COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION
AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES

HIGH-SILICA RESOURCES OF CLARKE, FREDERICK, PAGE, ROCKINGHAM, SHENANDOAH, AND WARREN COUNTIES, VIRGINIA

W. BURLEIGH HARRIS

MINERAL RESOURCES REPORT 11

VIRGINIA DIVISION OF MINERAL RESOURCES
James L. Calver
Commissioner of Mineral Resources and State Geologist

CHARLOTTESVILLE, VIRGINIA
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HIGH-SILICA RESOURCES OF CLARKE, FREDERICK, PAGE, ROCKINGHAM, SHENANDOAH, AND WARREN COUNTIES, VIRGINIA

By

W. BURLEIGH HARRIS

ABSTRACT

The principal high-silica resources of Clarke, Frederick, Page, Rockingham, Shenandoah, and Warren counties in the northern Valley and Ridge province of Virginia are in the Erwin Formation, Tuscarora Formation, Massanutten Sandstone, Ridgeley Sandstone, and Pocono Formation. Physical descriptions, sieve analyses, and chemical test data are presented for evaluation of potentially commercial high-silica raw material.

Composite samples from selected localities in the Erwin, Tuscarora, and Ridgeley, analyzed in a raw or unbeneficiated condition, have a silica content that ranges from 96.8 to 99.7 percent. The percentage of silica in beneficiated samples ranges from 98.6 to 99.7. A general decrease in percentage of Al_2O_3 and Fe_2O_3 upon simple beneficiation indicates that some clay- and silt-size particles and some iron-oxide stains on the quartz grains were effectively removed. Histograms and cumulative-frequency curves provide a visual guide to grain-size distribution, average grain size, and the degree of sorting. Chemical analyses of hand samples of the Erwin, Tuscarora, Massanutten, and Pocono indicate a silica content that ranges from 98.6 to 99.6 percent; sieve analyses were not performed because of the high degree of induration of these samples.

INTRODUCTION

A study of potential silica-sand resources in Clarke, Frederick, Page, Rockingham, Shenandoah, and Warren counties in the northern Valley and Ridge province of Virginia was started by the Virginia Division of Mineral Resources in November 1970. The purpose was to establish new specific information about selected sandstone and quartzite formations that might lead to their utilization for commercial high-silica purposes. In the six

counties, 113 sandstone and quartzite localities were examined. Eleven samples from nine of these localities warranted further study and were physically and chemically evaluated. Physical evaluations were made by the writer; chemical analyses were made by M.T.L. Industries in Towson, Maryland, under a cooperative agreement with the U. S. Bureau of Mines. This report contains physical descriptions, analyses, and chemical test data for potential high-silica raw materials in Frederick, Page, Rockingham, and Shenandoah counties. Numbers preceded by "R" (R-4515) correspond to localities where rock samples were collected (Plate 1). These samples are on file in the Virginia Division of Mineral Resources rock repository where they are available for examination. Exposures of sandstone and quartzite in Clarke and Warren counties were examined but not selected for analyses. An open-file report, describing 81 of the sandstone and quartzite localities in the six counties that were visited, but not sampled, is available (Harris, 1972).

The approximate boundaries of the George Washington National Forest and the Shenandoah National Park are shown in Plate 1. Privately owned tracts of land within the National Forest boundaries are not shown because of map scale. Sandstone and quartzite exposures were not examined in the Shenandoah National Park.

The principal high-silica resources of the study area are in the Erwin Formation, which is exposed in the eastern parts of Clarke, Page, Rockingham, and Warren counties; the Tuscarora Formation and Ridgeley Sandstone along and west of Little North Mountain in western Rockingham, Shenandoah, and Frederick counties; the Massanutten Sandstone in central Rockingham, eastern Shenandoah, and western Page and Warren counties; and the Pocono Formation in western Rockingham County (Plate 1). All distance measurements that are indicated as "along the road" are miles by road to specific sample localities.

ACKNOWLEDGEMENTS

The writer wishes to thank the residents of Clarke, Frederick, Page, Rockingham, Shenandoah, and Warren counties who provided access to private lands. Special thanks are due to D. C. Le Van who critically reviewed the manuscript and provided some field assistance. Appreciation is also extended to the U. S.

Bureau of Mines, which provided chemical analyses of selected samples, and particularly to Curtis D. Edgerton who provided liaison with the Bureau.

PROCEDURE

Exposures of sandstone and quartzite were measured and samples were taken at approximately 4- to 5-foot intervals. Material from each sampled interval was crushed by hand with a porcelain mortar and pestle; when tight cementation hindered disaggregation of the grains, the samples were broken into approximately 0.5 to 0.75 inch fragments, passed through a jaw crusher, and crushed as previously described. The individual samples were then mixed on a rolling cloth to form a composite sample, which was split and prepared for chemical and sieve analyses and beneficiation. Five hundred grams of each of the composite samples, except one 475-gram sample, were sieved on a Ro-Tap for a period of 10 minutes. If microscopic examination of the resulting individually sieved fractions revealed a large percentage of grain aggregates, those fractions were recrushed and the entire sample re-sieved for 10 additional minutes. Loss of the original sample during sieving ranged from 0.14 to 1.59 percent; the average loss was 0.56 percent.

The degree of sorting for the composite samples is based upon Folk's Inclusive Graphic Standard Deviation which includes 90 percent of the size-distribution of the total sample (1968, p. 46). When none of the sample was retained on the 10-mesh sieve or when the cumulative total of the sample retained on the 10- through 200-mesh sieves was not at least 95 percent of the total sample, the Inclusive Graphic Standard Deviation was not applicable. The Graphic Standard Deviation which includes the central 68 percent of the size distribution of the total sample was then used to determine the degree of sorting. Beneficiation consisted of agitation in water in a Waring Blendor for 15 minutes and then decanting. The samples were then oven dryed at 100°C. Beneficiated samples were sieved for 10 minutes on the Ro-Tap for grain-size distribution and were used for heavy mineral separations made with 1, 1, 2, 2-tetrabromoethane (sp. gr. 2.97). The heavy minerals were identified and in each sample comprised less than 0.5 percent. Tightly cemented quartzite at four localities was considered for possible metallurgical

use, and hand samples of these were chemically analyzed. Thin sections and grain mounts were prepared for crushed and hand samples, which were analyzed and studied to determine quartz content, sorting, cementation, and impurities.

SILICA-SAND INDUSTRIAL ACTIVITY

Unisil Corporation produces silica sand from the Ridgeley Sandstone approximately one mile south of Gore in Frederick County. The quarry is located on the nose of a northeastward-plunging anticline where the Ridgeley is greater than 200 feet thick (Butts and Edmundson, 1966, p. 60, 117). A chemical analysis of the processed sand produced from this locality by a predecessor company is as follows: SiO_2, 99.16 percent; Fe_2O_3, 0.029 percent; Al_2O_3, 0.43 percent; TiO_2, 0.034 percent; CaO, 0.08 percent; MgO, trace; loss on ignition, 0.18 percent (analysis by Sharp-Schurtz Co., Lancaster, Ohio and reported in Lowry, 1954).

The Massanutten sandstones have been produced intermittently at Burners Gap in Page County for use as building, wall, and coping stone. Erwin sandstones and quartzites have been quarried from several localities east of Luray for crushed stone, construction sand, and dimension stone.

GENERAL GEOLOGY

ERWIN FORMATION

The Erwin Formation of Cambrian age consists almost entirely of quartzites and well-indurated quartzose sandstones, which are cemented by secondary silica. The formation consists of upper and lower units of about equal thicknesses. In Plate 1 and in Figure 16 the combined outcrop of both units is shown. The upper unit of the Erwin consists of thin-bedded sandstones and quartzites that weather into friable blocks with iron-oxide stain. Petrographic examination of a thin section from one locality revealed very poorly sorted, very-fine to coarse, quartz grains generally cemented by secondary silica. Minor clay and silt-size silica commonly occur as matrix material in the upper Erwin unit. The lower unit of the Erwin consists of clean, well-indurated, massive quartzite. Generally, sutured grain boundaries are observed in thin section with occasional polycrystalline

quartz along the boundaries. Minor white to tan plagioclase feldspar and sericite are also present.

Sample R-4608

Location: The Erwin Formation was sampled in Rockingham County on the south side of State Road 759, 1.2 miles along the road east of its junction with State Road 606, in the Elkton East, Virginia, 7.5-minute quadrangle (Figure 1).

Figure 1. Erwin quartzite along Naked Creek along the south side of State Road 759, Rockingham County, sample R-4608.

Measured section: Quartzite, fine- to coarse-grained, white to light-gray with minor pink iron-oxide stain; minor grains of white to light-tan plagioclase feldspar. The quartzite is massive and breaks with a conchoidal fracture; along some surfaces are thin veneers of silica formed by the capillary action of water in the formation (case-hardening). The section consists of an upper 26 feet of quartzite, approximately 20 feet of covered interval, and a lower unit of 22 feet of quartzite similar to the upper 26 feet. Strike and dip of the section is N.80°E., 25°SE.

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Laboratory analyses: In thin section the quartzite of R-4608 consists of fine- to very coarse-grained (0.008-0.055 inches), rounded to subrounded, highly strained quartz grains. Bonding is generally by a quartz-to-quartz weld along sutured grain boundaries. Some polycrystalline quartz occurs along the boundaries. In places a simple tangential quartz weld and secondary quartz overgrowths occur. Minor constituents are traces of sericite, weathered feldspar, rounded chert grains, zircon, muscovite, tourmaline, leucoxene, biotite, and epidote (?).

The quartzite at this locality is too well cemented to be crushed for determination of grain-size distribution. A chemical analysis of a hand sample from the upper quartzite is shown in Table 1.

Table 1.—Chemical analysis of sample R-4608, Erwin Formation.

Constituents	*Percent*
SiO_2	99.3
Al_2O_3	0.3
Fe_2O_3	0.59
CaO	0.01
MgO	0.01
K_2O	0.07
MnO	nd
TiO_2	nd
CoO	nd
Na_2O	0.03
Loss on Ignition	0.01

nd—not detected

Samples R-4510 and R-4511

Location (R-4510, R-4511): The Erwin Formation was sampled southwest of Stanley in Page County on the east side of State Road 619, 0.7 mile along the road west of its junction with State Road 621, in the Stanley, Virginia, 7.5-minute quadrangle. The Erwin at this locality was divided into an upper unit designated R-4510 and a lower unit designated R-4511.

Measured section (R-4510): Sandstone, fine- to medium-grained, white to light-gray to dark yellowish-orange, subangular to rounded grains, well-indurated to slightly friable. The sandstone contains white to tan-orange feldspar and clay. Iron-oxide stain is scattered throughout the exposure, but is concentrated along bedding planes and fractures. Beds range in thick-

ness from several inches to 14 inches (Figure 2). Exposed thickness of the unit is 47 feet; strike and dip is E.-W., 27°N.

Laboratory analyses (R-4510): In thin section the sandstone consists of very fine- to coarse-grained, angular to rounded quartz grains bonded by a simple tangential quartz weld; minor suturing of grain boundaries is present. Generally the coarse fraction is rounded and has secondary quartz overgrowths. Very fine polycrystalline quartz also occurs along some grain boundaries. Quartzite fragments are a minor constituent.

Figure 2. Friable sandstone of the Erwin Formation just southwest of Stanley, Page County, sample R-4510.

The principal heavy minerals are zircon, tourmaline, leucoxene, and pyrite; other minor minerals are rutile, kyanite, magnetite, hematite, muscovite, and apatite(?).

Sieve and chemical analyses of raw (R-4510-A) and beneficiated (R-4510-B) material from the upper 47 feet of the measured section are shown in Table 2. Histograms and cumulative-frequency curves are shown in Figure 3. The raw material is moderately sorted; upon beneficiation the sample becomes moderately to moderately well sorted.

