of Jefferson County, West Virginia. The middle ledge is well exposed on the crest of the mountain along the Appalachian Trail above Shannondale. The best exposure of the upper ledge is in a large cut along Route 7 in the Bluemont Quadrangle just to the south; it is also well exposed along Route 9 across from the overlook on the west side of the Blue Ridge just north of Mannings, in the Charles Town quadrangle.

Harpers Formation

The Harpers Formation was named by Keith (1894b, p. 333) for exposures in the Potomac Gorge at Harpers Ferry, several miles north of the Round Hill quadrangle. The unit is relatively weak, and forms the lower slopes and small foothills at the west base of the Blue Ridge. The Harpers is composed mostly of silt-sized or finer grains, but the grain size increases near the top where the formation grades into the overlying Antietam Quartzite. Distinctive mappable units within the formation such as the sandstone and quartzite mapped in the Ashby Gap quadrangle to the southwest are lacking in the Round Hill quadrangle. Bedding is mostly obscure, but cleavage is everywhere conspicuous. Exposures are sparse, except in stream cuts in the upper part of the unit near the Shenandoah River. As a result, recognition of the folding and faulting that is probably pervasive within the outcrop belt is difficult.

The fine grain size of the Harpers Formation suggests a deepening of the depositional basin. The formation is considered by Schwab (1986, p. 126) to represent marine delta front deposits. Simpson and Eriksson (1986) interpreted deposits in the correlative Hampton Formation to the south as inner to outer shelf deposits that represent a regressive sequence.

The Harpers Formation is largely concealed beneath colluvium from the Weverton Quartzite and a thin but extensive soil cover. The most accessible exposures in the quadrangle are in cuts along Route 9 between Mountain Mission and Mannings; the most complete section is exposed in Raven Rocks Hollow, in the southwest corner of the quadrangle. The transition into the overlying Antietam Quartzite, consisting of interbedded siltstone and quartzite, is well exposed along Furnace Run between the gravel pit and the dam.

Antietam Quartzite

The Antietam Quartzite, named by Keith (1894b, p. 335) for exposures along Antietam Creek in Maryland, is the uppermost formation of the Chilhowee Group. The resistant quartzite forms a low ridge west of the Blue Ridge but, unlike the Weverton Quartzite, rarely with outcropping ledges; instead, the crest and slopes are commonly littered with light-gray case-hardened float blocks and cobbles generally less than ten inches across. This lack of outcrop probably results from intensive weathering along the bedding planes, which breaks up the rock in the subsurface. This unit contains the oldest fossils found in the Round Hill quadrangle, the trace fossil *Skolithos*. No other fossils were found, although Nickelsen (1956, p. 251) reported trilobite fragments and valves of inarticulate brachiopods within the quadrangle. The Antietam grades into the overlying Tomstown Dolomite through an interval of medium- to coarse-grained calcite-cemented sandstone about 15 ft thick, which is rarely exposed; it can be seen at the Howell zinc prospect on the east bank of the Shenandoah River about a mile northeast of Riverside.

Schwab (1986, p. 126) considered the Antietam to be a beach-longshore bar complex. Simpson and Eriksson (1986) described the correlative Erwin Formation in southwest and central Virginia as nearshore deposits affected by longshore currents and waves. These interpretations are consistent with the clean, quartzose lithology and sedimentary features of the Antietam in the Round Hill quadrangle.

The Antietam is concealed in most places under colluvium and residuum, but is exposed in many places along the west bank of the Shenandoah River where it intersects the outcrop belt.

