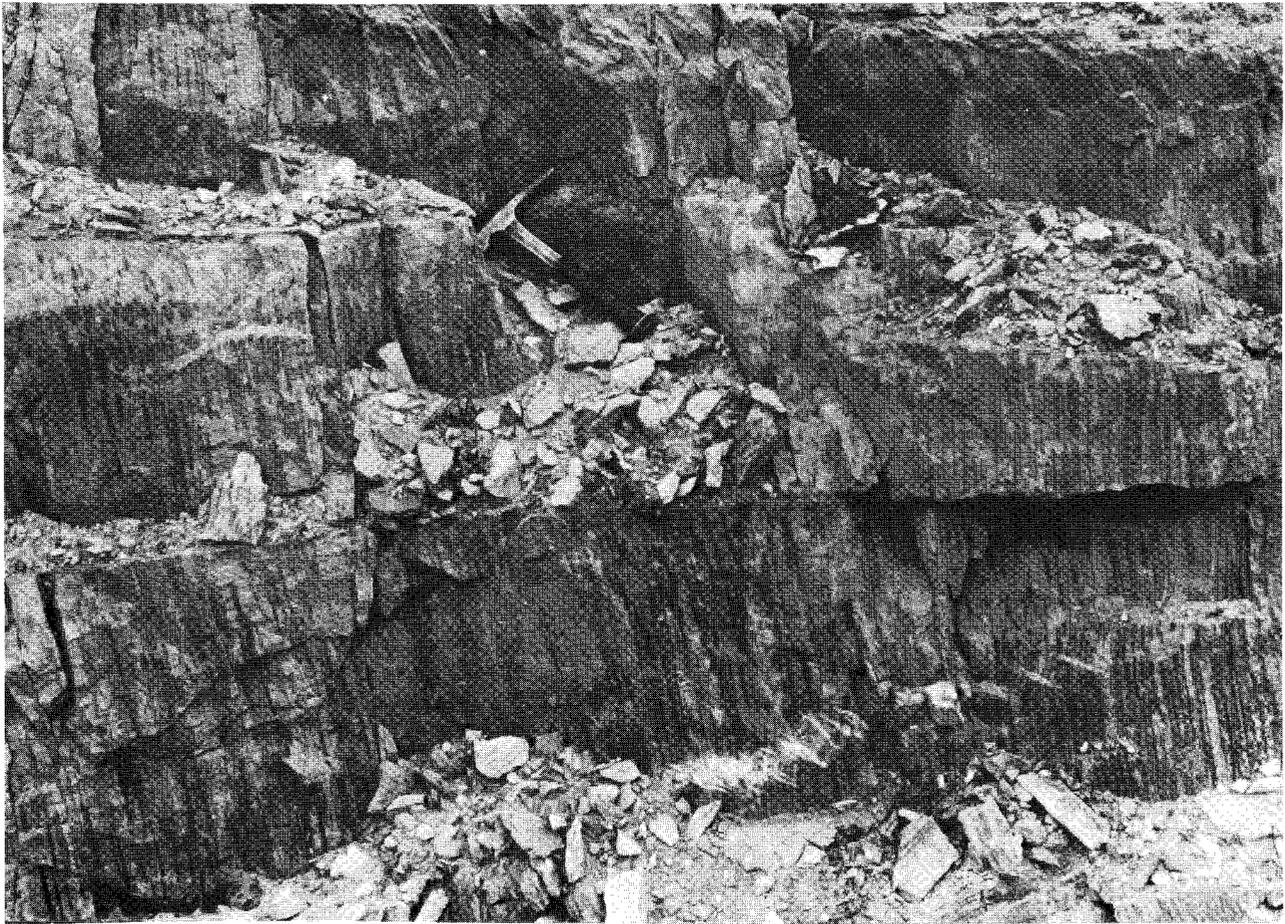




VIRGINIA DIVISION OF MINERAL RESOURCES PUBLICATION 32

HIGH-SILICA RESOURCES IN AUGUSTA, BATH, HIGHLAND, AND ROCKBRIDGE COUNTIES, VIRGINIA

Palmer C. Sweet



COMMONWEALTH OF VIRGINIA

DEPARTMENT OF CONSERVATION AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES

Robert C. Milici, Commissioner of Mineral Resources and State Geologist

CHARLOTTESVILLE, VIRGINIA

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FRONT COVER: Sediment-filled and iron-oxide stained *Skolithus* burrows in Antietam quartzite, Augusta County (Photo by Thomas M. Gathright, II).

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1981

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HIGH-SILICA RESOURCES IN AUGUSTA, BATH, HIGHLAND, AND ROCKBRIDGE COUNTIES, VIRGINIA

By
Palmer C. Sweet

ABSTRACT

The principal high-silica resources of Augusta, Bath, Highland, and Rockbridge counties in the central Valley and Ridge province of Virginia are in the Antietam and Tuscarora formations, and the Keefer and Ridgeley sandstones. Physical descriptions, sieve analyses, and chemical test data are presented so that the commercial potential of high-silica resources can be evaluated.

Composite samples from each of the principal resource units at selected localities were analyzed for silica content in a raw or unbeneficiated condition; silica content of the units ranges from 97.2 to 99.1 percent. The percentage of silica in beneficiated samples ranges from 98.9 to 99.5 percent for the same samples. 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 on the quartz grains were effectively removed. Grain-size distribution, average grain size, and degree of sorting for most samples is shown by histograms and cumulative frequency curves.

INTRODUCTION

A study of potential high-silica resources in the Valley and Ridge province was begun by the Virginia Division of Mineral Resources in November, 1970. A report on the high-silica resources in Clarke, Frederick, Page, Rockingham, Shenandoah and Warren counties was published earlier (Harris, 1972).

