HYDROGEOLOGIC SETTING OF SPRINGS ON SHORT HILL MOUNTAIN, LOUDOUN COUNTY, NORTHERN VIRGINIA

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INTRODUCTION

Geologic mapping of bedrock and surficial materials at a scale of 1:12,000 contributed to an understanding of the hydrogeologic setting of springs on Short Hill Mountain, Loudoun County, northern Virginia. Short Hill Mountain is a nearly continuous east-sloping hogback more than 11 mi (18 km) long and 1 mi (1 to 3 km) wide within the Blue Ridge physiographic province (fig. 1). Maximum elevation is approximately 1,440 ft (450 m) above sea level with local topographic relief as much as 1,000 ft (300 m). The study area is located within the Purcellville, Va. and Harpers Ferry, W. Va.-Va.-Md. 7.5-minute quadrangles and within the Frederick, Md. 1:100,000-scale quadrangle. Short Hill Mountain is the recumbent northwest limb of the allochthonous South Mountain anticlinorium and is composed of folded and faulted sedimentary and metamorphic rocks of Precambrian to Cambrian age (Nickelsen, 1956).

An objective of this investigation is to determine ground-water behavior in a mountainous terrain; ground-water behavior helps define mechanisms of local and regional ground-water recharge and discharge. Although the hydrogeology of these crystalline rocks is not well known (Sinnott and Cushing, 1978), the subject is important because of increasing water demand, and because of potential contamination problems resulting from the recent land-use change from rural-agricultural to high-density suburban development nearby.

More than 60 observed springs indicate zones of local ground-water discharge. Flow from most of the springs is largely controlled by topography, bedding-plane partings along lithologic contacts, and faults; joints, fractures, and rock cleavage apparently act as local conduits of ground-water flow. Recharge zones occur where inclined pervious strata parallel to the slopes crop out or are present at shallow depth. Outcrop and dip slopes of impervious units are generally characterized by deposits resulting from rapid overland flow, whereas colluvium mantles much of the mountain slopes and acts as areas of interflow (shallow subsurface runoff of ground water). Major landslides are common, and rock slides, block streams, and large colluvial deposits may act as local catchment basins of interflow. Bedrock hydrogeologic units that may be aquifers where fractured include the Weverton Quartzite, Catoctin Formation, and granodiorite gneiss. Interbedded quartzite and phyllite are highly anisotropic ground-water units and may act as either recharge or discharge zones. The inferred distribution of recharge and discharge zones suggests that Short Hill Mountain may be a significant recharge area for many of the crystalline rocks of this region. These data are qualitative; therefore, in the future, they should be integrated with water-well data to relate ground-water flow in Short Hill Mountain to that in adjacent lowlands.

Acknowledgments

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GEOLOGY

Bedrock lithology and structure, surficial deposits, and springs were mapped at a scale of 1:12,000 on topographic maps with 5 ft (1.5 m) contours provided by the Loudoun County Department of Natural Resources. The geologic map is modified from Nickelsen (1956). Color-infrared aerial photographs at a scale of 1:24,000 were used to map bedrock fractures in the adjacent lowlands.

The oldest geologic unit in the study area is Precambrian granodiorite gneiss which is highly fractured and exhibits numerous shear zones. The rock is generally poorly exposed and is intruded by dikes and sills of late Precambrian Catoctin metabasalt. The contact of granodiorite gneiss with the overlying Swift Run Formation on the eastern dip slope is unconformable. No Swift Run is found between granodiorite gneiss and Catoctin Formation on the west slope. To the north, the granodiorite gneiss contact on the western outcrop slope with the Harpers Formation is a fault (Nickelsen, 1956). The Swift Run Formation grades upward from sericitic, quartz-pebble conglomerate and sandy phyllite near the base to phyllites of the upper unit; lenses of marble locally occur just below the contact with the Catoctin Formation. The Swift Run Formation varies in thickness from 0 to 500 ft (0 to 152 m). The Catoctin Formation is characterized by massive to foliated metabasalt with epidosite, schistose volcaniclastics, and metasedimentary phyllites. Numerous fine- to coarse-grained "greenstone" metabasalt dikes and sills intrude both the Swift Run Formation and granodiorite gneiss. The Catoctin contact on the western outcrop slope with the Weverton Quartzite and Harpers Formation is a normal fault (Nickelsen, 1956). The Catoctin Formation varies in thickness from 50 to 600 ft (15 to 182 m); dikes and sills are about ± 1 m thick.