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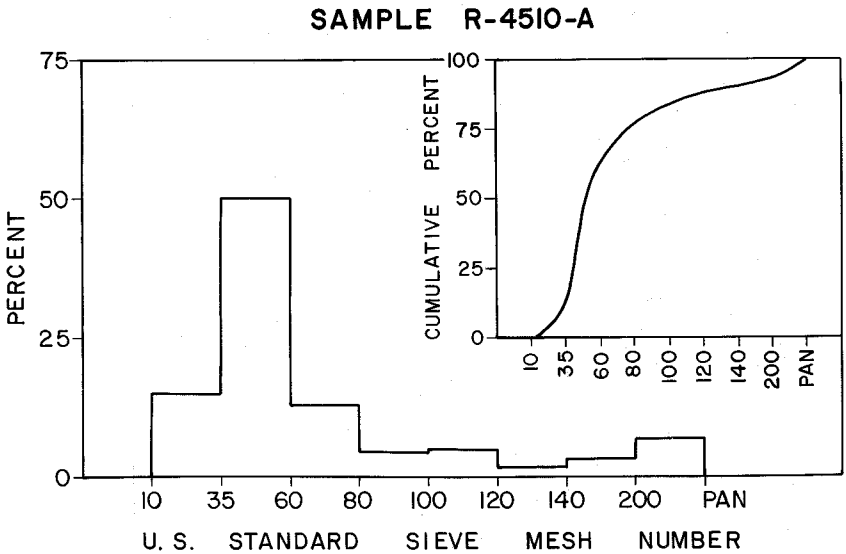
Table 2.—Sieve and chemical analyses of sample R-4510, Erwin Formation.

	SAMPLE R-4510-A (Raw Sample)	*SAMPLE R-4510-B* (Beneficiated)
SIEVE ANALYSES		
U. S. Standard Sieve Mesh No.	*Percent Retained*	
10	0	0
35	14.88	12.64
60	50.28	54.34
80	13.16	16.62
100	4.50	6.22
120	4.90	5.34
140	1.84	2.04
200	3.34	1.98
Pan	6.74	0.46
CHEMICAL ANALYSES		
Constituents	*Percent*	
SiO_2	97.8	99.6
Al_2O_3	1.4	0.3
Fe_2O_3	0.20	0.10
CaO	0.19	0.03
MgO	0.17	0.03
K_2O	0.11	0.03
MnO	nd	nd
TiO_2	nd	nd
CoO	nd	nd
Na_2O	0.03	0.02
Loss on Ignition	1.06	0.26

nd—not detected

Measured section (R-4511): Quartzite, fine- to medium-grained, white-gray to light yellowish-orange, subangular to rounded grains, well-indurated. The quartzite is highly iron stained in part and highly fractured. Bedding ranges from 1 to 14 inches in thickness (Figure 4). Exposed thickness of the unit is 94 feet; strike and dip is E.-W., 27°N.



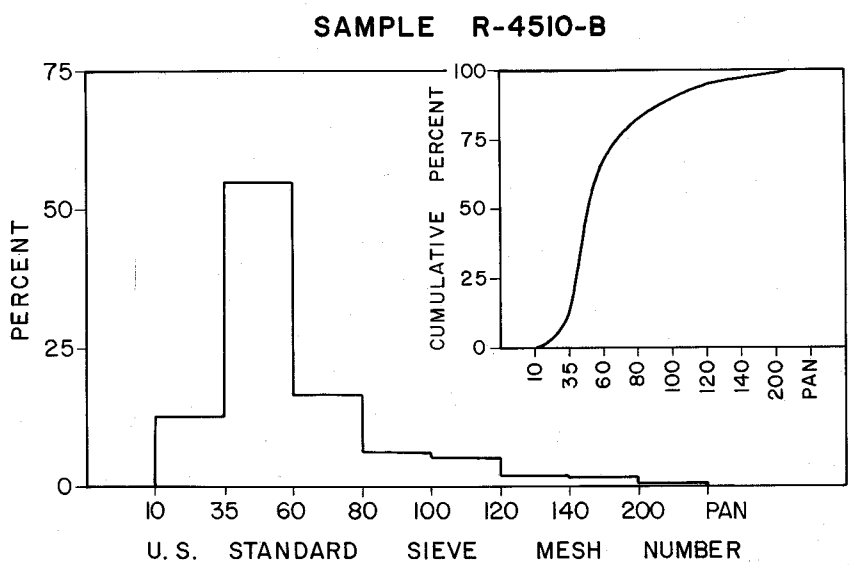


Figure 3. Histograms and cumulative-frequency curves of sample R-4510, Erwin Formation.

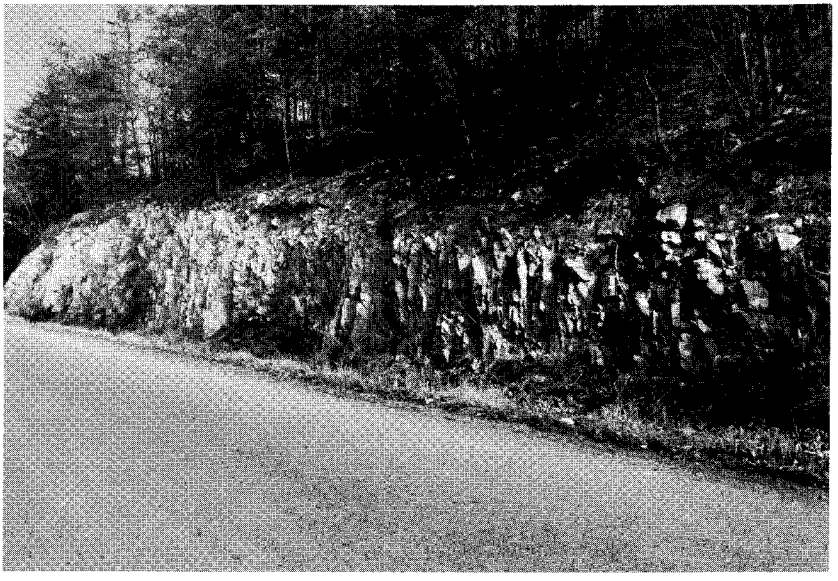
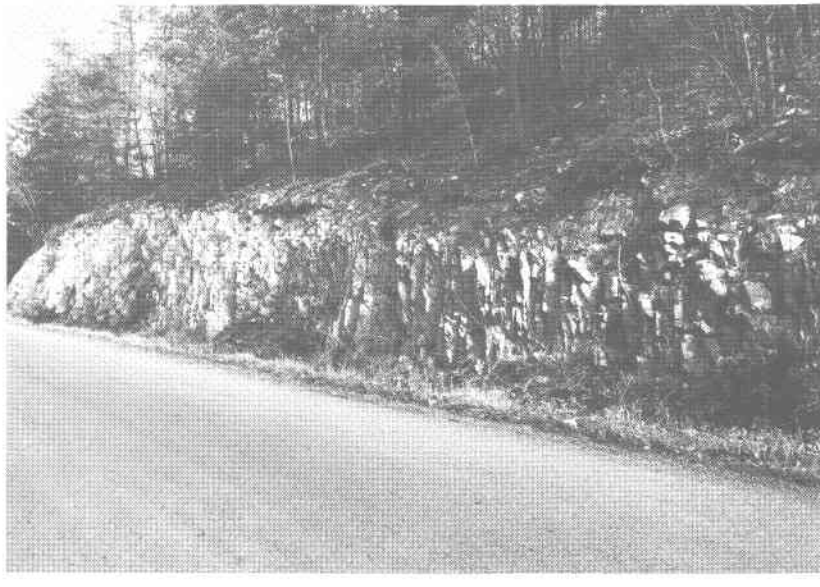


Figure 4. Well-indurated sandstone of the Erwin Formation just southwest of Stanley, Page County, sample R-4511.

Laboratory analyses (R-4511): The quartzite in the lower 94 feet of the measured section was too well cemented to be crushed for determination of grain-size distribution. A hand sample (R-4511) was chemically analyzed and the results are shown in Table 3. In thin section the sample consists of very-fine to medium, rounded to subangular, quartz grains bonded by a tangential quartz weld with some grain-boundary suturing. Quartz overgrowths form the cement. Minor constituents are muscovite and quartzite fragments; heavy minerals identified in thin section are zircon, tourmaline, and leucoxene.

Table 3.—Chemical analysis of sample R-4511, Erwin Formation.

Constituents	*Percent*
SiO_2	99.3
Al_2O_3	0.6
Fe_2O_3	0.33
CaO	0.07
MgO	0.06
K_2O	0.03



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SiO_2	99.3
Al_2O_3	0.6
Fe_2O_3	0.33
CaO	0.07
MgO	0.06
K_2O	0.03

Constituents	*Percent*
MnO	nd
TiO_2	nd
CoO	nd
Na_2O	0.02
Loss on Ignition	0.56

nd—not detected

Other Localities

Excellent exposures of the Erwin are present in Rockingham County, where the thickness is between 800 and 1000 feet (Brent, 1960, p. 20), near Hawksbill Creek on the east side of U. S. Highway 340, 0.4 mile by road mileage west of its intersection with State Road 754; on the north side of State Road 625, 0.1 mile west of its junction with State Road 623; and on top of Huckleberry Mountain approximately 3.5 miles due east of Elkton. In Page County the Erwin is exposed along the Norfolk and Western Railway, 0.1 mile east of State Road 618; in the quarry on the west side of Piney Hill, 0.1 mile due east of State Road 611; and for a distance of about 0.3 mile along the fire road on top of Pine Mountain. In the central and northern parts of Page County the Erwin seldom exceeds 450 feet in thickness (Allen, 1967, p. 20). The Erwin is exposed in Warren County along the Southern Railway track about 3 miles east of Front Royal where Lee (1961, p. 39-40) reported it to be 1485 feet thick; in the quarry just south of State Road 643, 0.9 miles by road east of its junction with State Road 624; and on State Road 603, 0.5 mile along the road south of its junction with State Road 643. In Clarke County the Erwin is exposed on the south end of Gibson Ridge, 0.1 mile east of State Road 638.

TUSCARORA FORMATION

The Tuscarora Formation of Silurian age generally consists of clean, very fine- to very coarse-grained sandstone and quartzite, and conglomerate with rounded quartz pebbles observed up to one inch in length. Rock fragments of metaquartzite and a matrix consisting of sericite, clay, and secondary quartz are often present in each lithology. Grains bonded by a tangential quartz weld characterize the Tuscarora, but there are sutured grain contacts and cementation by secondary quartz over-

growths. The Tuscarora is generally well indurated and has often been called a quartzite; however at some localities the rock is poorly cemented, friable, and readily weathers to sand.

Sample R-4584

Location: The Tuscarora Formation was sampled in Frederick County along the north side of U. S. Highway 55, 0.8 mile by road east of its intersection with State Road 609, in the Mountain Falls, Virginia-West Virginia, 7.5-minute quadrangle (Figure 5).