In the four counties comprising the present report, Augusta, Bath, Highland and Rockbridge counties, 249 sandstone and quartzite localities were examined. Thirteen samples from twelve of these localities warranted further study and were evaluated physically and chemically. Physical evaluations were made by W. Burleigh Harris and the writer. Chemical analyses were made by Spectrum Laboratories, Inc. in Piscataway, New Jersey. Samples are designated by numbers preceded by "R" (R-5585). Distributions of formations and samples are shown in Figure 1. Samples are on file in the Virginia Division of Mineral Resources rock repository, where they are available for examination. Locations of sample sites are designated by Universal Transverse Mercator coordinates (UTM). Descriptions of 226 of the sandstone and quartzite localities in Augusta, Bath, Highland and Rockbridge counties where samples were not collected is

on open file at the Division of Mineral Resources (Sweet, 1978b).

ACKNOWLEDGMENTS

The writer thanks the residents of Augusta, Bath, Highland and Rockbridge counties who provided access to private lands. Many exposures in Augusta and Highland counties were examined by W. Burleigh Harris in 1972. Appreciation is also extended to the U.S. Bureau of Mines, which provided chemical analyses of selected samples, and to Curt D. Edgerton, who provided liaison with the Bureau.

PROCEDURES

Exposures of sandstone and quartzite were measured and sampled at approximately 3-foot intervals. Material from each sampled interval was crushed by hand with a porcelain mortar and pestle; in cases where 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 further crushed by mortar and pestle. 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 were sieved on a Ro-Tap for 10 minutes. If examination with a microscope 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 0.50 percent; the average loss was 0.28 percent.

The degree of sorting for the composite samples is based upon the Inclusive Graphic Standard Deviation which includes 90 percent of the size-distribution of the total (Folk, 1968, p. 46). Beneficiation consisted of agitating material in water in a Waring Blender for 15 minutes and then decanting. The samples were then oven dried at 100°C. Beneficiated samples were sieved for 10 minutes on the Ro-Tap for grain-size distribution. In addition, tightly cemented quartzite from four localities was considered for possible metallurgical use. Hand samples of the quartzite were chemically analyzed, and studied in thin section to determine quartz content, sorting, cementation, and impurities.

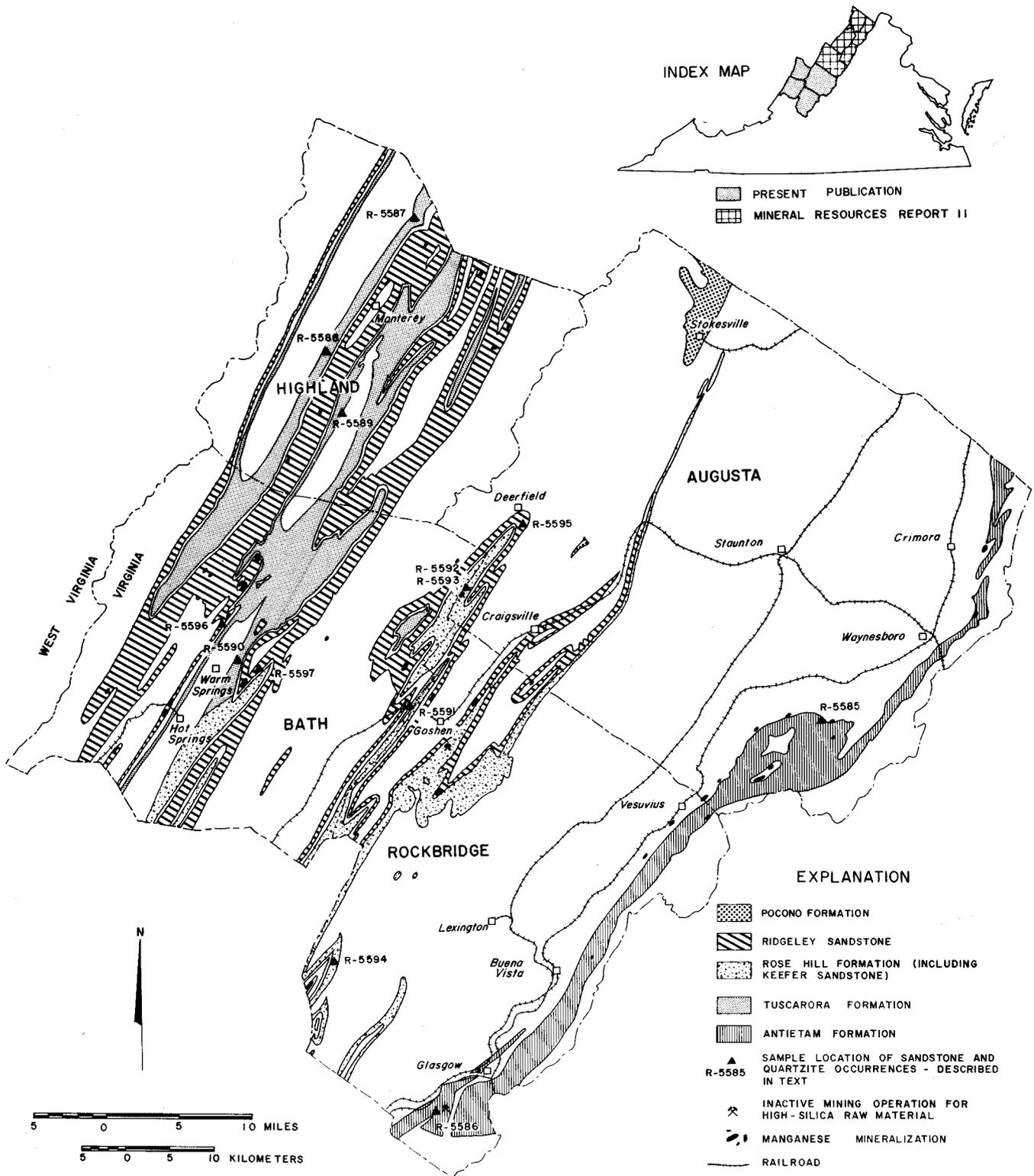


Figure 1. Principal sandstone and quartzite occurrences and manganese mineralization in Augusta, Bath, Highland and Rockbridge counties.

SILICA-SAND INDUSTRIAL ACTIVITY

Locher Silica Corporation formerly produced a glass sand from the Rose Hill Formation (which is stratigraphically below the Keefer Sandstone) approximately two miles (3.2 km) southwest of Goshen in Rockbridge County. The quarry is on the north-west slope of Bratton Mountain, in the Millboro 7.5-minute quadrangle.