The contact of the Catoctin Formation with the overlying Cambrian Weverton Quartzite is abrupt, with no intervening Loudoun Formation recognized (Nickelsen, 1956). The Weverton Quartzite is highly fractured and consists of two mappable units that are undifferentiated on this map. The middle to lower Weverton is a massive to thin-bedded sequence of relatively clean quartzites interbedded with phyllites. The quartzite is well sorted lower in the section (Nickelsen, 1956). The quartzites interbedded with phyllites form a series of dip-slope ledges and hogbacks more numerous than the three cited by Nickelsen (1956). The upper Weverton is typically a greenish-gray to "gun-metal" blue (Nickelsen, 1956), coarse-grained, conglomeratic quartzite. At the southern terminus of Short Hill Mountain, faulting and erosion have reduced the Weverton Quartzite to less than half its original thickness of approximately 500 ft (152 m).

Metasiltstones of the Cambrian Harpers Formation form the core of an isoclinal syncline that plunges to the north and is recumbent to the northwest. The metasiltstone outcrop is broader to the northeast on the upper portion of the west slope where the maximum thickness is approximately 1,000 ft (304 m). The isoclinal syncline is complicated by a normal fault at the base of the west slope that places the Harpers Formation in fault contact with sheared Precambrian granodiorite gneiss. Resistant quartzite units of the Weverton cap and preserve the structure as a positive topographic feature. All bedrock units are inclined and display cleavage and foliation which dip to the southeast.

Surficial geologic units are widespread, contrary to Sinnott and Cushing's (1978, p. I-9) statement that "because of the elevated, resistant rocks in the Blue Ridge, they tend to be stripped of surficial weathered material." Mountain-slope colluvium of Weverton Quartzite is abundant in the form of talus, block streams, and rock slides. Colluvial deposits grade to debris or alluvial fans probably as a result of deposition due to decreased gradient at the break in slope at the base of Short Hill Mountain. Bedrock landslides of Weverton Quartzite are numerous and include rock slides, rock slumps, and gravitational sags (sackung) (Schultz and Southworth, 1989). Their origin may be due to a combined function of the overturned synclinal structure, interbedded quartzite, phyllite, and metasiltstone that dip steeply parallel to the slopes, and elevated pore pressures due to ground-water flow within the fractured lithologic units. All bedrock landslides are coincident with ground-water discharge zones, suggesting a causal relationship. Water wells in the gap at Hillsboro, Va., suggest that approximately 10 ft (3 m) of alluvium is present along the North Fork Catoctin Creek.

Excavations at the base of the east slope of Short Hill Mountain have revealed that saprolite on phyllite of the Swift Run and Catoctin Formations extends to depths greater than several meters, and that is overlain by a veneer of quartzite colluvium (1 ft or <0.30 m).