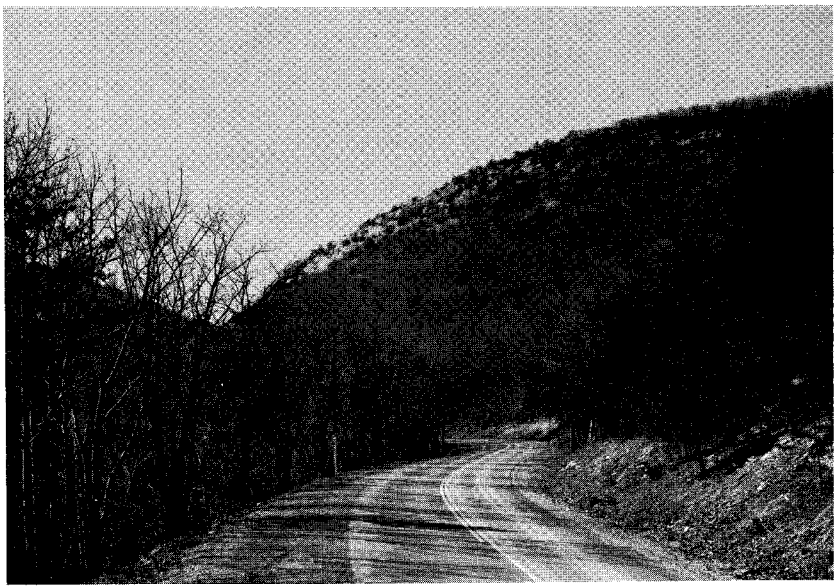

Figure 5. Tuscarora Formation along Short Mountain and U. S. Highway 55, Frederick County, sample R-4584.

Measured section: Sandstone, fine- to medium-grained, white to light-gray to light yellowish-orange, subangular to rounded grains. The sandstone is well indurated and iron-oxide stain occurs throughout. Fracture and bedding surfaces are case-hardened. A minor amount of white to light-tan feldspar is present. The bedding ranges from 3 to 18 inches in thickness. The upper 12 feet of sandstone contains interbeds of white, rounded quartz pebbles that are up to about 0.6 inch in length;

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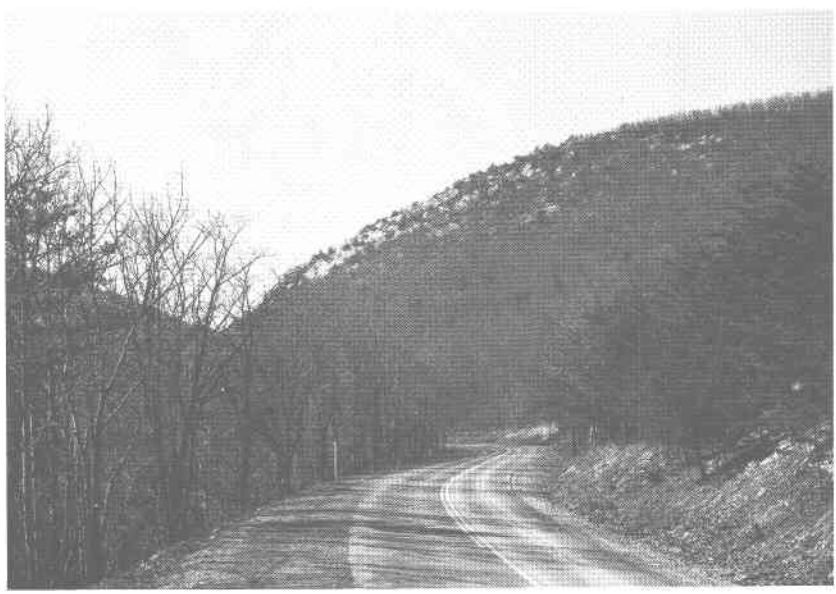

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the thickest pebble zone is 8 inches. Exposed thickness of the formation is 102 feet; strike and dip is N.40°E., 60°SE.

Laboratory analyses: Several thin sections examined from sample R-4584 show that the sandstone consists of fine- to very coarse-grained (.006-.091 inches), subangular to rounded quartz grains, some with well-developed secondary quartz overgrowths. The grains are generally bonded by a simple tangential quartz weld although some grain boundaries are sutured. Minor constituents of the framework are rounded to subangular chert grains, quartzite grains, metamorphic rock fragments, and feldspar. The matrix contains some clay with very fine grains of quartz and sericite. Other minerals identified in thin section are muscovite, tourmaline, and leucoxene.

Because of the well-indurated nature of the sandstone, the samples were not crushed for sieve analyses. A chemical analysis, however, of a hand sample is shown in Table 4.

Table 4.—Chemical analysis of sample R-4584, Tuscarora Formation.

Constituents	*Percent*
SiO_2	99.6
Al_2O_3	0.6
Fe_2O_3	0.10
CaO	0.01
MgO	0.01
K_2O	0.09
MnO	nd
TiO_2	nd
CoO	nd
Na_2O	0.04
Loss on Ignition	0.18

nd—not detected

Samples R-4516 and R-4517

Location (R-4516, R-4517): The Tuscarora Formation was sampled in Frederick County along the forest road which leads to the lookout tower on top of Great North Mountain at a locality 2.0 miles and N.13°W. from the junction of State Road 753 and State Road 600 in the Hayfield, Virginia, 7.5-minute quadrangle. The Tuscarora at this exposure was divided into an upper unit

designated R-4516 and a lower unit designated R-4517 (Figure 6).

Figure 6. Tuscarora Formation along the forest road on Great North Mountain, Frederick County, sample R-4516.

Measured section (R-4516): Sandstone and quartzite, fine- to very coarse-grained, white to light yellowish-orange, subangular to rounded grains, slightly friable to very well-indurated. Some white rounded quartz pebbles as much as 0.8 inch in length are scattered throughout, and are concentrated enough in places to form a conglomerate. Bedding ranges from 6 to 18 inches in thickness. Exposed thickness of the upper unit is 75 feet; strike and dip is N.37°E., 20°SE.

Laboratory analyses (R-4516): A thin section from the exposure shows that the rock consists of fine- to very coarse-grained sandstone, with subangular to rounded grains. The quartz grains are generally strained and are bonded by a tangential quartz weld; however, minor suturing of contacts and minor traces of polycrystalline quartz are also present along grain boundaries. Other constituents are quartzite grains, sericite, and siltstone grains in which the clay has become sericitized and is monocrystalline. Heavy minerals identified in thin section are tourmaline, leucoxene, magnetite, and zircon.

designated R-4516 and a lower unit designated R-4517 (Figure 6).

Figure 6. Tuscarora Formation along the forest road on Great North Mountain, Frederick County, sample R-4516.

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Laboratory analyses (R-4516): A thin section from the exposure shows that the rock consists of fine- to very coarse-grained sandstone, with subangular to rounded grains. The quartz grains are generally strained and are bonded by a tangential quartz weld; however, minor suturing of contacts and minor traces of polycrystalline quartz are also present along grain boundaries. Other constituents are quartzite grains, sericite, and siltstone grains in which the clay has become sericitized and is monocrystalline. Heavy minerals identified in thin section are tourmaline, leucoxene, magnetite, and zircon.

Because of the well-indurated nature of R-4516, sieve analyses were not made. A chemical analysis of a hand sample from the exposure is given in Table 5.

Table 5.—Chemical analysis of sample R-4516, Tuscarora Formation.

Constituents	*Percent*
SiO_2	99.6
Al_2O_3	0.4
Fe_2O_3	0.29
CaO	0.03
MgO	0.01
K_2O	0.05
MnO	nd
TiO_2	nd
CoO	nd
Na_2O	0.03
Loss on Ignition	0.34

nd—not detected

Measured section (R-4517): Sandstone, very fine- to very coarse-grained, white to very light-gray to light yellowish-orange. White, rounded quartz pebbles up to 1.0 inch in length are scattered throughout. Most of the sandstone is very friable to slightly friable, but some is well indurated. Exposed thickness of the lower unit is 50 feet; strike and dip is N.43°E., 23°SE.

Laboratory analyses (R-4517): The lower member of the Tuscarora at this locality, designated R-4517, was sampled separately because of the more friable nature of the sandstone. In thin section the sandstone generally consists of medium- to very coarse, subangular to rounded, slightly iron-oxide stained quartz grains bonded by a tangential quartz weld. Some finer grained quartz is present. The grain weld is very weak as demonstrated by the ease of disaggregation. Some grains show well-developed secondary quartz overgrowths. Minor constituents present are quartzite fragments and sericite.

The heavy mineral suite is composed principally of zircon, tourmaline, leucoxene, and hematite. Other minerals include rutile, kyanite, muscovite, pyrite, fluorite, apatite, and biotite(?).

Sieve and chemical analyses of the raw (R-4517-A) and beneficiated (R-4517-B) material are shown in Table 6. Histograms and cumulative-frequency curves of sieve analyses are shown in

Figure 7. Both raw and beneficiated material are moderately sorted.

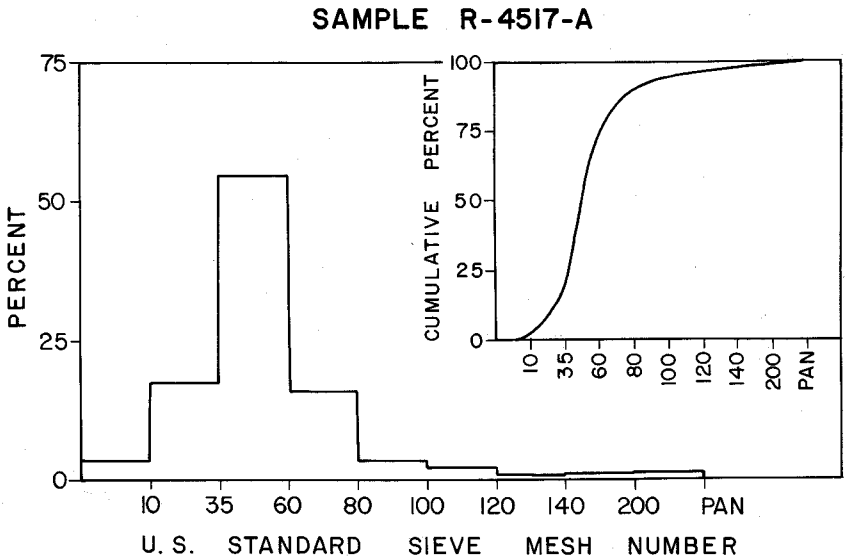
Table 6.—Sieve and chemical analyses of sample R-4517, Tuscarora Formation.

	SAMPLE R-4517-A (Raw Sample)	*SAMPLE R-4517-B* (Beneficiated)
SIEVE ANALYSES		
U. S. Standard Sieve Mesh No.	*Percent Retained*	
10	3.36	1.62
35	17.56	15.56
60	54.50	56.74
80	15.82	17.06
100	3.36	3.82
120	2.16	2.50
140	0.74	0.68
200	0.98	0.32
Pan	1.38	0.88
CHEMICAL ANALYSES		
Constituents	*Percent*	
SiO_2	98.4	98.6
Al_2O_3	0.3	0.2
Fe_2O_3	0.15	0.13
CaO	0.02	0.03
MgO	0.05	0.02
K_2O	0.03	0.01
MnO	nd	nd
TiO_2	nd	nd
CoO	0.01	nd
Na_2O	0.03	0.03
Loss on Ignition	0.35	0.37

nd—not detected

Other Localities

Excellent exposures of the Tuscarora can be seen in Rockingham County just north of State Road 812, 0.6 mile along the road west of its intersection with State Road 613 on Little North Mountain; and at Brocks Gap and Hopkins Gap where its thickness ranges from 53 feet to possibly 130 feet, respectively (Brent, 1960, p. 44). In Shenandoah County exposures may be seen on State Road 675, 0.2 mile south of Wolf Gap; on State Road 691, 1.2 miles by road west of its junction with State Road 789; on the west side of State Road 600, 2.3 miles along the road west of its