Lambert Brothers, Division of Vulcan Materials Co., last operated the Greenlee Quarry, located about 2.5 miles (4.0 km) southwest of Glasgow in Rockbridge County, in early 1966. Metallurgical stone was produced from the Antietam Formation.

Residual sand from the Antietam Formation is now being utilized as masonry sand near Stuarts Draft in southern Augusta County; similar materials were produced in eastern Augusta County. In Rockbridge County, two miles (3.2 km) north of Glasgow, the Antietam Formation is quarried and marketed as roadstone and concrete aggregate.

USES OF HIGH-SILICA RESOURCES

McLaws (1971, p. 1-34) reports the following special commercial uses of material produced from high-silica resources.

Abrasive sand for:

1. blasting
2. banding
3. glassgrinding
4. sandpaper
5. scouring
6. stonegrinding and marblegrinding
7. stonemasonry

Building products sand for:

1. asbestos cement pipe
2. asphalt roofing tile
3. sand-lime brick

Glass sand

Hydraulic fracturing sand

Refractory sand for:

1. making foundry moldings
2. coring
3. lining furnaces (fire sand)
4. making pottery moldings
5. making silica (refractory) brick

Miscellaneous sand for:

1. chemical processes
2. coal washing
3. traction
4. filtering
5. providing sources of silica
6. metallurgical processes

A general discussion of sand and gravel resources in Virginia and specifications for some uses of high-silica resources is provided in Sweet (1978a, p. 67-

74); a detailed discussion is given in McLaws (1971, p. 1-34).

DESCRIPTIONS OF SAMPLES FROM HIGH-SILICA RESOURCES

ANTIETAM FORMATION

Quartzites and well-indurated quartzose sandstones cemented by secondary silica characterize the Antietam Formation (Cambrian). The formation is divided into upper and lower units. The lower unit is a clean massive, well-indurated quartzite. The upper unit generally consists of thin- to medium-bedded sandstones and quartzites that contain an abundance of iron-oxide stains. In Augusta County, the formation is generally highly fractured and weathered and contains an abundance of iron-oxide as stain on weathered surfaces. In Rockbridge County the formation is generally less fractured and contains a larger percentage of well-indurated quartzite. Near Lexington, this quartzite is 600 feet (183 m) thick (Bick, 1960, p. 10). A sample from one locality on the northeast side of U.S. Highway 60 about 1.5 miles (2.4 km) southeast of its intersection with U.S. Highway 501 in Buena Vista, Rockbridge County, contains some granules (>2mm) and some *Skolithus* burrows (7mm diameter).

Sample R-5585

Location: The Antietam Formation was sampled 6.25 miles (10.06 km) north of Love, Augusta County on the north side of the Coal Road approximately 8900 feet (2713 m) and S22°E from the center of Shenandoah Acres lake in the Big Levels, Virginia, 7.5-minute quadrangle (UTM: N 4,204,820, E 674,250; Zone 17).

Description: Sandstone, white to orangish-brown to dusky red near the top of the exposure, with medium and some coarse subrounded to rounded grains. Iron-oxide stain is predominant as a coating on grains; some stain is also concentrated along joints and fractures. Sandstone ranges from poorly indurated to very friable. Unit is weathered. Bedding thickness varies from 4 to 16 inches (10 to 41 cm); average is about 12 inches (30 cm). Exposed thickness is 46 feet (14 m), including about 15 feet (4.5 m) of covered interval near the base of the exposure. Strike is N15°W; dip is 14°NE.

Laboratory analyses: In thin section the sandstone consists of fine- to medium-grained, subrounded to rounded quartz bonded by quartz. Minor constituents are feldspar, sericite, muscovite and tourmaline (?).

Sieve and chemical analyses of the raw material (R-5585-A) and beneficiated material (R-5585-B) are shown in Table 1. Histograms and cumulative

frequency curves of the sieve analyses are shown in Figures 2 and 3. The raw material is moderately sorted; upon beneficiation the sample becomes moderately well sorted.

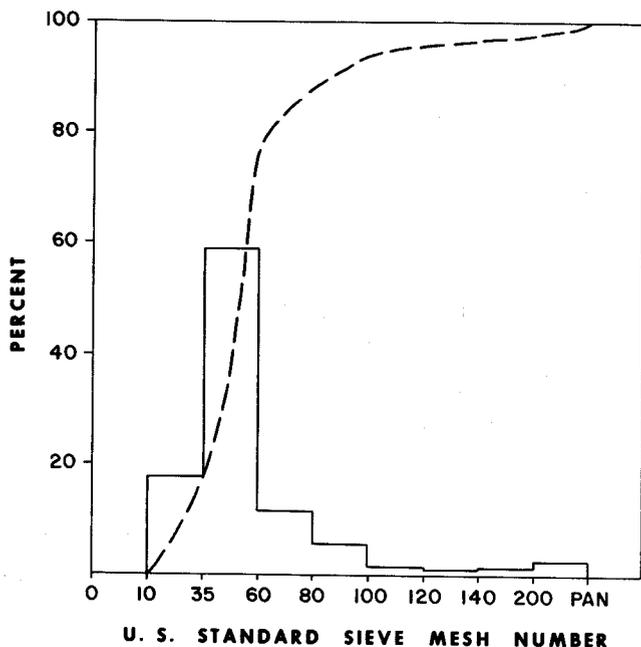


Figure 2. Histogram and cumulative frequency curve of sample R-5585-A, Antietam Formation.