Tomstown Dolomite

The Tomstown Dolomite was named by Stose (1906, p. 208) for exposures of white to dark-gray pure and impure "limestones" at Tomstown, Franklin County, Pennsylvania. The Tomstown, essentially a dolomite sequence in the Round Hill quadrangle, is the basal unit of the great Cambrian and Ordovician carbonate platform deposits, as much as 10,000 ft thick, of the Appalachian miogeocline. The outcrop belt of the formation forms the southeastern margin of the Great Valley, at the northwest base of the Blue Ridge. The Tomstown was apparently deposited on a shallow carbonate bank with very little influx of clastic material; the lithologic change from the underlying Chilhowee Group rocks is relatively abrupt. Outcrops of the Tomstown are common along the Shenandoah River, and there are some sections of virtually complete exposure along the river bluffs for as much as 2,000 ft or more. A distinctive reddish clay soil is typically developed over the formation, and in much of the area the basal beds are marked by abandoned pits from which residual iron ore was obtained in the last century. Fossils are rare: Resser (1938, p. 23) reported none from the belt between Harpers Ferry and Front Royal, although many species of trilobites, gastropods, and brachiopods, as well as *Archaeocyathus*, were recorded from other Tomstown (Shady) localities in the central and southern Appalachians (listed by Butts, 1940, p. 55). Byrd and others (1973) reported on a collection of *Salterella conulata* from near Berryville, in the adjacent Ashby Gap quadrangle. Fossils from the Tomstown Dolomite indicate an Early Cambrian age for the formation.

Barnaby and Read (1987) interpreted the Shady Dolomite in southwest Virginia as carbonate ramp to rimmed shelf deposits on a drowned clastic shelf, with subsidence rates on the order of

0.005–0.010 cm/yr (0.002–0.004 in/yr); they suggest that periodic regressions exposed the platform to meteoric diagenesis.

In areas of poor exposure, where the shale beds marking the base of the Waynesboro Formation are not exposed, the upper contact of the Tomstown Dolomite was placed to separate a predominantly dolomitic sequence below from a predominantly limy sequence above. The basal Waynesboro Formation also includes argillaceous limestone and calcareous shale, which are locally missing as a result of minor faulting. In the adjacent Berryville quadrangle (Edmunson and Nunan, 1973, p. 19), the upper contact of the Tomstown (Shady) Formation was placed at the base of the oolitic chert unit, and is thus three or four hundred feet below the contact as mapped herein.

Waynesboro Formation

The Waynesboro Formation was named by Stose (1906, p. 209) for the town in southern Pennsylvania. He described it as mostly ripple-marked purple shale and calcareous sandstone. In the Round Hill quadrangle, in addition to these rock types (which occur mainly in the upper part of the formation), the Waynesboro includes much carbonate rock, in a ratio of limestone to dolomite of about 4:1. The largely reddish-gray siliceous beds, mainly shale and siltstone, are the most distinctive part of the unit and are considered typical and diagnostic. The siltstone (with minor sandstone) is more resistant to weathering than the adjacent carbonate rocks and thus forms a conspicuous low ridge that marks the outcrop belt. Exposures are generally poor except along the Shenandoah River, where virtually the entire section is exposed in bluffs along meander loops in the northern part of the quadrangle; these exposures superbly show tight folding and associated faulting that are apparently characteristic of the unit in this area.

The Waynesboro has yielded few fossils in the central Appalachians. Stose (1906, p. 209) reported trilobites and other fossils that suggested a Middle Cambrian age, but Resser (1938, p. 9) placed the Waynesboro (Rome) Formation in the Lower Cambrian because the few fossil fragments found indicated the *Olenellus* zone. Butts (1940, p. 66) listed 17 fossil species from the formation, all but two of which are trilobites; most of these were regarded as Middle Cambrian in age. No fossils have been found in the unit in the Round Hill quadrangle.

The correlative Rome Formation in southwest Virginia has been interpreted by Barnaby and Read (1987) to represent a period of regression in the slowly subsiding carbonate platform. The Waynesboro of the Round Hill quadrangle, with a lesser content of red siltstone and shale, probably represents less intensive, shorter-term regressive episodes than the Rome.

Elbrook Formation

The Elbrook Formation ("limestone") was named by Stose (1906, p. 209) for exposures of cherty magnesian limestone in a quarry near the town of Elbrook, southern Pennsylvania. The unit lies mostly northwest of the Shenandoah River, so outcrops are limited. The best exposures in the quadrangle are located along Bullskin Run near Kabletown. Fossils are rare in the Elbrook, but the Middle Cambrian trilobite *Glossopleura bassleri* has been found near Winchester (Resser, 1938, p. 23; Butts, 1940, p. 78). The formation is mostly finely laminated limestone and dolomite, but thin mudstone beds occur locally. The limestone and dolomite are interbedded throughout the section, but dolomite is more abundant near the base. Karst topography is common on the Elbrook.