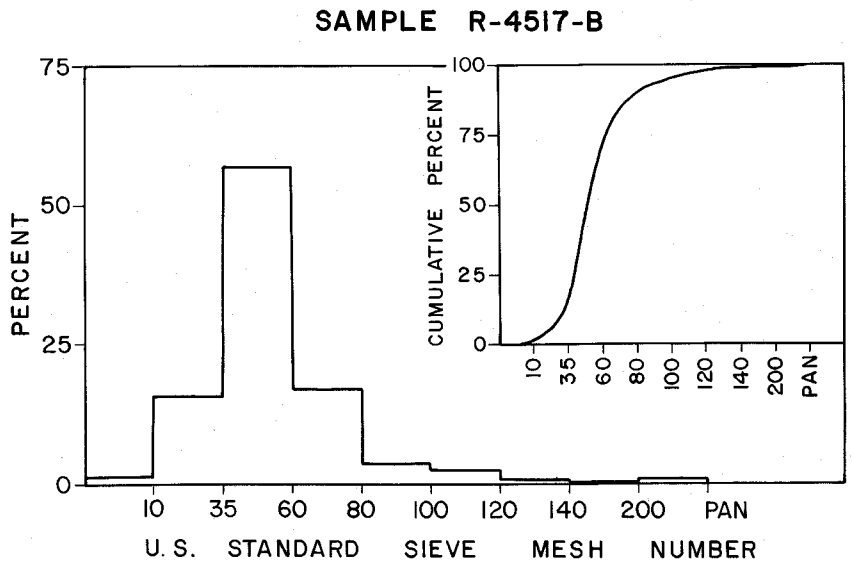


Figure 7. Histograms and cumulative-frequency curves of sample R-4517, Tuscarora Formation.

intersection with State Road 623; on Deerhead Knob, 1 mile north-northeast of Hudson Crossroads; and along the north side of State Road 606, 0.1 mile southeast of its junction with State Road 623. In Frederick County exposures are present on the east side of Paddy Gap, 1 mile west of State Road 600; on the west side of State Road 619, 1.4 miles along the road west of its intersection with State Road 622; along Duck Run where it has a thickness of approximately 300 feet (Butts and Edmundson, 1966, p. 41); and in Baldwin Gap, 1 mile northwest of Marlboro where it has a thickness of 40 feet (Butts and Edmundson, 1966, p. 41).

MASSANUTTEN SANDSTONE

The Massanutten Sandstone of Silurian age is the principal ridge-forming rock of the Massanutten Mountain area in Page, Rockingham, Shenandoah, and Warren counties. The Massanutten consists predominantly of fine- to very coarse-grained, light-gray to light yellowish-orange sandstone and quartzite that contain quartz-pebble conglomerates with pebbles as much as 0.8 inch in length. The sandstones and quartzites are generally hard, well indurated, and cemented by some secondary silica and by a tangential quartz weld. Sericite and clay may form a minor portion of the matrix. In places the Massanutten contains white to very light-gray thin shales, and red siltstone and shale.

Sample R-4617

Location: The Massanutten Sandstone crops out in Page County along Pitt Spring Run, 6100 feet and S.72°W. from the intersection of State Road 685 and Forest Service Road 375 in the Tenth Legion, Virginia, 7.5-minute quadrangle (Figure 8).

Measured section: Quartzite, fine- to medium-grained, white to medium-gray, rounded to subangular grains with iron stain scattered throughout. A few zones of coarse, rounded to subangular quartz grains up to 10 inches thick also occur. Several thin zones, 1 to 2 inches thick, of fine- to coarse-grained sandstone are very slightly friable, but are highly iron-oxide stained. Beds range in thickness from 2 to 16 inches. Exposed thickness of this unit is 407 feet, but it contains several covered intervals; strike and dip is N.20°E., 85°SE. to vertical.

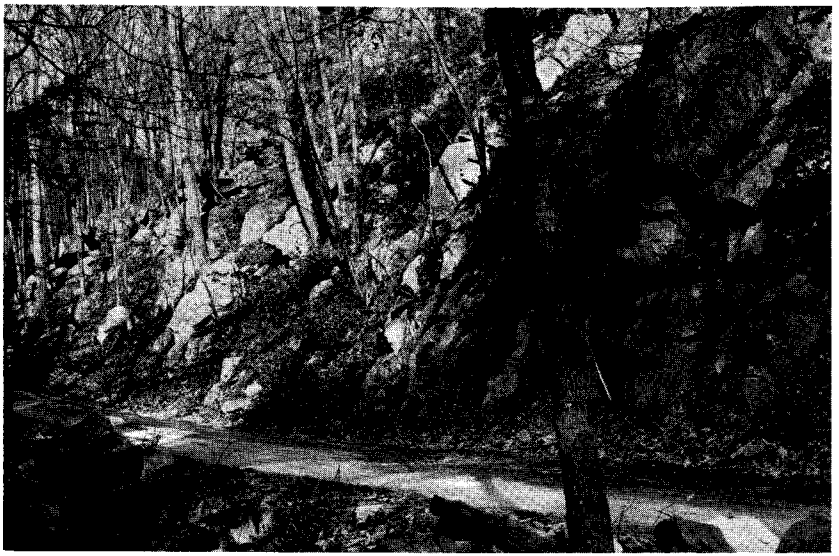


Figure 8. Massanutten Sandstone along Pitt Spring Run, Page County, sample R-4617.

Quartzite, fine- to coarse-grained, white to tan-gray, rounded to angular grains, very hard and well-indurated, cemented by secondary silica. At the base is a quartz-pebble conglomerate with rounded quartz pebbles up to about 0.8 inch in length. Beds range in thickness from 2 to 16 inches. Joint surfaces are case-hardened and some are slickensided. Sample R-4617 was taken from this interval. Thickness of the unit is 198 feet.

Sandstone, very fine- to fine-grained, light-gray to tan, slightly argillaceous. The sandstone weathers to a buff red, and is highly iron stained. Thicknesses of beds range from 2 to 9 inches, and total thickness of the unit is 2 feet.

Laboratory analyses: In thin section the quartzite consists of medium to very-coarse (0.01 to 0.08 inch), rounded to subangular quartz grains that are tightly bonded by a tangential quartz weld and with secondary quartz overgrowths. Some suturing of grain boundaries is also present. The minor matrix is composed of very fine quartz, hematite, and sericite; other minerals are muscovite, zircon, monazite, and epidote(?).

A chemical analysis of a hand sample from the lower quartzite unit is shown in Table 7.

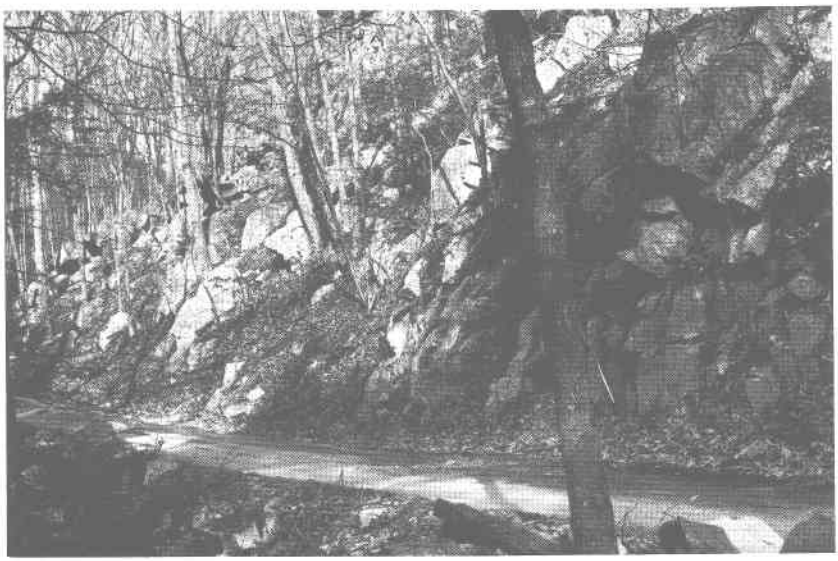


Figure 8. Massanutten Sandstone along Pitt Spring Run, Page County, sample R-4617.

Quartzite, fine- to coarse-grained, white to tan-gray, rounded to angular grains, very hard and well-indurated, cemented by secondary silica. At the base is a quartz-pebble conglomerate with rounded quartz pebbles up to about 0.8 inch in length. Beds range in thickness from 2 to 16 inches. Joint surfaces are case-hardened and some are slickensided. Sample R-4617 was taken from this interval. Thickness of the unit is 198 feet.

Sandstone, very fine- to fine-grained, light-gray to tan, slightly argillaceous. The sandstone weathers to a buff red, and is highly iron stained. Thicknesses of beds range from 2 to 9 inches, and total thickness of the unit is 2 feet.

Laboratory analyses: In thin section the quartzite consists of medium to very-coarse (0.01 to 0.08 inch), rounded to subangular quartz grains that are tightly bonded by a tangential quartz weld and with secondary quartz overgrowths. Some suturing of grain boundaries is also present. The minor matrix is composed of very fine quartz, hematite, and sericite; other minerals are muscovite, zircon, monazite, and epidote(?).

A chemical analysis of a hand sample from the lower quartzite unit is shown in Table 7.

Table 7.—Chemical analysis of sample R-4617, Massanutten Sandstone.

Constituents	*Percent*
SiO_2	98.6
Al_2O_3	0.4
Fe_2O_3	0.44
CaO	0.01
MgO	nd
K_2O	0.03
MnO	nd
TiO_2	nd
CoO	0.01
Na_2O	0.03
Loss on Ignition	0.03

nd—not detected

Other Localities

In Rockingham County excellent exposures of the Massanutten can be seen at the "Peak", Harshberger Gap, in Ruckles Gap where Brent reports a thickness of 646 feet (1960, p. 75), and at Fridley Gap where the thickness is 529 feet (Brent, 1960, p. 74). Exposures are also present in Page County at Catherine Furnace, just north of New Market Gap, along State Road 675 about 2.3 miles by road west of its junction with State Road 615, and at Moreland Gap. At Burners Gap, the type locality, Thornton (1953, p. 74) measured a thickness of 700 feet. In Shenandoah County the Massanutten can be seen in Edinburg Gap, Woodstock Gap, along State Road 658 on Powell Mountain, at Mine Gap, and at Blue Hole.

RIDGELEY SANDSTONE

The Ridgeley Sandstone of Devonian age is predominantly a medium- to coarse-grained, white to light-tan to light-gray sandstone that in places contains a calcareous matrix. Some of the sandstone becomes friable and readily breaks into individual sand grains when the carbonate matrix is leached. Carbonate cement is present in the Ridgeley north of U. S. Highway 50 along the northern end of Great North Mountain in Frederick County and at Brocks Gap in Rockingham County. Where the

rock is well indurated, the quartz grains generally show a welded boundary with very minor suturing of grain contacts. Secondary quartz overgrowths that fill the original intergranular porosity occur in places. Conglomeratic zones of white to gray, rounded quartz pebbles up to 1.0 inch in length were observed in the Ridgeley. In west-central Shenandoah County and southern Frederick County manganese mineralization has occurred in places in and associated with the Ridgeley. Minerals are present as vein fillings along fractures and as replacements of the matrix and have been identified as pyrolusite, manganite, psilomelane, and cryptomelane.

The Ridgeley Sandstone is generally high in purity and is produced at several localities in the Appalachian Basin for use as glass sand.

The U. S. Geological Survey made chemical analyses of the Ridgeley at two localities (Carter, 1968, p. 353). A partial chemical analysis from the Bear Garden Mountain locality in Frederick County showed the following: SiO_2, 96.1 percent; FeO and Fe_2O_3, 0.18 percent; and Al_2O_3, 1.70 percent. A partial analysis from Orkney Springs, Shenandoah County consisted of SiO_2, 96.5 percent; FeO and Fe_2O_3, 0.16 percent; and Al_2O_3, 1.00 percent.

At Rock Enon Springs, Frederick County, the average iron content of the Ridgeley Sandstone collected as chips across the exposure is 0.03 percent (Butts and Edmundson, 1966, p. 117).