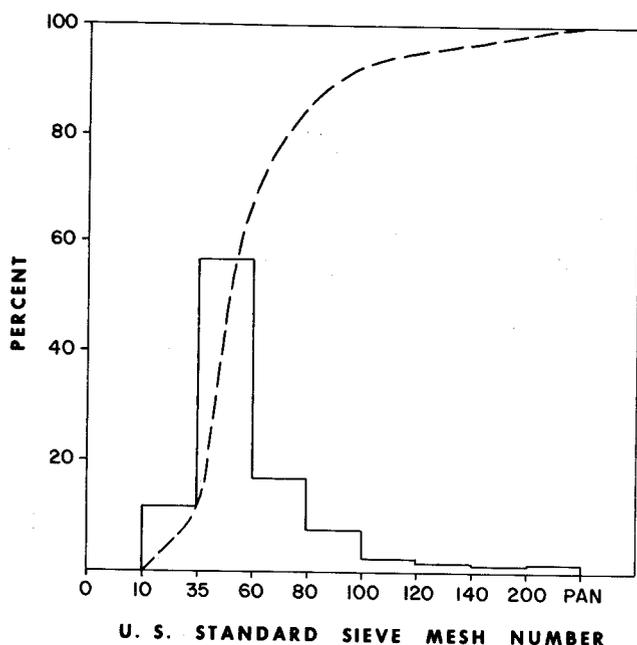


Figure 3. Histogram and cumulative frequency curve of sample R-5585-B, Antietam Formation.

Table 1. Sieve and chemical analyses of sample R-5585, Antietam Formation.

SIEVE ANALYSES

U.S. Standard Sieve Mesh No.	SAMPLE R-5585-A	SAMPLE R-5585-B
	Percent Retained	
10	0	0
35	17.95	11.93
60	58.43	56.30
80	11.46	16.81
100	5.73	7.66
120	1.47	2.20
140	1.18	1.63
200	1.29	1.51
Pan	2.20	1.57

CHEMICAL ANALYSES

(Spectrum Laboratories, Inc.)

Constituents	Percent	
SiO ₂	97.60	99.30
Al ₂ O ₃	1.67	0.40
Fe ₂ O ₃	0.34	0.19
MgO	0.03	0.02
CaO	0.05	0.03
K ₂ O	0.05	0.01
CrO ₂	<0.01	<0.01
TiO ₂	0.01	<0.01
CoO	<0.01	0.01

Sample R-5586

Location: The Antietam Formation (Figure 4) was sampled 1.8 miles (2.9 km) southeast of Natural Bridge in Rockbridge County in the abandoned quarry of Vulcan Materials Company (Greenlee Quarry) at the end of State Road 782 extended, approximately 2.0 miles (3.2 km) by road southeast of its intersection with State Road 759 in the Snowden, Virginia 7.5-minute quadrangle (UTM: N 4,162,710, E 634,520; Zone 17).

Description: Quartzite, white to bluish-gray, with medium to coarse subangular to subrounded grains. Quartzite is slightly indurated with brownish-orange to dark-reddish iron-oxide stain; the stain is along the bedding planes and on the grains. The base of the exposure contains some large current ripple marks. Higher parts of unit contain white to bluish-gray quartzite with scattered rust and reddish iron-oxide stain on the well-indurated material. A 3-foot (1 m) interval in the middle of the section contains an 8-inch (20 cm), iron-oxide-stained quartzite bed, interbedded gray and gray-green arenaceous shales, and several thin quartzite beds. The upper 48 feet (14 m) of the exposure consists of yellowish-gray clayey saprolite and thick-bedded, dark-gray quartzite beds with red stain on

the grains. Some reddish *Skolithus* burrows (6 mm diameter) are present in some pale-blue quartzite. Overall the unit is well indurated; bedding varies from 1 to 6 feet (0.3 m to 1.8 m), the average is 3 feet (1 m). Only the lower 72 feet (22 m) were sampled. Exposed thickness is 120 feet (37 m). Strike is N46°E; dip is 29°NW to 41°NW.

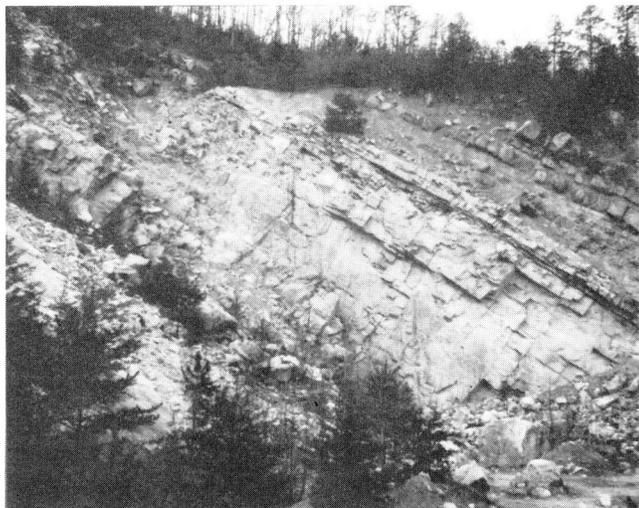


Figure 4. Antietam Formation in the old abandoned Greenlee Quarry, Rockbridge County (sample R-5586). Bed near center is 6-foot thick.

Laboratory analyses: In thin section the quartzite consists of medium to coarse, subangular to rounded, strained quartz grains. Generally, grain boundaries are sutured, although a few are tightly bonded by a simple quartz weld. Some polycrystalline quartz grains occur along the boundaries. There are minor amounts of feldspar and epidote.

The quartzite at this locality is too well cemented to be crushed for sieve determination of grain-size distribution. A chemical analysis of a hand sample is shown in Table 2.

Table 2. Chemical analysis of Sample R-5586, Antietam Formation (Spectrum Laboratories, Inc.)

Constituents	Percent
SiO ₂	99.3
Al ₂ O ₃	0.47
Fe ₂ O ₃	0.31
MgO	0.02
CaO	<0.01
K ₂ O	0.35
CrO ₂	<0.01
TiO ₂	<0.01
CoO	<0.01

TUSCARORA FORMATION

The Tuscarora Formation (Silurian) consists of very fine- to coarse-grained sandstone and quartzite. Rounded, white quartz pebbles, up to 9 mm in length, were present in the base of some exposures. Quartz grains in the Tuscarora are generally bonded by a simple quartz weld, although there are some sutured contacts along grain boundaries. Some secondary quartz overgrowths also occur. The rock varies from a well-indurated, at places massive, quartzite to a friable sandstone. At one locality, where U.S. Highway 250 runs between Doe Hill and Bear Mountain approximately 2.5 miles (4.0 km) west of McDowell, the formation consists of three members: an upper 75+-foot-thick (23 m) white to light-gray quartzite, a medial 15+-foot-thick (5 m) argillaceous sandstone-quartzite and a lower 40+-foot-thick (12 m) quartzite. The argillaceous sandstone consisted of six- to eight-inch (15- to 20-cm) thick sandstone-quartzite beds interbedded with light-gray, soft shale. Lowry (1954, p. 33) reported a sample of Tuscarora from Monterey Mountain, Highland County had a SiO₂ content of 99.60 percent.