The Elbrook was deposited during post-Waynesboro transgression on the passive margin carbonate shelf. The beds represent a cyclic peritidal facies on the aggraded, reef-rimmed shelf (Koerschner and Reed, 1989).

Terrace deposits

Cobbles and gravels are abundant and conspicuous on hills adjacent to the Shenandoah River as high as 550 ft in elevation, and as much as 200 ft above the river level. Deposits shown on the map are probably as much as 20 ft thick but are much thinner in most places. Boundaries are generally indistinct and are approximately located because of downslope movement of the terrace material by slope wash or creep. Small deposits and isolated patches of cobbles are not shown. Clasts are mostly rounded quartz or quartzite derived from Chilhowee Group and older rocks. The age of the deposits is uncertain, but it seems reasonable to accept the analysis of King (1950, p. 60–62), who assigned similar deposits to the south to the Pleistocene.

Colluvium

Deposits of rubble found at the base of cliffs and ledges, choking hollows on mountain sides, and forming barren scree slopes near mountain crests, are collectively shown (by overprint pattern) as colluvium. Boundaries are approximate. Only very thick and conspicuous deposits are shown, as thin colluvium mantles most of the mountain slopes. As shown on the map, the unit includes both gravity and debris flow deposits. The rubble is composed of angular blocks generally from about 1 to 5 ft but locally as much as 15 ft across. The blocks are mostly derived from quartzite ledges in the Weverton or Antietam Quartzites or from massive greenstone, especially epidosite, in the Catoctin Formation. The deposits show no sign of recent movement and most are presumed to be at least as old as Pleistocene, but some may be younger.

Alluvium

Deposits of unconsolidated, fining-upward material forming floodplains along the Shenandoah River and its major tributaries and along small streams in the eastern part of the quadrangle are shown as alluvium. Bedrock is exposed in the channels of most of these streams, even where extensive alluvial deposits are present. Travertine is common along the bed of tributaries on carbonate bedrock. Alluvium is composed chiefly of silt and sand, with local gravel deposits at the base of these finer sediments or exposed locally in stream channels. Gravel is composed of rounded clasts of quartz, quartzite, greenstone, and lesser amounts of other rock types; locally derived clasts of carbonate rocks are found in some places. Some gravel deposits are cemented by iron-manganese oxides. Alluvium is apparently as much as 20 ft thick. Deposition of alluvium is continuing; the age of the oldest alluvium is not known, but is probably Holocene.

STRUCTURAL GEOLOGY AND TECTONIC HISTORY

The basement rocks in the Round Hill quadrangle were deformed and metamorphosed to granulite facies during Grenville time, about 1.0–1.1 Ga, and the cover rocks were metamorphosed to greenschist facies during the Late Paleozoic Alleghanian orogeny, at which time the basement was retrograded (Mitra, 1987). Although no evidence has been found, effects attributable to the Late Ordovician Taconic orogeny cannot be ruled out. Structural elements present in the quadrangle include folds, faults, penetrative and spaced cleavage, foliation and compositional banding, and joints.

Folds

The principal structure in the region is the Blue Ridge - South Mountain anticlinorium (Keith, 1894b; Espenshade, 1970) (fig. 2), an allochthonous (Harris, 1979) regional fold overturned toward the northwest. The Round Hill quadrangle contains rocks on the northwest (overturned) flank of this fold. Broad, open map-scale folds can be traced through the carbonate units west of the Shenandoah River. The anticline just east of Meyerstown and Kabletown appears to be an extention of the Cool Spring anticline of the adjacent Berryville quadrangle (Edmundson and Nunan, 1973). The Catoctin Formation exposed in the southeastern corner of the quadrangle appears to lie in a narrow syncline, the axis of which lies just east of the quadrangle boundary; the basement rocks to the west thus apparently are in the core of an anticline (the "Rohersville anticline" of Jonas and Stose, 1939). Smaller-scale mesoscopic folds are common in all of the cover rocks. Locally the Chilhowee Group rocks are involved in extensive nappe-like recumbent folds (see cross section A-A′). Fold axes trend northeast-southwest, are generally horizontal or plunge gently in either direction, and all folds verge northwestward. Axes of the small-scale folds commonly trend about N5–15° E, 10 to 20° more northerly than the anticlinorium.