Sample R-4515

Location: The Ridgeley Sandstone was sampled in Shenandoah County on the north side of State Road 675, 1.40 miles by road northwest of its junction with State Road 717, in the Wolf Gap, West Virginia-Virginia, 7.5-minute quadrangle (Figure 9).

Measured section: Sandstone, fine- to medium-grained, white to light-tan to light-gray, subangular to rounded grains, slightly iron-oxide stained with concentration primarily along fractures. Traces of white to tan, highly weathered feldspar grains are present. The sandstone is well indurated to slightly friable but weathers readily into individual quartz grains. A 3-inch zone of medium to coarse, well-rounded quartz pebbles occurs near the center of the exposure; a 15-inch zone of coarse, white to medium-gray, rounded quartz pebbles are present at the top of the

Figure 9. Ridgeley Sandstone on the north side of State Road 675, just east of Great North Mountain, Shenandoah County, sample R-4515.

exposure. Beds range in thickness from 6 inches to about 2 feet. Exposed thickness of the unit is 31 feet; strike and dip is N.34°E., 43°SE.

Laboratory analyses: Thin sections of the sandstone are seen to consist of fine to medium, subangular to rounded quartz grains, generally having undulose extinction and bonded by a simple tangential quartz weld. Some grain boundaries are sutured and secondary quartz overgrowths also occur. Minor constituents are subangular to rounded quartzite and siltstone grains, and shreds of sericite as interstitial material.

Heavy-mineral separation reveals a suite composed principally of leucoxene, zircon, and various-colored tourmalines. Minor minerals include rutile, hematite, apatite, pyrite, magnetite, and muscovite.

Sieve and chemical analyses of the raw material (R-4515-A) and beneficiated material (R-4515-B) are shown in Table 8. Histograms and cumulative-frequency curves of sieve analyses are shown in Figure 10. The raw material is moderately sorted in its unbeneficiated state; beneficiation improves the sample to moderately well sorted.

Figure 9. Ridgeley Sandstone on the north side of State Road 675, just east of Great North Mountain, Shenandoah County, sample R-4515.

exposure. Beds range in thickness from 6 inches to about 2 feet. Exposed thickness of the unit is 31 feet; strike and dip is N.34°E., 43°SE.

Laboratory analyses: Thin sections of the sandstone are seen to consist of fine to medium, subangular to rounded quartz grains, generally having undulose extinction and bonded by a simple tangential quartz weld. Some grain boundaries are sutured and secondary quartz overgrowths also occur. Minor constituents are subangular to rounded quartzite and siltstone grains, and shreds of sericite as interstitial material.

Heavy-mineral separation reveals a suite composed principally of leucoxene, zircon, and various-colored tourmalines. Minor minerals include rutile, hematite, apatite, pyrite, magnetite, and muscovite.

Sieve and chemical analyses of the raw material (R-4515-A) and beneficiated material (R-4515-B) are shown in Table 8. Histograms and cumulative-frequency curves of sieve analyses are shown in Figure 10. The raw material is moderately sorted in its unbeneficiated state; beneficiation improves the sample to moderately well sorted.

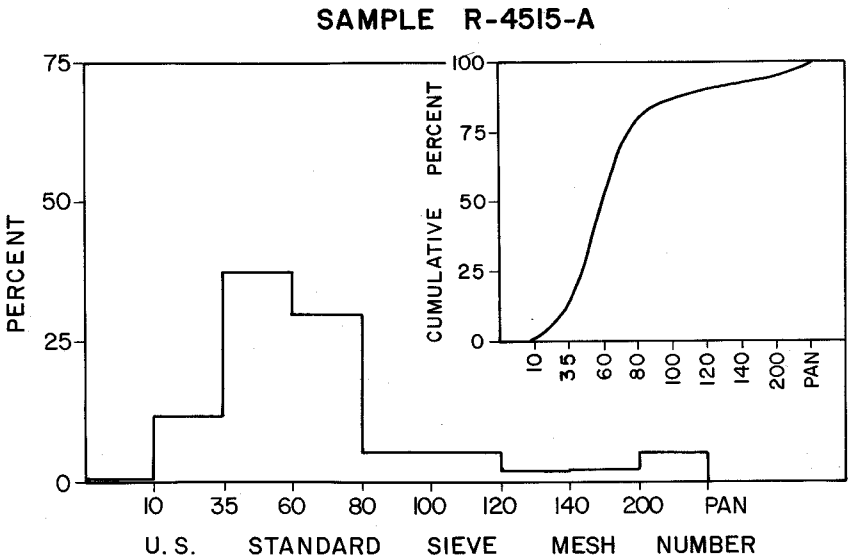
Table 8.—Sieve and chemical analyses of sample R-4515, Ridgeley Sandstone.

	SAMPLE R-4515-A (Raw Sample)	*SAMPLE R-4515-B* (Beneficiated)
SIEVE ANALYSES		
U. S. Standard Sieve Mesh No.	*Percent Retained*	
10	0.56	0.40
35	12.12	4.42
60	37.70	43.00
80	30.06	36.34
100	5.50	7.32
120	5.50	5.32
140	1.66	1.20
200	1.74	0.48
Pan	4.44	0.76
CHEMICAL ANALYSES		
Constituents	*Percent*	
SiO_2	98.7	99.7
Al_2O_3	0.8	0.3
Fe_2O_3	0.38	0.10
CaO	0.02	0.03
MgO	0.04	0.02
K_2O	0.07	0.06
MnO	nd	nd
TiO_2	nd	nd
CoO	nd	nd
Na_2O	0.03	0.02
Loss on Ignition	0.74	0.38

nd—not detected

Sample R-4519

Location: The Ridgeley Sandstone was sampled at the south end of Spring Mountain in Shenandoah County, approximately 3300 feet and S.84°W. of the junction of State Highway 263 and State Road 610, in the Orkney Springs, Virginia-West Virginia, 7.5-minute quadrangle (Figure 11).



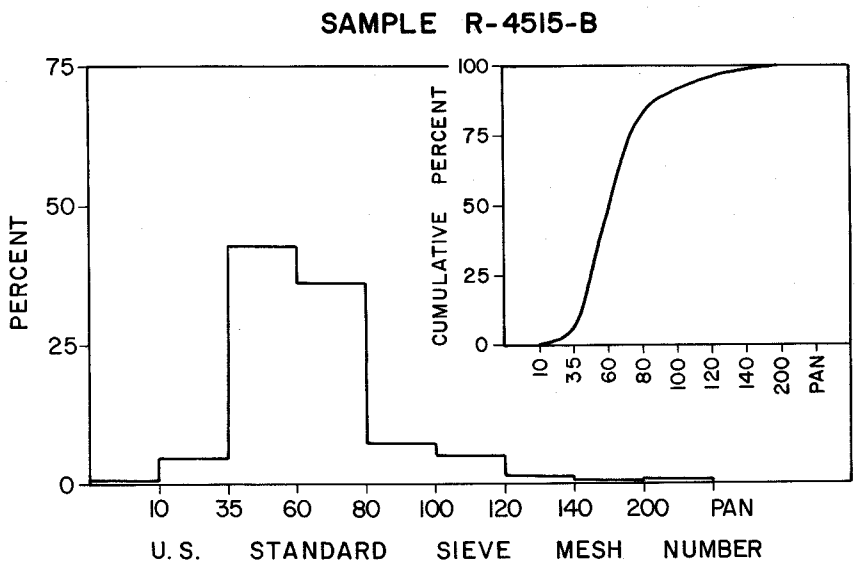


Figure 10. Histograms and cumulative-frequency curves of sample R-4515, Ridgeley Sandstone.

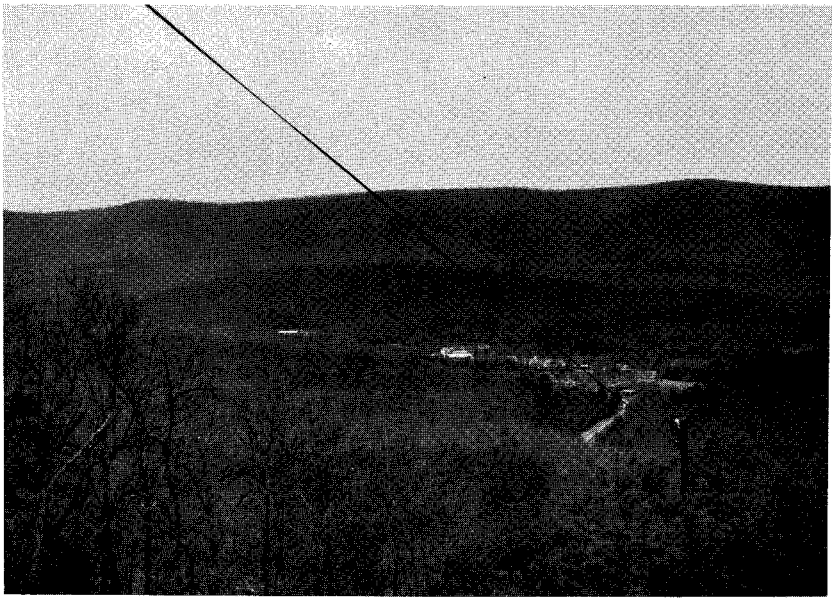


Figure 11. Spring Mountain, west of Orkney Springs, Shenandoah County, site of Ridgeley Sandstone, sample R-4519.

Measured section: Sandstone, fine- to medium-grained, white to light yellowish-orange, angular to subrounded grains, with moderate iron-oxide stain. Minor amounts of white to light-tan weathered feldspar grains are present. The sandstone is well indurated to slightly friable. Beds range in thickness from 2 to 14 inches, the majority of which are 8 to 12 inches. Exposed thickness is 36 feet; strike and dip are N.37°E. to N.44°E., 72°SE.

Laboratory analyses: Petrographic examination of a thin section of sandstone from this exposure shows that the rock is composed of very well-sorted, fine- to medium-fine, subangular to subrounded quartz grains. The quartz grains are generally bonded by a simple tangential quartz weld, with some minor suturing of grain boundaries. The sandstone is moderately iron-oxide stained and contains a minor amount of siltstone, and clay detritus. The matrix also contains some sericite.

Heavy-mineral separation reveals that the principal heavy minerals are tourmaline, leucoxene, and hematite; other minerals are zircon, garnet, rutile, muscovite, pyrite, magnetite, and plagioclase feldspar.

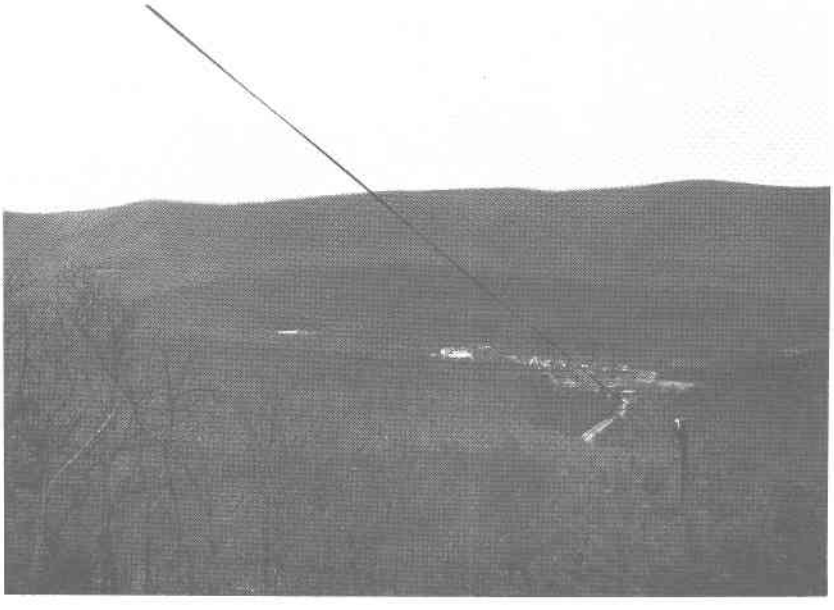


Figure 11. Spring Mountain, west of Orkney Springs, Shenandoah County, site of Ridgeley Sandstone, sample R-4519.