HYDROGEOLOGY

Short Hill Mountain is centrally located within the Potomac River drainage basin, east of the confluence with the Shenandoah River at Harpers Ferry, W. Va. The Potomac River flows eastward with base level at approximately 240 ft (73 m) above sea level. The crest of the mountain forms the drainage divide, and interfluves define five subdrainage basins that include Piney Creek, Dutchman Creek, Milltown Creek, North Fork Catoctin Creek and South Fork Catoctin Creek (fig. 2). The elongate hogback mountain is structurally continuous but is breached by the North Fork Catoctin Creek at about 500 ft (152 m) above sea level at Hillsboro. More than 60 springs were classified as a combination of both topographic-depression springs and contact springs. The distribution of these springs has been used to define general regions of recharge and discharge (fig. 2). Freeze and Cherry (1979) generally define highlands as recharge areas and lowlands as discharge areas, but further refinements can be made on Short Hill Mountain. The apparent zone of recharge is from the bench of Harpers Formation high on the west slope to the dip slope of Weverton Quartzite on the east, where inclined strata of quartzite, phyllite, and metasiltstone parallel the slope and are exposed or shallow. The outcrop slope of the Harpers Formation is generally covered, but incised channels in residual soil suggest overland flow with minor interflow (fig. 3). Massive quartzite beds within the Weverton Quartzite generally have low porosity and permeability; thus, the dip slope is characterized by rapid overland flow as indicated by piles of forest litter distributed on the dip slopes after storms. Interflow presumably increases where colluvium mantles the shallow quartzite. Maximum interflow takes place where convex hillslopes of colluvium are intersected by deeply incised channels at the base of the slope.

Discharge zones are common along the break in slope at the base of the mountain, and apparently are a function of topography and lithologic contacts. These zones create dark tonal anomalies on color-infrared aerial photographs taken in early spring, and trees in these zones are the first to bear leaves in spring. Regional discharge zones are topographically higher on the east slope (650 to 980 ft or 200 to 300 m) than on the west slope (490 to 650 feet or 150 to 200 m) and both decrease in elevation northward to the Potomac River. Exceptions are springs at quartzite and phyllite contacts as high as 1,300 ft (400 m) above sea level. Most of these springs are ephemeral (wet-weather), but others have consistently supplied municipal water for two centuries (Hillsboro Bicentennial Committee, 1976). Brunswick, Md., receives its municipal water from two springs, one on Short Hill Mountain from which water is piped under the Potomac River to Brunswick, and one spring on nearby South Mountain (the extension of Short Hill Mountain); both these springs yield more than 200,000 gallons per day (8 liters per second) (K. Brower, Brunswick Water Authority, 1989, oral commun.). Discharge zones are areas with seasonally high water tables and may present such development problems as poor foundation conditions and failure of septic systems.

Potentially significant hydrogeologic units that may be aquifers include the granodiorite gneiss, Catoctin Formation, and Weverton Quartzite. The anisotropic flow of ground water between the quartzite, phyllite, and metasiltstones is indicated by springs high on the slope. Hydraulic conductivity (K) models for similar inclined units are taken from Hubbert (1940) and Hodge and Freeze (1977) (fig. 4). Whether K is greater for the quartzites or for the phyllites and metasiltstones on Short Hill Mountain is at present unknown; however, springs in phyllite units below massive quartzite beds of the Weverton are well exposed where Maryland Route 340 cuts through South Mountain near Weverton, Md., and where Interstate Route 66 cuts through the same rocks at Thoroughfare Gap, Va. Thus, massive quartzite beds may serve as leaky confining beds (aquitards with low K) and thin quartzite interbedded with phyllite may act as a local aquifer (high K).

Contact springs at the base of the Weverton Quartzite dip slope, where Catoctin Formation phyllite is covered by colluvium, are probably also controlled by permeability differences. Fractures and joints well exposed on dip slopes of Weverton undoubtedly are pathways for water. Metabasalt dikes in contact with the metasediments of the Catoctin act as other local zones of discharge. The aphanitic metabasalt dikes have low permeability and act as hydrologic barriers; thus, ground water commonly is discharged at the contacts. Likewise, many springs occur in the poorly exposed, fractured granodiorite gneiss near intrusive bodies of Catoctin metabasalt. Trainer and Watkins (1975) suggest that all of these crystalline rocks store and transmit water through fractures.

Numerous springs in colluvial deposits of large bedrock landslides suggest a causal relationship that is not yet clear. Interflow is certainly increased in these deposits due to increased porosity, but the initial site of infiltration may be bedrock contacts upslope at the head of the slide scar. Although colluvial slope deposits as much as 3 ft (1 m) thick mantle much of the slope below the zone of recharge, ground-water discharge is believed to be a function of both topography and bedrock contacts between lithologic units with different permeabilities. Interflow and infiltration within the colluvium is ephemeral, yet large colluvial deposits near the slope base may act as local catchment basins for shallow ground water.