Faults

Faulting in the quadrangle is apparently limited to a few minor mappable faults and numerous small outcrop-scale dislocations. The thrust fault along the Shenandoah River in the southwestern corner of the map, which places Antietam Quartzite over Tomstown Dolomite, terminates about 2 mi to the southwest in the Ashby Gap quadrangle (Gathright and Nystrom, 1974). It is mapped across the southeast corner of the Berryville quadrange (Edmundson and Nunan, 1973), but its northeastward extension into the Round Hill quadrangle is covered by surficial deposits. Butts (1940, p. 440) postulated a "Blue Ridge thrust" along the western boundary of the Blue Ridge province in Virginia. Regional thrust faults were shown on the west side of the Blue Ridge in the Round Hill quadrangle area by Keith (1894a,b) and Grimsley (1916), and Stose and Stose (1946, p. 111) interpreted the Weverton-Harpers contact as a major thrust ("Harpers Ferry Overthrust"). No such faults were recognized by Cloos (1951), Nickelsen (1956), or Gathright and Nystrom (1974), and no evidence for major thrust faulting was found at the Weverton-Harpers contact during the present study. However, the Tomstown-Waynesboro contact, where well exposed along the Shenandoah River in the northern part of the quadrangle, is characterized by numerous small-scale structures and a lack of most of the red beds that are typically present at the base of the Waynesboro; this may represent intraformational movement associated with intensive, recumbent folding to the east (cross section A-A′). Alternatively, these features may be the result of a splay, such as the one shown on cross section B-B′, from a regional sole thrust. Sense of movement on minor structures supports the former interpretation.

Nickelsen (1956) mapped a large-scale normal fault along the western base of Short Hill Mountain in the adjacent Purcellville quadrangle. This fault was mapped as extending into the basement rocks southwestward and ending about two miles before entering the Round Hill quadrangle. Parker (1968) mapped the contact of the Catoctin Formation with Proterozoic gneisses as a fault in the Bluemont quadrangle to the south, along a projection of the Short Hill fault, and regional compilations (for example, Espenshade and Clarke, 1976, Fig. 1) show the fault to be continuous through the southeastern corner of the Round Hill quadrangle. Although evidence of faulting at the contact between the Catoctin and basement rocks has been found in the Lincoln quadrangle (Milton, unpublished data), the presence of the Swift Run Formation in normal stratigraphic sequence suggests that no major fault is present on this trend in the Round Hill quadrangle.

Ductile deformation zones, narrow zones of mylonitized rock with a large component of simple shear, are characteristic of basement terrane in the Blue Ridge of northern Virginia (Mitra, 1979). No such zones significant at map scale were found in the Round Hill quadrangle, very likely due to inadequate exposure.

Cleavage

A penetrative cleavage is conspicuous throughout the Round Hill quadrangle, particularly in the finer grained rocks. This foliation, termed "Blue Ridge - South Mountain cleavage" by Mitra and Elliot (1980), has a very uniform orientation in this area, as shown on fig. 3; the strike averages about N25°E, parallel to the axis of the anticlinorium here, and the dip ranges mostly between about 10° and 40°SE. Cleavage was mapped in all of the stratigraphic units of the cover, but is most widespread and pervasive in the Harpers Formation. It results from aligned micaceous minerals and elongated grains of quartz or carbonate minerals due to pressure solution and "dislocation creep" (Mitra and Elliot, 1980, p. 307). Cleavage attitudes are apparently axial planar to folds in the cover rocks. According to Mitra and Elliott (1980, p. 311), they are also asymptotic to thrusts in basement rocks, and thus steeper to the