Measured section: Sandstone, fine- to medium-grained, white to light yellowish-orange, angular to subrounded grains, with moderate iron-oxide stain. Minor amounts of white to light-tan weathered feldspar grains are present. The sandstone is well indurated to slightly friable. Beds range in thickness from 2 to 14 inches, the majority of which are 8 to 12 inches. Exposed thickness is 36 feet; strike and dip are N.37°E. to N.44°E., 72°SE.

Laboratory analyses: Petrographic examination of a thin section of sandstone from this exposure shows that the rock is composed of very well-sorted, fine- to medium-fine, subangular to subrounded quartz grains. The quartz grains are generally bonded by a simple tangential quartz weld, with some minor suturing of grain boundaries. The sandstone is moderately iron-oxide stained and contains a minor amount of siltstone, and clay detritus. The matrix also contains some sericite.

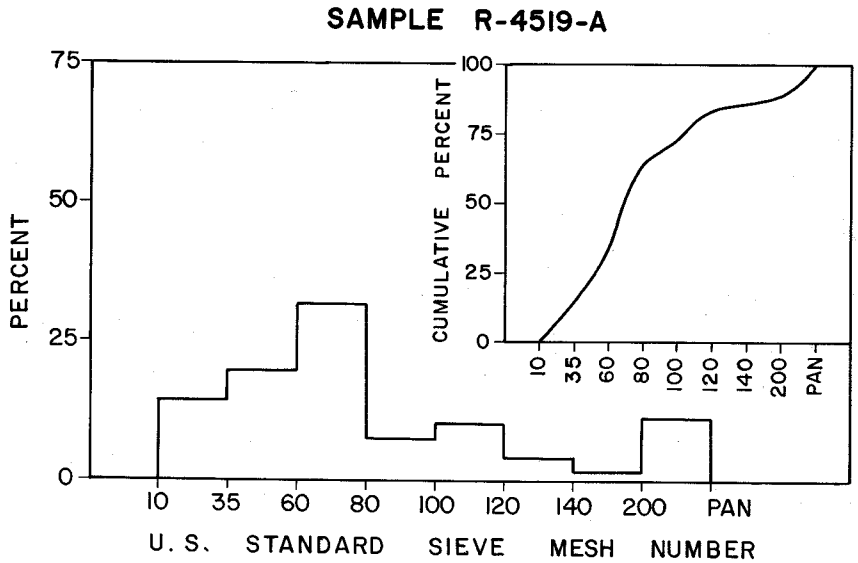
Heavy-mineral separation reveals that the principal heavy minerals are tourmaline, leucoxene, and hematite; other minerals are zircon, garnet, rutile, muscovite, pyrite, magnetite, and plagioclase feldspar.

Sieve and chemical analyses of the raw material (R-4519-A) and beneficiated material (R-4519-B) are shown in Table 9. Histograms and cumulative-frequency curves of the sieve analyses are shown in Figure 12. The raw material is moderately sorted; upon beneficiation it becomes well sorted.

Table 9.—Sieve and chemical analyses of sample R-4519, Ridgeley Sandstone.

	SAMPLE R-4519-A (Raw Sample)	*SAMPLE R-4519-B* (Beneficiated)
SIEVE ANALYSES		
U. S. Standard Sieve Mesh No.	*Percent Retained*	
10	0	0
35	14.32	0.61
60	19.42	18.11
80	31.48	50.23
100	7.20	11.33
120	10.84	11.94
140	3.62	2.44
200	1.46	1.43
Pan	11.20	2.32
CHEMICAL ANALYSES		
Constituents	*Percent*	
SiO_2	96.8	99.6
Al_2O_3	2.2	0.6
Fe_2O_3	0.48	0.16
CaO	0.03	0.02
MgO	0.05	0.02
K_2O	0.19	0.07
MnO	nd	nd
TiO_2	nd	0.1
CoO	nd	nd
Na_2O	0.03	0.03
Loss on Ignition	1.24	0.17

nd—not detected



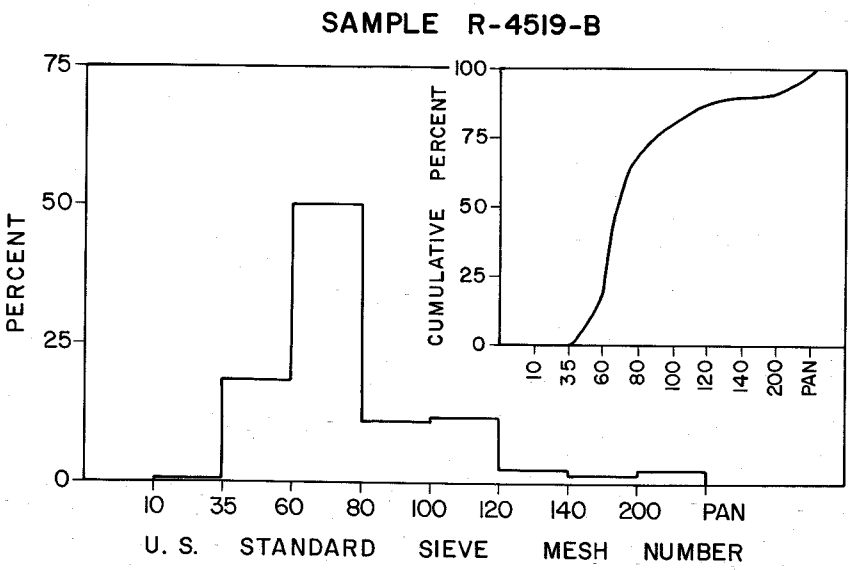


Figure 12. Histograms and cumulative-frequency curves of sample R-4519, Ridgeley Sandstone.

Sample R-4525

Location: The Ridgeley Sandstone was sampled along Bear Garden Mountain in Frederick County at a location approximately 6300 feet and N.75°W. from the southern junction of U. S. Highway 522 and State Road 696 in the Ridge, West Virginia-Virginia, 7.5-minute quadrangle (Figure 13).

Figure 13. Ridgeley Sandstone on Bear Garden Mountain, Frederick County, sample R-4525.

Measured section: Sandstone, fine- to medium-grained, white to tan-gray, subangular to rounded grains. Minor iron-oxide stains are present and primarily concentrated along bedding planes and fractures. Traces of white to tan highly weathered feldspar are also present. The sandstone is slightly indurated to very friable, and contains a few interbeds of light to medium-gray sandstone 6 to 8 inches thick. Case-hardening occurs along some surfaces. The exposed thickness is 127 feet; strike and dip are N.38°E., 63°SE.

Laboratory analyses: Petrographic examination of a thin section from the exposure reveals that the rock is composed of medium to coarse, very well-sorted, subrounded to rounded quartz grains. The grains generally display undulose extinction and

Sample R-4525

Location: The Ridgeley Sandstone was sampled along Bear Garden Mountain in Frederick County at a location approximately 6300 feet and N.75°W. from the southern junction of U. S. Highway 522 and State Road 696 in the Ridge, West Virginia-Virginia, 7.5-minute quadrangle (Figure 13).

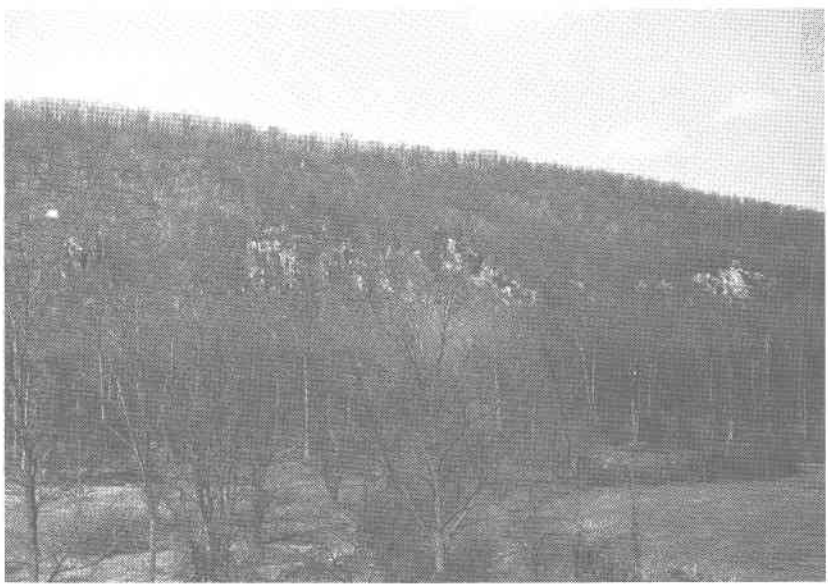


Figure 13. Ridgeley Sandstone on Bear Garden Mountain, Frederick County, sample R-4525.

Measured section: Sandstone, fine- to medium-grained, white to tan-gray, subangular to rounded grains. Minor iron-oxide stains are present and primarily concentrated along bedding planes and fractures. Traces of white to tan highly weathered feldspar are also present. The sandstone is slightly indurated to very friable, and contains a few interbeds of light to medium-gray sandstone 6 to 8 inches thick. Case-hardening occurs along some surfaces. The exposed thickness is 127 feet; strike and dip are N.38°E., 63°SE.

Laboratory analyses: Petrographic examination of a thin section from the exposure reveals that the rock is composed of medium to coarse, very well-sorted, subrounded to rounded quartz grains. The grains generally display undulose extinction and

are bonded by a simple tangential quartz weld; however, minor grain boundary suturing occurs. Minor quartzite grains are also present.

Heavy minerals separated and identified are principally tourmaline, zircon, rutile, and leucoxene. Other minerals present are magnetite, hematite, muscovite and garnet(?).

Sieve and chemical analyses of the raw (R-4525-A) and beneficiated (R-4525-B) material are shown in Table 10. Histograms and cumulative-frequency curves of sieve analyses are shown in Figure 14. The raw material is well sorted and becomes very well sorted upon beneficiation.

Table 10.—Sieve and chemical analyses of sample R-4525, Ridgeley Sandstone.