Sample R-5587

Location: The Tuscarora Formation was sampled 6.25 miles (10.06 km) north-northeast of Monterey in Highland County on the north side of State Road 642 approximately 1.8 miles (2.9 km) by road west of its junction with U.S. Highway 220 in the Monterey, Virginia 7.5-minute quadrangle (UTM: N 4,261,570, E 627,780; Zone 17).

Description: Quartzite, white to very light-gray where fresh, pale-yellowish-orange to dark-yellowish-orange along fracture surfaces and bedding planes, with very fine to fine, subrounded to rounded, very well-sorted grains. Iron is on some grains and is concentrated principally along fractures. Thin interval near the base is slightly friable but the rest of the exposure is very well indurated. Bedding ranges from 8- to 16-inches thick (20 to 40 cm), and is irregular; there are some cross-beds. Exposed thickness of the unit is 36 feet (11 m). Strike is N33°E, dip is 42°SE, the rocks are overturned.

Laboratory analyses: In thin section the quartzite consists of fine to medium, subrounded to rounded grains that are tightly cemented by quartz. Some grain boundaries are sutured. There are minor amounts of sericite and feldspar.

The quartzite at this locality is too indurated to be crushed for sieve determination of grain size.

A chemical analysis of a hand sample is shown in Table 3.

Table 3. Chemical analysis of Sample R-5587, Tuscarora Formation (Spectrum Laboratories, Inc.)

Constituents	Percent
SiO ₂	98.6
Al ₂ O ₃	0.28
Fe ₂ O ₃	0.34
MgO	0.01
CaO	0.01
K ₂ O	0.46
CrO ₂	<0.01
TiO ₂	<0.01
CoO	<0.01

Sample R-5588

Location: The Tuscarora Formation (Figure 5) was sampled 3.55 miles (5.72 km) north of Mustoe in Highland County on the north side of State Road 637 approximately 0.1 mile (0.2 km) by road north of its junction with State Highway 84 at Vanderpool Gap in the Mustoe, Virginia-West Virginia 7.5-minute quadrangle (UTM: N 4,248,060, E 619,110; Zone 17).

Description: Quartzite, white to medium-gray, gray to dark-yellowish-orange along fractures, with very fine to fine, and in some intervals, medium to coarse, subrounded to rounded grains.

Iron-oxide stain is scattered throughout but is principally concentrated along fractures. Most fracture surfaces are case-hardened. Bedding ranges from 8 to 24 inches (20 to 60 cm) thick but generally averages 12 to 18 inches (30 to 46 cm). Measured section is from base of formation, which is covered, to approximately 1 foot (0.3 m) from its top. Exposed thickness of the unit is 69 feet (21 m); strike is N29°E; dip is 58°SE.

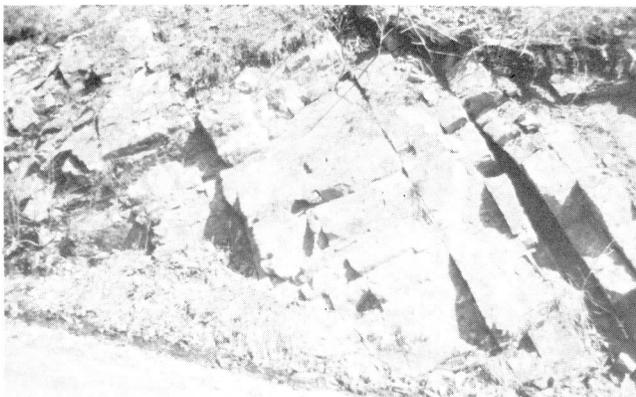


Figure 5. Tuscarora Formation at Vanderpool Gap, Highland County (sample R-5588).

Laboratory analyses: In thin section the quartzite consists of medium, mainly subangular quartz

grains that are bonded by a simple quartz weld. Some quartz overgrowths are present; there are no sutured contacts.

The quartzite at this locality is too indurated to be crushed for sieve determination of grain size distribution.

A chemical analysis of a hand sample is in Table 4.

Table 4. Chemical analysis of Sample R-5588, Tuscarora Formation (Spectrum Laboratories, Inc.)

Constituents	Percent
SiO ₂	98.6
Al ₂ O ₃	0.51
Fe ₂ O ₃	0.10
MgO	0.03
CaO	<0.01
K ₂ O	0.07
CrO ₂	<0.01
TiO ₂	<0.01
CoO	<0.01

Sample R-5589

Location: The Tuscarora Formation (Figure 6) was sampled 0.25 miles (0.40 km) west-northwest of Trimble in Highland County on the north side of the junction of State Road 606 and State Road 607 in the Monterey SE, Virginia 7.5-minute quadrangle (UTM: N 4,240,420, E 620,330; Zone 17).

Description: Quartzite, white to light gray to brown to dark-yellowish-orange along fractures, with very fine to fine and some medium, subrounded to rounded grains. Iron stain is meager on quartz grains, but abundant on some fracture surfaces. There are minor amounts of light-green-gray shale clasts. Bedding ranges from about 6 to 24 inches (15 to 61 cm), but averages about 18 inches (46 cm). There are some cross-beds. Exposed thickness of the unit is 76 feet (23 m). Strike is N30°E; dip is 74°NW.



Figure 6. Tuscarora Formation, Highland County, on the north side of the junction of State Roads 606 and 607 (sample R-5589).

Laboratory analyses: In thin section the quartzite consists of fine, subrounded quartz grains with a simple quartz weld; there are some sutured contacts. Minor constituents include feldspar and sericite.