A schematic cross section summarizes the understanding of the relationship of bedrock lithology and structure to the hydrogeology of Short Hill Mountain (fig. 5). Inferred potentiometric lines analogous to those in figure 4 suggest that the hydrogeologic configuration in the isoclinal syncline of Weverton Quartzite. In this interpretation, the inclined fractured quartzite, phyllite, and metasiltstone units are recharge zones of meteoric water. Ground-water discharges on the dip slope as flow lines intersect the surface in depressions and along fractures and less permeable contacts in the outermost units. Toward the core of the syncline, ground water may flow parallel to bedding in both limbs. Substantial ground water may be stored in fractures within the synclinal hinge, as at the Maryland Route 40 roadcut through the Sideling Hill syncline where springs discharge from the hinge of a syncline. Springs discharge at contacts high on the slope as a function of artesian flow, probably in areas of upward hydraulic gradient where fractures intersect bedding. Water from these springs on the upper slope becomes interflow in local catchment basins of colluvium downslope. How or if this water recharges the crystalline rock in the surrounding lowlands is unknown.

Fracture traces and linear drainages in lowlands underlain by crystalline rock were interpreted from color aerial photographs. These linear trends generally parallel joints (Nickelsen, 1956) and fractures mapped in the Weverton Quartzite (see map and fig. 6), and may be favorable sites for ground-water exploration.

CONCLUSIONS

Detailed mapping of geology and springs has contributed to the understanding of the bedrock lithology, structure, and the general hydrogeologic framework of Short Hill Mountain. The highest concentration of spring discharge is along the lower slope in zones as much as 330 ft (100 m) wide, but most springs seem to be controlled by formational contacts, fractures, or boundaries between lithologies of different permeability. Thin colluvium on residuum commonly covers bedrock; springs may provide information related to these subsurface contacts.

The granodiorite gneiss, Catoctin Formation, and Weverton Quartzite are potentially important fractured aquifers. Anisotropic boundaries, such as contacts between quartzite and phyllite, metabasalt and fractured metasediments, and metabasalt and other fractured crystalline rocks, are probable conduits for ground-water flow and discharge. Highly fractured quartzites and cleaved metamorphic rocks show numerous springs. Colluvial deposits of quartzite provide conduits for interflow and thus may serve as local catchment basins.

Ground-water discharge by springs is abundant on the mountain and is an integral component of the regional aquifer system. Water wells sited along fracture traces observed on aerial photographs or above the zone of springs at the base of the mountain may intersect water-bearing fractures. However, a thorough water-well drilling and pump test program is necessary to evaluate the ground-water resources.

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Figure 1.--Map showing the hydrogeologic setting of Short Hill Mountain. Index map shows location of figures 1 and 2.

SCALE 1:24 000
1 MILE
1 KILOMETERS
CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