	SAMPLE R-4525-A (Raw Sample)	*SAMPLE R-4525-B* (Beneficiated)
SIEVE ANALYSES		
U. S. Standard		
Sieve Mesh No.	*Percent Retained*	
10	0	0
35	1.48	0.76
60	84.08	90.00
80	7.88	7.04
100	1.38	1.04
120	1.06	0.54
140	0.46	0.14
200	0.36	0.14
Pan	2.64	0.10
CHEMICAL ANALYSES		
Constituents	*Percent*	
SiO_2	99.7	99.7
Al_2O_3	0.3	0.3
Fe_2O_3	0.12	0.11
CaO	0.02	0.02
MgO	nd	0.01
K_2O	0.01	0.02
MnO	nd	nd
TiO_2	0.1	0.1
CoO	nd	nd
Na_2O	0.03	0.04
Loss on Ignition	0.21	0.01

nd—not detected

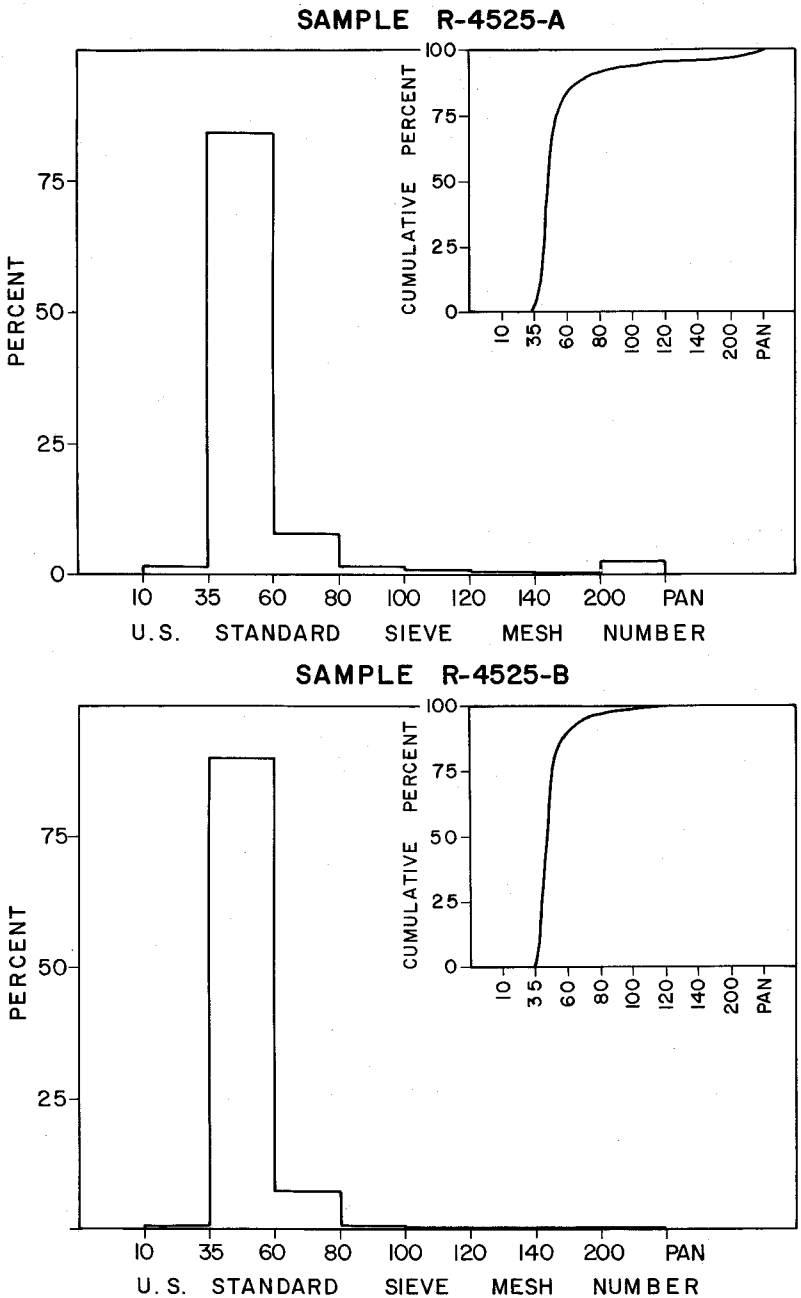


Figure 14. Histograms and cumulative-frequency curves of sample R-4525, Ridgeley Sandstone.

Other Localities

Other exposures of the Ridgeley are in Rockingham County on the north side of State Highway 259 at Chimney Rock, 0.9 mile by road west of its junction with State Road 613, where the thickness is 55 feet (Brent, 1960, p. 51) and on the north side of State Highway 259, 1.7 miles along the road west of its junction with State Road 612, where an incomplete section was found by the writer to be about 100 feet thick. In Shenandoah County the Ridgeley Sandstone is well exposed at a site 0.5 mile west of State Road 610 and Tomahawk Pond; at the south end of Furnace Knob just west of the Henrietta Furnace ruins at Shenandoah Alum Springs where it is 50 feet thick (Kindle, 1912, p. 43); on the south side of Bull Gap; just west of State Road 691, 0.3 mile along the road north of its intersection with State Road 717; on the south side of State Road 600, 0.9 mile by road east of its junction with State Road 603; and on the west side of State Road 600, 0.1 mile by road northeast of its junction with State Road 603. On Capola Mountain the Ridgeley is exposed and has a thickness of 120 feet (Monroe, 1942, p. 138). In Frederick County the Ridgeley is exposed on Mineral Ridge, 0.4 mile south of State Road 600 where its thickness is 40 feet in the abandoned No. 8 tunnel of the Mineral Ridge mine (Monroe, 1942, p. 125); on the north side of State Road 600, 1.1 miles by road south of its junction with State Road 604; along Richards Run approximately 0.7 mile northwest of Mountain Falls where its thickness is 65 feet (Butts and Edmundson, 1966, p. 59); in the water gap at Rock Enon Springs where the thickness is greater than 100 feet in a section measured by the writer; and in the quarry of Unisil Corporation, about 1 mile south of Gore, where its thickness is greater than 200 feet (Butts and Edmundson, 1966, p. 60, 117). A carbonate facies of the Ridgeley is well exposed on the south side of U. S. Highway 522, 0.4 mile by road north of its junction with State Road 688. In the Massanutten Mountain area the Ridgeley is a sandstone about 10 feet thick (Butts, 1940, p. 293); at the abandoned Powells Fort mine, Stose and Miser report a thickness of 20 feet (1922, p. 96).

POCONO FORMATION

The Pocono Formation of Mississippian age consists of a series of massive, well-indurated, white to gray, thick-bedded sandstones and interbedded shales. Thin-section examination of a

sample of sandstone from Briery Branch, Rockingham County, indicates that the rock is composed of fine to medium, rounded to angular, poorly sorted quartz grains with a large percentage of muscovite and quartzite fragments and minor feldspar; the matrix consists of silt, clay, and sericite. At some localities the sandstone is much better sorted and contains practically no matrix material.

Sample R-4518

Location: The Pocono was sampled at Rawley Springs in Rockingham County on the south side of State Road 847 approximately 0.1 mile by road west of its junction with U. S. Highway 33, in the Rawley Springs, Virginia, 7.5-minute quadrangle (Figure 15).

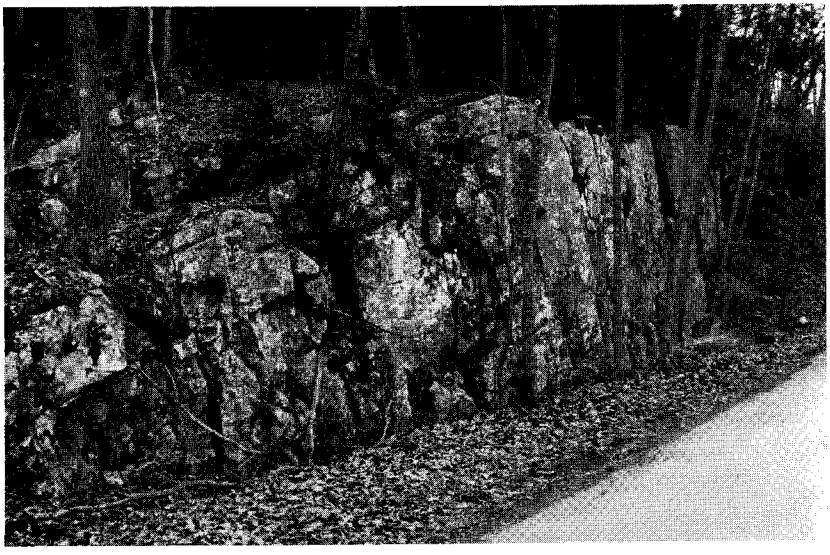


Figure 15. Pocono Sandstone along State Road 847 at Rawley Springs, Rockingham County, sample R-4518.

Measured section: Sandstone, very fine- to medium-grained, light-tan to light yellowish-orange to light-red, angular to rounded grains. The sandstone is hard, massive, and highly stained by iron oxide at the top of the exposure; the staining decreases in amount down-section. Exposed thickness is 22 feet; strike and dip are N.43°E., 22°SE.

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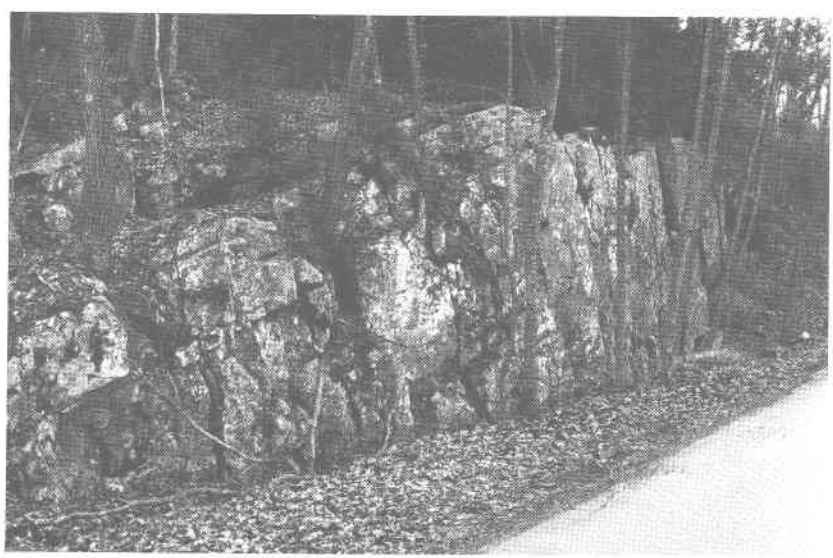

Figure 15. Pocono Sandstone along State Road 847 at Rawley Springs, Rockingham County, sample R-4518.

Measured section: Sandstone, very fine- to medium-grained, light-tan to light yellowish-orange to light-red, angular to rounded grains. The sandstone is hard, massive, and highly stained by iron oxide at the top of the exposure; the staining decreases in amount down-section. Exposed thickness is 22 feet; strike and dip are N.43°E., 22°SE.

Laboratory analyses: In thin section the sandstone is composed of very fine to medium, subrounded to angular quartz grains generally bonded by a simple tangential quartz weld. Some grains display very minor suturing of contacts and well-developed secondary quartz overgrowths. Grains of siltstone, chert, and quartzite are also present in the framework; minor minerals are biotite, muscovite, and zircon.

The Pocono at this locality is too well indurated to be crushed for sieve analyses. A chemical analysis of a composite of several hand samples from the exposure is shown in Table 11.

Table 11.—Chemical analysis of sample R-4518, Pocono Sandstone.

Constituents	*Percent*
SiO_2	98.7
Al_2O_3	0.8
Fe_2O_3	0.29
CaO	0.03
MgO	0.04
K_2O	0.24
MnO	nd
TiO_2	0.1
CoO	0.01
Na_2O	0.04
Loss on Ignition	0.34

nd—not detected

Other Localities

Excellent exposures of the Pocono Sandstone in western Rockingham County can also be seen on the north side of State Road 924 along Briery Branch; on the north side of the forest road in Hone Quarry Run, 0.4 mile by road west of its junction with State Highway 257; on the north side of the forest road along Wood Creek, 2 miles by road west of its junction with State Road 742; and on the north side of U. S. Highway 33, for a distance of about 2.2 miles by road west of its junction with State Road 847.

USES OF HIGH-SILICA RAW MATERIAL

High-silica resources, because of their purity, are sources of materials having special and somewhat restricted commercial uses. These uses are given by Murphy (1960, p. 763-772) as follows:

Abrasive Uses

1. blasting sand
2. glass-grinding sand
3. stone-sawing and rubbing sand

Miscellaneous Uses

1. coal-washing sand
2. hydraulic-fracturing sand
3. filler sand
4. standard testing sand
5. traction sand

Glass and Chemical Uses

Metallurgical Uses

Refractory Uses

1. core sand
2. furnace-bottom sand
3. ganister mix
4. naturally bonded molding sand
5. refractory pebble
6. runner sand

A detailed discussion of the specifications and uses of high-silica raw materials is given in McLaws (1971, p. 1-34) and in Murphy (1960, p. 763-772).