The quartzite at this locality is too indurated to be crushed for sieve determination of grain size distribution.

The chemical analyses of a hand sample is shown in Table 5.

Table 5. Chemical analysis of Sample R-5589, Tuscarora Formation (Spectrum Laboratories, Inc.)

Constituents	Percent
SiO ₂	99.3
Al ₂ O ₃	0.28
Fe ₂ O ₃	0.31
MgO	0.02
CaO	0.01
K ₂ O	0.08
CrO ₂	<0.01
TiO ₂	<0.01
CoO	0.01

Sample R-5590

Location: The Tuscarora Formation was sampled 5.0 miles (8.0 km) northeast of Hot Springs in Bath County on the southwest side of State Highway 39 approximately 1.75 miles (2.82 km) by road southeast of its intersection with U.S. Highway 220 near the crest of Warm Springs Mountain in the Warm Springs, Virginia, 7.5-minute quadrangle (UTM: N 4,211,885, E 608,290; Zone 17).

Description: Sandstone, white to very light-gray, with fine to medium, and some coarse, subrounded to rounded grains. Yellowish-orange, reddish and some black iron-oxide stain is on surfaces of grains, especially in the middle of the exposure. There are some quartz granules (3 mm) near the middle of the exposure where the unit contains coarse-grained sand. Sandstone varies from very friable to well indurated and it is almost a quartzite in several places. Approximately 90 percent of the rock in the exposure is slightly friable to very friable; about 15 feet (5 m) in the bottom of the lower 1/3 of the exposure is very friable. Bedding ranges from 8 to 48 inches (20 to 122 cm); it averages 20 to 24 inches (51 to 61 cm). Exposed thickness is 116 feet (35 m). Strike is N 41°E; dip is 76°SE to 83°SE.

Laboratory analyses: In thin section the sandstone consists of fine to medium with some coarse, subangular to subrounded grains that are bonded by quartz; there is some suturing of grain boundaries. Very minor constituents include subrounded chert and feldspar fragments; the clay matrix contains

sericite.

Sieve and chemical analyses of the raw material (R-5590-A) and beneficiated material (R-5590-B) are shown in Table 6. Histograms and cumulative frequency curves of the sieve analyses are shown in Figures 7 and 8. The raw sample is moderately sorted; upon beneficiation the sample becomes moderately well sorted.

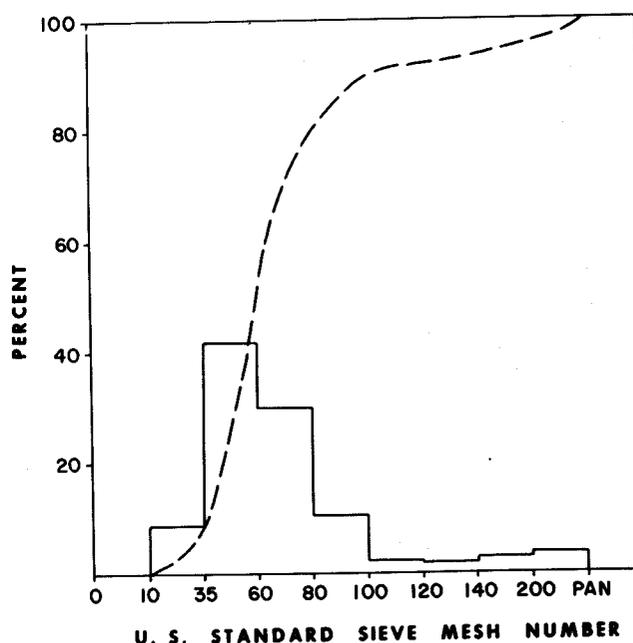


Figure 7. Histogram and cumulative frequency curve of sample R-5590-A, Tuscarora Formation.

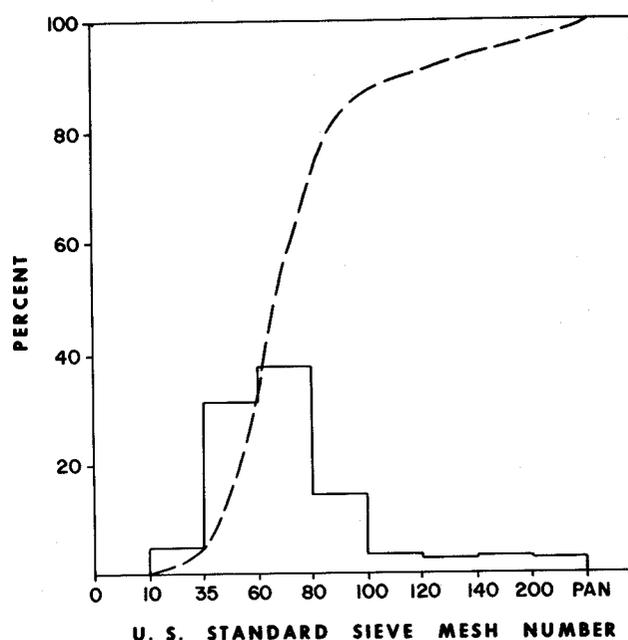


Figure 8. Histogram and cumulative frequency curve of sample R-5590-B, Tuscarora Formation.

Table 6. Sieve and chemical analyses of sample R-5590, Tuscarora Formation.

SIEVE ANALYSES

U.S. Standard Sieve Mesh No.	SAMPLE R-5590-A	SAMPLE R-5590-B
	Percent Retained	
10	0	0
35	8.43	5.22
60	41.23	31.01
80	29.86	37.63
100	10.16	14.10
120	1.98	3.36
140	1.87	2.74
200	2.38	2.87
Pan	3.58	2.73

CHEMICAL ANALYSES

(Spectrum Laboratories, Inc.)