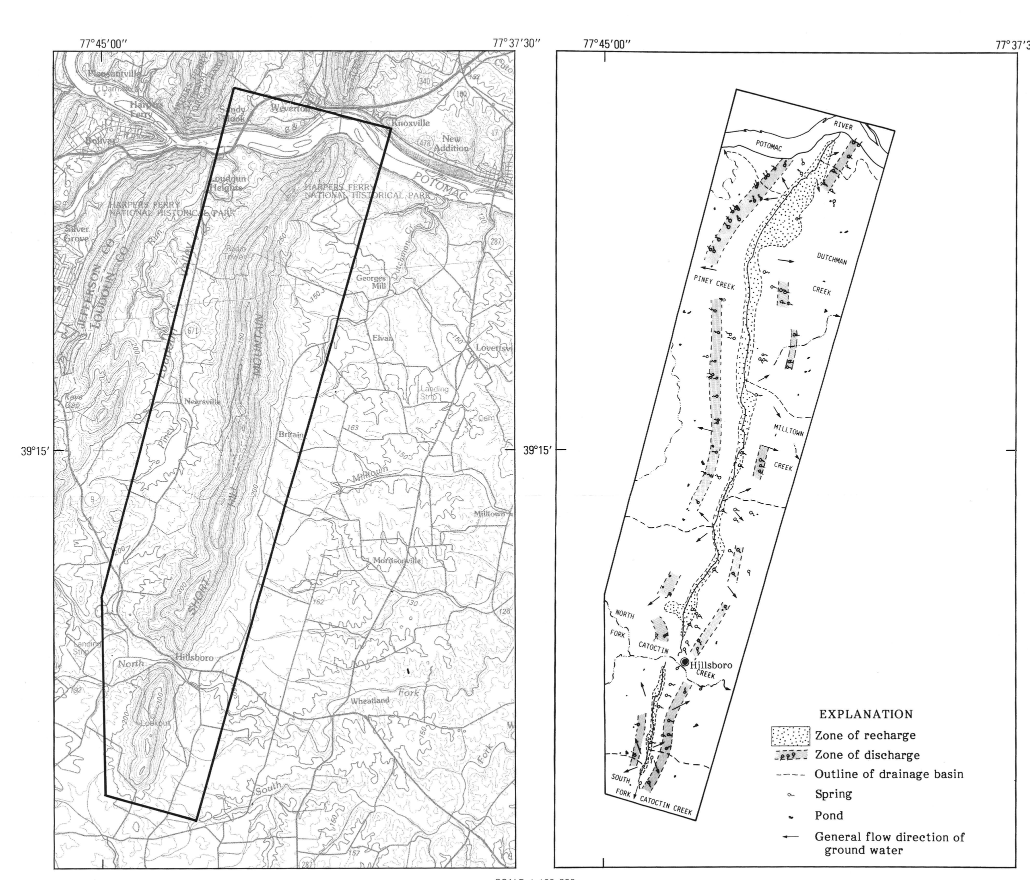


Figure 2.--1:100,000-scale metric topographic map and ground-water map of Short Hill Mountain. Springs between the two zones are contact springs.

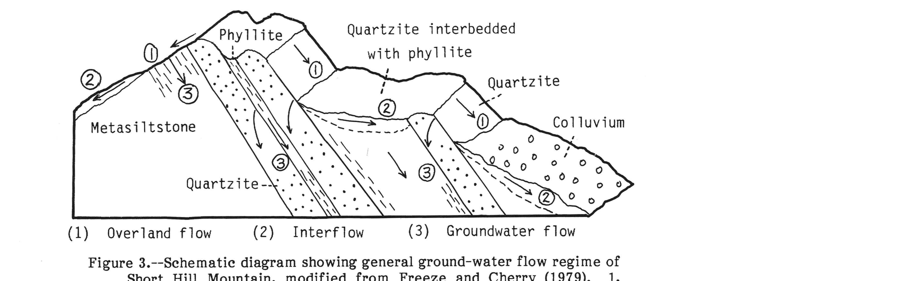


Figure 3.--Schematic diagram showing general ground-water flow regime of Short Hill Mountain, modified from Freeze and Cherry (1979). 1, Overland flow; 2, Interflow; 3, Ground-water flow.

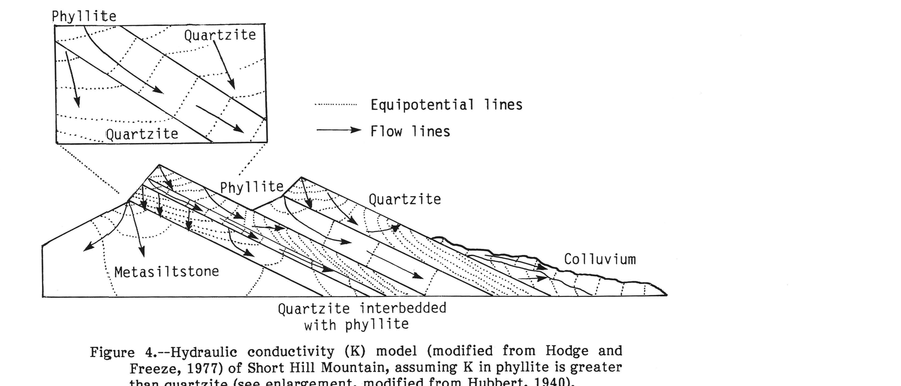


Figure 4.--Hydraulic conductivity (K) model (modified from Hodge and Freeze, 1977) of Short Hill Mountain, assuming K in phyllite is greater than quartzite (see enlargement, modified from Hubbert, 1940).