MANGANESE MINERALIZATION

Mining and prospecting for manganese ore have been conducted at many localities in the study area. Most zones of mineralization have been found in and associated with the sandstones and quartzites. Because manganese oxides may have associated trace amounts of cobalt, which is a powerful colorant, the known manganese distribution throughout the area is shown in Figure 16. Cobalt has been found associated with iron and manganese deposits along the west side of the Blue Ridge in Rockingham and Page counties (Pierce, 1944, p. 274; Watson, 1907, p. 578-580; McCreath, 1883, p. 25, 29). Traces of cobalt have been found in table ore at the Mineral Ridge manganese mine in Frederick County (letter of transmittal to Hy-Grade Manganese Company Inc., p. 24, 1927). Commercial silica occurrences may be present within the areas of manganese mineralization as indicated on Figure 16; however, the mineralization should be considered as a possible factor in more extensive evaluations of the high-silica resources at specific locations.

RESULTS

Chemical and sieve analyses of selected sandstone and quartzite samples are indicative of potential sources of high-silica raw material in Frederick, Page, Rockingham, and Shenandoah counties.

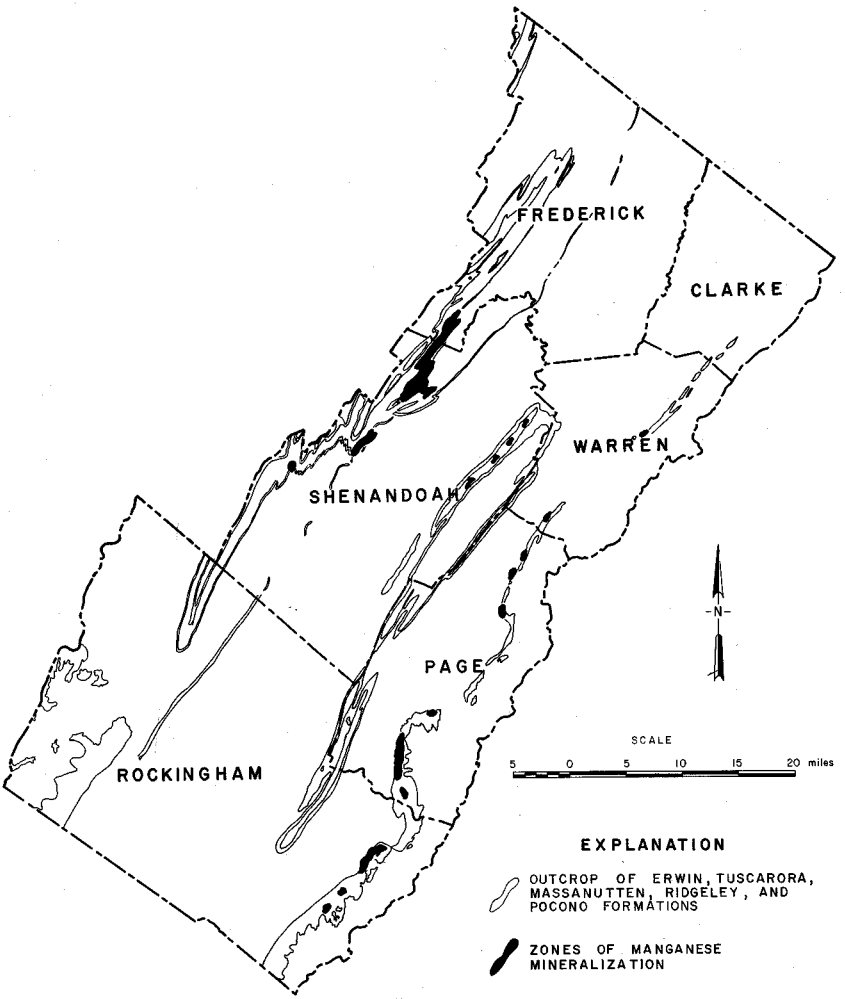

Figure 16. Manganese mineralization in Clarke, Frederick, Page, Rockingham, Shenandoah, and Warren counties, Virginia.

The Erwin Formation consists of an upper unit of thin-bedded sandstones and quartzites which weather to friable blocks and a lower unit of clean, well-indurated massive quartzite. Three samples of the Erwin contain 99.3, 99.3, and 97.8 percent silica; the latter was 99.6 percent silica upon simple beneficiation.

The Tuscarora is generally a clean, very fine- to very coarse-grained, well-indurated sandstone and quartzite, some of which

weathers to a friable sandstone. Three samples contain 99.6, 99.6, and 98.4 percent silica; upon beneficiation the latter was 98.6 percent.

The Massanutten Sandstone consists of fine- to very coarse-grained sandstone and quartzite with some quartz-pebble conglomerate. A sample from Page County contains 98.6 percent silica.

The Ridgeley Sandstone is predominantly a medium- to coarse-grained, very clean sandstone that commonly is friable. The silica content of three samples ranges from 96.8 to 99.7 percent; upon beneficiation the silica content ranges from 99.6 to 99.7 percent.

The Pocono Formation consists of thick-bedded sandstones and interbedded dark shales; the sandstone generally is poorly sorted and contains muscovite, quartzite fragments, silt, clay, feldspar and sericite. A sample of the sandstone contains 98.7 percent silica.

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GLOSSARY[1]

graphic standard deviation—A measure of the uniformity or sorting of a sediment that embraces the central 68 percent of the size distribution.

$$\frac{\phi 84 - \phi 16}{2}$$

inclusive graphic standard deviation—A measure of the uniformity or sorting of a sediment that embraces 90 percent of the size distribution.

$$\frac{\phi 84 - \phi 16}{4} + \frac{\phi 95 - \phi 5}{6.6}$$

sutured contacts—Highly irregular or contorted grain boundaries formed by pressure solution (Figure 17).

overgrowth—A mineral deposited in optical continuity with a crystal grain (Figure 17).

polycrystalline quartz—An assemblage of crystal grains which occur along some quartz grain boundaries (Figure 17).

[1] Definitions adapted from Dapples, E. C., 1972; Folk, Robert L., 1968; and the American Geological Institute, 1962.

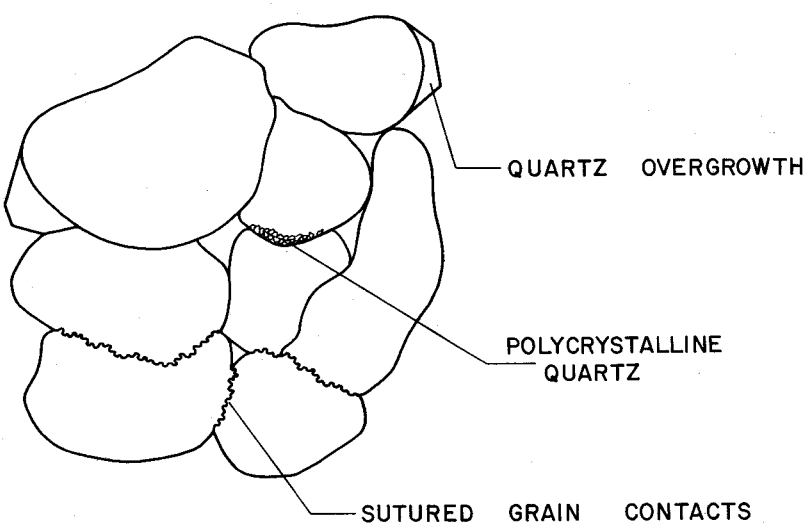

Figure 17. Examples of some terminology used in glossary.

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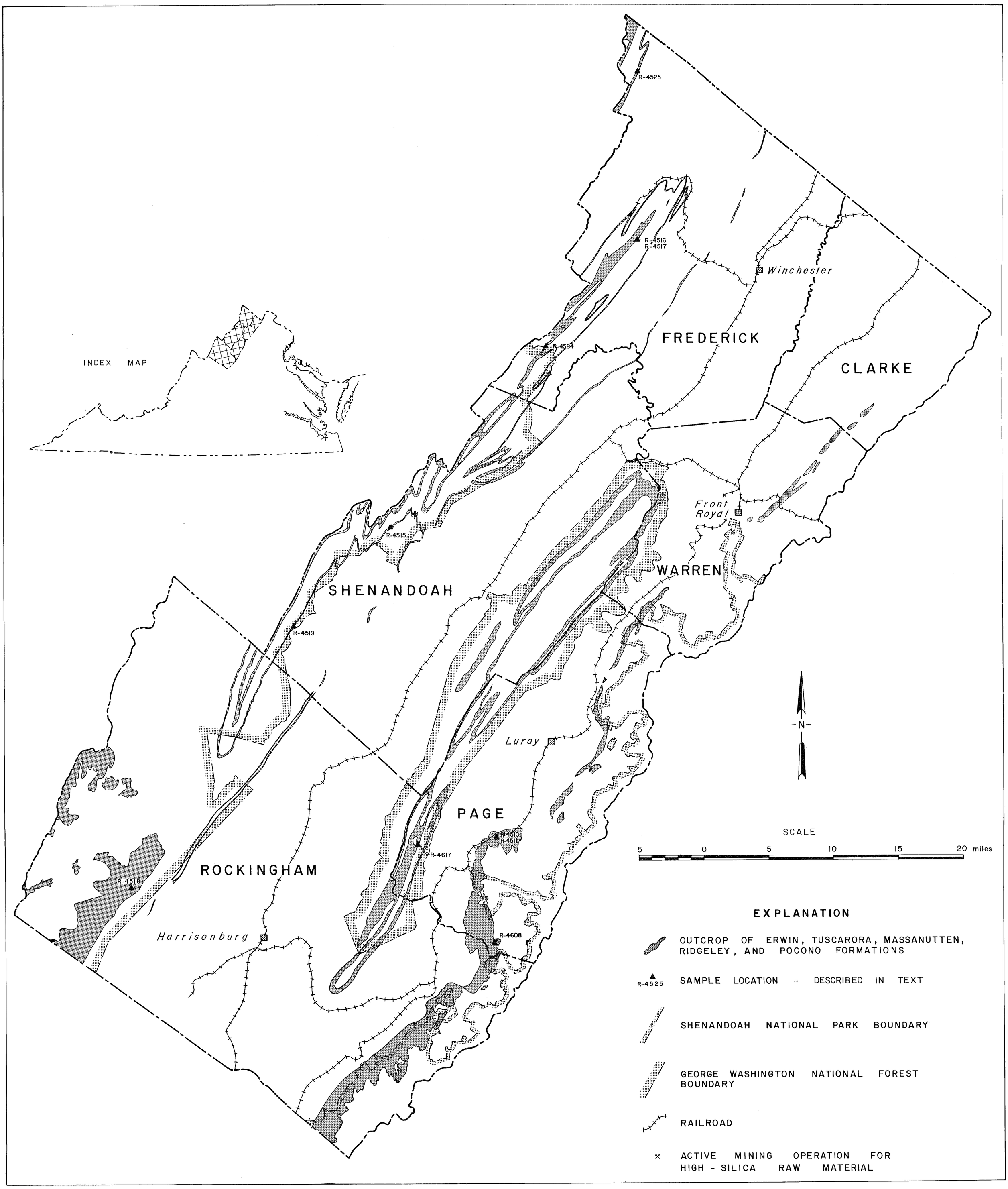

PRINCIPAL SANDSTONE AND QUARTZITE OCCURRENCES IN CLARKE, FREDERICK, PAGE, ROCKINGHAM, SHENANDOAH, AND WARREN COUNTIES, VIRGINIA

By W. Burleigh Harris
1972