Constituents	Percent	
SiO ₂	99.0	99.3
Al ₂ O ₃	0.40	0.19
Fe ₂ O ₃	0.17	0.06
MgO	0.02	0.01
CaO	0.03	0.23
K ₂ O	0.03	0.01
CrO ₂	<0.01	<0.01
TiO ₂	<0.01	0.03
CoO	0.01	<0.01

Sample R-5591

Location: The Tuscarora Formation (Figure 9) was sampled at Panther Gap in Bath County off the southwest side of the C. & O. Railroad tracks, parallel to State Highway 39-42 at the Bath-Rockbridge county line in the Green Valley, Virginia, 7.5-minute quadrangle (UTM: N 4,206,940, E 628,530; Zone 17).

Description: Sandstone, white to light-brown or orange, with fine to medium and some coarse, subrounded to rounded grains. There is some brown to black iron-oxide stain and rare white, coarse, subangular to rounded granules. The unit, which is cross-bedded in part, ranges from slightly indurated to very friable; induration of unit increases up-section. Some of the friable sandstone occurs near the top of the section. Approximately 15 feet (5 m) of friable material is in the middle one-third of the unit. Bedding ranges from very thin to 4-feet thick (1 m), and averages 16 to 20-inches (41-51 cm) thick. The exposed thickness is 49 feet (15 m). Strike is N25°E to N35°E; dip is 33°SE.

Laboratory analyses: In thin section the sandstone generally consists of faintly iron-oxide-stained, fine to coarse, subrounded to rounded quartz grains



Figure 9. Tuscarora Formation at the Bath-Rockbridge County line (sample R-5591).

bonded by quartz. There is some suturing of grain contacts. There are minor amounts of quartzite (?) fragments and sericite.

Sieve and chemical analyses of the raw material (R-5591-A) and beneficiated material (R-5591-B) are shown in Table 7. Histograms and cumulative frequency curves of the sieve analyses are shown in Figures 10 and 11. Both the raw and beneficiated material are moderately well sorted.

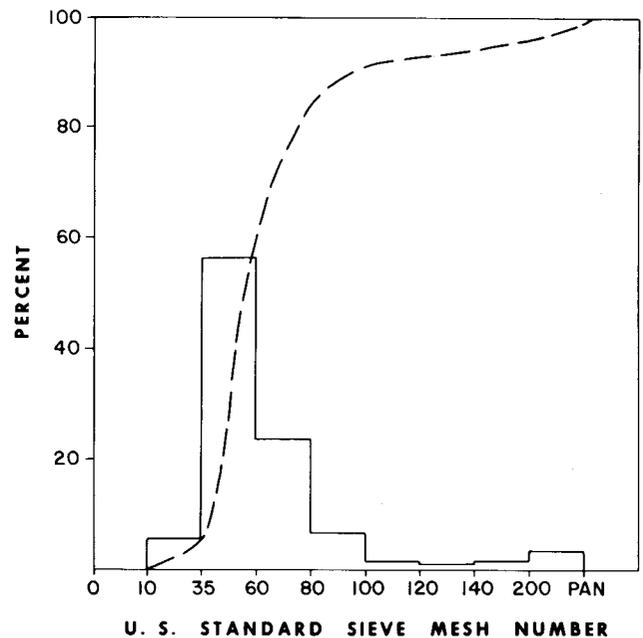


Figure 10. Histogram and cumulative frequency curve of sample R-5591-A, Tuscarora Formation.

Table 6. Sieve and chemical analyses of sample R-5590, Tuscarora Formation.

SIEVE ANALYSES		
U.S. Standard Sieve Mesh No.	SAMPLE R-5590-A	SAMPLE R-5590-B
	Percent Retained	
10	0	0
35	8.43	5.22
60	41.23	31.01
80	29.86	37.63
100	10.16	14.10
120	1.98	3.36
140	1.87	2.74
200	2.38	2.87
Pan	3.58	2.73

CHEMICAL ANALYSES (Spectrum Laboratories, Inc.)		
Constituents	Percent	
SiO ₂	99.0	99.3
Al ₂ O ₃	0.40	0.19
Fe ₂ O ₃	0.17	0.06
MgO	0.02	0.01
CaO	0.03	0.23
K ₂ O	0.03	0.01
CrO ₂	<0.01	<0.01
TiO ₂	<0.01	0.03
CoO	0.01	<0.01

Sample R-5591

Location: The Tuscarora Formation (Figure 9) was sampled at Panther Gap in Bath County off the southwest side of the C. & O. Railroad tracks, parallel to State Highway 39-42 at the Bath-Rockbridge county line in the Green Valley, Virginia, 7.5-minute quadrangle (UTM: N 4,206,940, E 628,530; Zone 17).

Description: Sandstone, white to light-brown or orange, with fine to medium and some coarse, subrounded to rounded grains. There is some brown to black iron-oxide stain and rare white, coarse, subangular to rounded granules. The unit, which is cross-bedded in part, ranges from slightly indurated to very friable; induration of unit increases up-section. Some of the friable sandstone occurs near the top of the section. Approximately 15 feet (5 m) of friable material is in the middle one-third of the unit. Bedding ranges from very thin to 4-feet thick (1 m), and averages 16 to 20-inches (41-51 cm) thick. The exposed thickness is 49 feet (15 m). Strike is N25°E to N35°E; dip is 33°SE.

Laboratory analyses: In thin section the sandstone generally consists of faintly iron-oxide-stained, fine to coarse, subrounded to rounded quartz grains

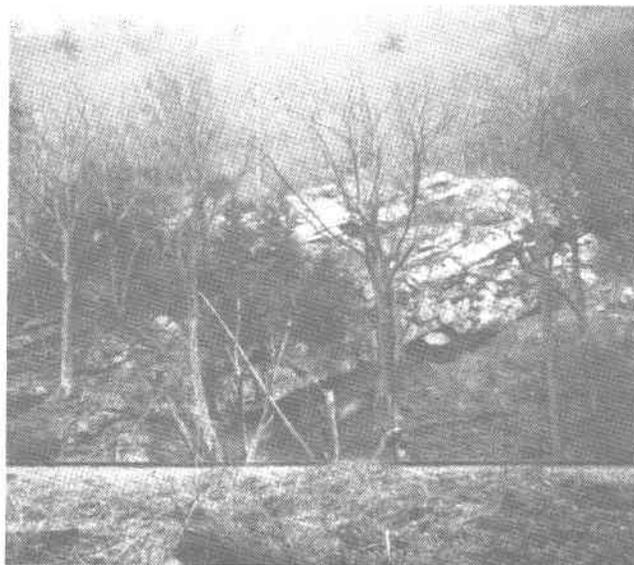


Figure 9. Tuscarora Formation at the Bath-Rockbridge County line (sample R-5591).

bonded by quartz. There is some suturing of grain contacts. There are minor amounts of quartzite (?) fragments and sericite.