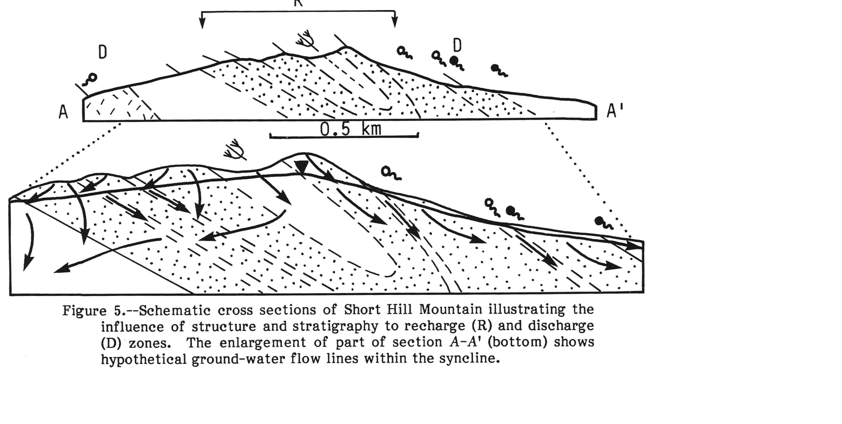


Figure 5.--Schematic cross sections of Short Hill Mountain illustrating the influence of structure and stratigraphy to recharge (R) and discharge (D) zones. The enlargement of part of section A-A' (bottom) shows hypothetical ground-water flow lines within the syncline.

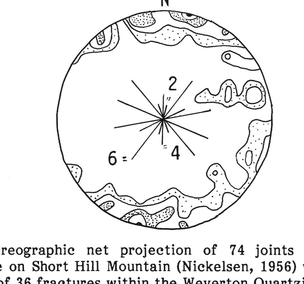
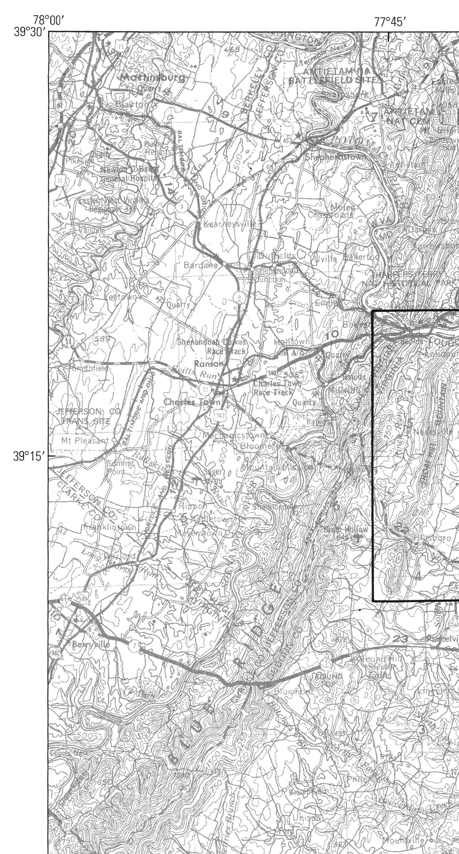


Figure 6.--Stereographic net projection of 74 joints of the Weverton Quartzite on Short Hill Mountain (Nickelsen, 1956) with an inset rose diagram of 36 fractures within the Weverton Quartzite. The length of the vectors of the rose diagram are proportional to the frequency (2, 4, or 6 stations).



Index map

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