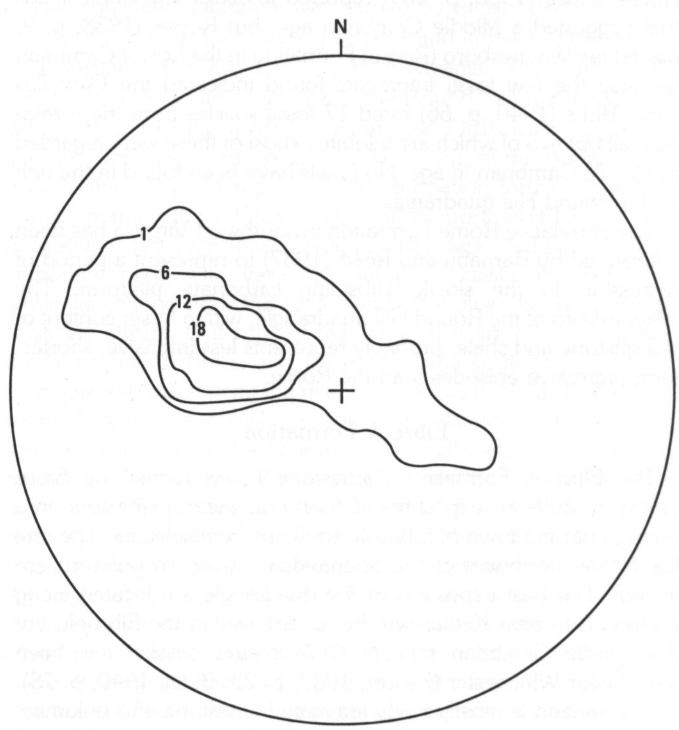

Figure 3.—Equal area projection (lower hemisphere) of 141 poles to cleavage in cover rocks of the Round Hill quadrangle. Contours at 18, 12, 6, and 1 per 1 percent area

east where the thrusts are deeper. In an unoriented sample of Loudoun Formation phyllite from one locality, the penetrative cleavage was overprinted with a later crenulation cleavage, indicating at least two deformational events. A crenulation cleavage is particularly well developed in the thinly laminated units of the upper part of the Swift Run Formation. Mitra and Elliot (1980, p. 311) described the Blue Ridge - South Mountain cleavage as axial planar to cover-rock folds and asymptotic to thrust faults in basement rocks, and thus coeval with the folding and thrusting. Therefore, cleavage is the result of a single deformational event (necessarily Alleghanian, since Devonian rocks to the west are involved). The effects of earlier orogenies, such as the Taconian, have not been recognized. A tectonite front for orthoquartzites has been identified by Mitra (1987, p. 589) along the Blue Ridge front, east of which the rocks show a dislocation-creep strain fabric resulting in a "well defined preferred dimensional or lattice orientation," while younger quartzites to the west have only pressure solution and cataclastic fabric.

Joints

Jointing is common in all of the rocks, but is most conspicuous in the more competent Weverton and Antietam Quartzites. Joints are predominantly steeply dipping and most trend across the regional strike at about N55°W. Locally the Weverton is highly veined, with the quartz-filled veins parallel to bedding, cleavage, or the common joint trend. Calcite-filled veins are common in the Tomstown Dolomite and Waynesboro and Elbrook Formations, and the Waynesboro locally has veins of pink potassium feldspar.

Tectonic history

The oldest rocks in the Round Hill quadrangle, forming the core of the Blue Ridge anticlinorium, are basement rocks of Middle Proterozoic age. These rocks are within the external Shenandoah massif of the Laurentian margin (Rankin and others, 1989). They are of problematic origin, and elsewhere within the anticlinorium may include sedimentary as well as volcanic and plutonic protoliths. The Grenville event produced a granitic complex metamorphosed to granulite facies. This complex was later intruded by a series of anorogenic granitic and felsitic rocks of Late Proterozoic age, forming the Robertson River pluton, which is exposed in the core of the Blue Ridge anticlinorium some ten miles south of the Round Hill quadrangle (Clarke, 1984, p. 159) These continental rocks underwent a passive margin rifting event in Late Proterozoic time, associated with the opening of the Iapetus Ocean. At this time coarse, feldspar-rich fluvial sediments, suggesting a source area of high relief, were deposited unconformably on an irregular surface of Grenville basement rocks. These (Swift Run Formation) sediments later became finer grained and were interbedded with tuffs and very local lacustrine (?) carbonate deposits. Basaltic flows of the Catoctin Formation followed, with intermittent deposition of fine-grained sediments and tuffs. These rift facies rocks were succeeded by miogeoclinal drift facies sediments of the Chilhowee Group and overlying carbonate sequence. In southwestern Virginia, the transition from rift to drift facies was placed in the upper part of the Unicoi Formation (apparent equivalent of the Weverton Quartzite) by Simpson and Sundberg (1987), on the basis of marine fossils in the upper Unicoi and basalt flows in the lower. No fossils were found in the Weverton, but these coarse alluvial sediments give way to fine-grained deltaic deposits of the Harpers Formation and fossiliferous littoral marine deposits of the Antietam Quartzite. Continental breakup in this area is thus probably an Early Cambrian event, reflected in the transition from Weverton to Harpers or Antietam sedimentation. The Lower and Middle Cambrian carbonate sequence indicates a slowly subsiding, quiescent passive margin shelf environment. The next tectonic event recognized in the area is late Paleozoic (Alleghanian) compressional deformation, which produced folding, faulting, low-grade (greenschist) metamorphism, and cleavage in the cover rocks, and imposed retrograde metamorphism and foliation on the basement rocks.

MINERAL RESOURCES

At the present time no mineral resources are being exploited in the Round Hill quadrangle.

In the northern part of the quadrangle, residual iron ore (limonite, or "brown ore") was mined in the Nineteenth Century from deposits formed by weathering processes on the Tomstown Dolomite near its contact with the underlying Antietam Quartzite. King (1950, p. 65–66) postulated that the concentration of iron in deposits of this type took place during the Tertiary Period. The nodular ore was taken mostly from open cuts and worked at the old Shannondale furnace, which still stands on the banks of Furnace Run at Shannondale. A sample of this ore was reported by Grimsley (1916, p. 586) to contain 50.8% metallic iron. According to Lesley (1859, p. 65) the furnace was built in 1837 and in 1855 produced 250 tons of iron. Remains of the largest workings are found on both sides of the Shenandoah River near Mountain Mission and Shannondale, but a few smaller pits lie to the south.

Zinc ore has apparently been mined from the lowermost Tomstown Dolomite at the Howell zinc prospect, on the east bank of the river a mile northeast of Riverside. A study of the prospect by Ludlum (1955) revealed the remains of an old shaft, but no records of mining were found. Ludlum (1955, p. 859–860) reported the presence of cockade or halo zoning of sphalerite, galena, and pyrite, along with secondary white, sparry dolomite and feldspar. The prospect has not been commercially exploited because of the low tenor and limited distribution of the ore.

High-magnesium dolomite in the Tomstown Dolomite is quarried in an extensive operation at Millville, West Virginia, two miles north of the Round Hill quadrangle (Grimsley, 1916), and in the Stuart M. Perry quarry near Castlemans Ferry, Virginia, two miles west of the southwestern corner of the quadrangle (Edmundson and Nunan, 1973, p. 78; Gathright and Nystrom, 1974, p. 46). Dolomite of exceptional purity has been obtained from the Millville workings since 1901, and has been shipped to Pittsburgh for use in the steel manufacturing industry (Grimsley, 1916, p. 401–402). Smaller pits have been opened locally in the Tomstown and overlying carbonate rocks in the Round Hill quadrangle, presumably for use as road metal or for agricultural lime. A general description of the limestone and dolomite resources in this area, including chemical analyses, is given by Edmundson (1945) and Woodward (1939, p. 109–111; 1949, p. 237–242).

The more resistant rock types have been used locally for construction of houses and barns, and especially stone fences. The most commonly used rocks include quartzites of the Weverton and epidosite from the Catoctin Formation, but all stratigraphic units producing float are employed. A quarry in the Antietam Quartzite on Furnace Run apparently supplied fill material for construction of the nearby dam.

Groundwater is an important resource in the quadrangle. While generally in plentiful supply, yields from specific sources range widely. The towns of Round Hill and Purcellville have spring-fed reservoirs within the quadrangle at the base of the Blue Ridge. In areas along and east of the Blue Ridge, underlain by siliciclastic sedimentary and metamorphic rocks, numerous wells supply households with groundwater from bedrock, where the water probably moves through fractures. In areas of carbonate bedrock, west of the Shenandoah River, where karst topography is dominant, solution channels are likely; well depth and yield are particularly variable, and pollution of water supplies is a potential hazard.

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