Sieve and chemical analyses of the raw material (R-5591-A) and beneficiated material (R-5591-B) are shown in Table 7. Histograms and cumulative frequency curves of the sieve analyses are shown in Figures 10 and 11. Both the raw and beneficiated material are moderately well sorted.

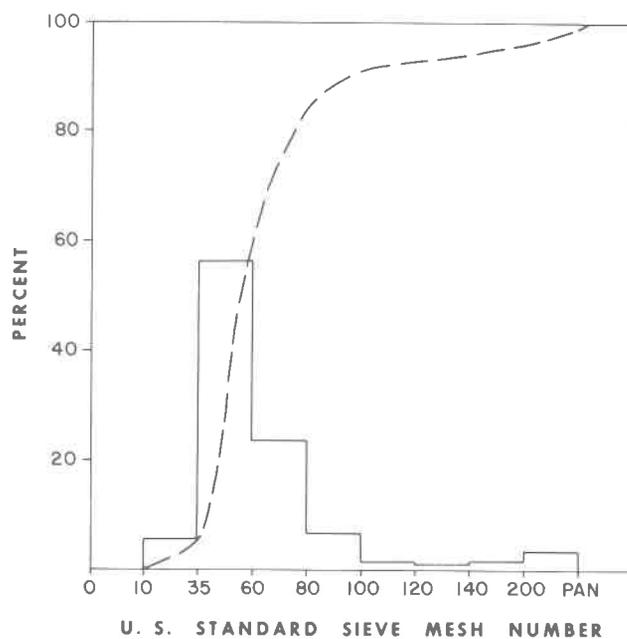


Figure 10. Histogram and cumulative frequency curve of sample R-5591-A, Tuscarora Formation.

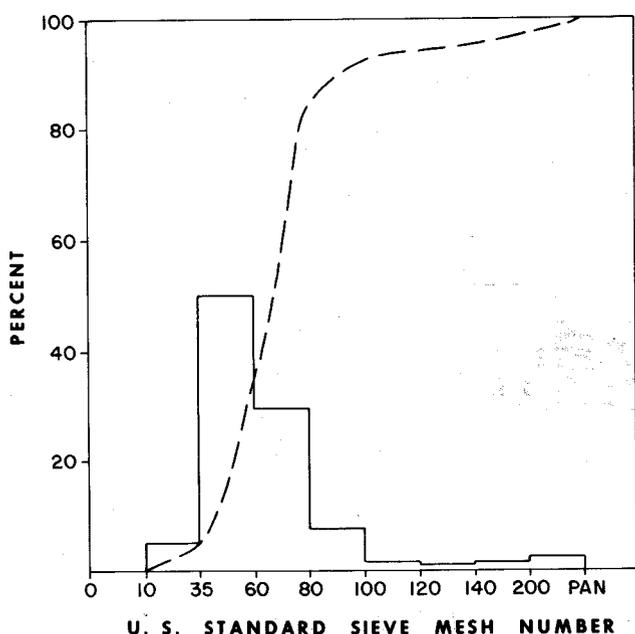


Figure 11. Histogram and cumulative frequency curve of sample R-5591-B, Tuscarora Formation.

Table 7. Sieve and chemical analyses of sample R-5591, Tuscarora Formation.

SIEVE ANALYSES

U.S. Standard Sieve Mesh No.	SAMPLE R-5591-A	SAMPLE R-5591-B
	Percent Retained	
10	0	0
35	5.73	5.09
60	56.10	49.98
80	23.76	29.59
100	6.19	7.92
120	1.31	1.87
140	1.22	1.41
200	1.71	1.74
Pan	3.53	2.03

CHEMICAL ANALYSES

(Spectrum Laboratories, Inc.)

Constituents	Percent	
SiO ₂	98.9	99.4
Al ₂ O ₃	0.65	0.33
Fe ₂ O ₃	0.10	0.05
MgO	0.04	0.01
CaO	0.02	<0.01
K ₂ O	0.08	0.08
CrO ₂	<0.01	<0.01
TiO ₂	0.01	<0.01
CoO	<0.01	<0.01

KEEFER SANDSTONE

The Keefer Sandstone (Silurian) is a white to gray-brown, very fine- to medium-grained, well-indurated quartzite to indurated to friable sandstone. Quartz grains are bonded by a quartz weld and are commonly cementated by secondary quartz overgrowths. There are rare conglomeratic lenses containing subrounded quartz pebbles. In western Augusta and northern Rockbridge counties, the maximum thickness of this unit is estimated to be 300 feet (91 m) (Kozak, 1970, p. 12).

Lowry (1954, p. 41) reports the following partial chemical analysis on a sample of Keefer on the northwest slope of Little North Mountain, Augusta County: SiO₂-99.30 percent, Al₂O₃-0.33 percent, Fe₂O₃-0.06 percent, TiO₂-0.01 percent. Lowry also reports that samples from localities on North and Middle mountains, Rockbridge County have SiO₂ contents of 99.56 percent and 99.21 percent, respectively.

Sample R-5592

Location: The Keefer Sandstone was sampled 5.35 miles (8.61 km) southwest of Deerfield in Augusta County on the top of Walker Mountain approximately 23,700 feet (7,224 m) S42°W from the junction of State Road 600 and State Road 692 in the Deerfield, Virginia, 7.5-minute quadrangle (UTM: N 4,221,310, E 635,020; Zone 17). The Keefer at this exposure was divided into an upper unit designated R-5592 and a lower unit designated R-5593.

Description: Sandstone, white to yellowish and dark-yellowish-brown, with fine to medium, subrounded to rounded grains; unit is friable to slightly indurated. There is some iron-oxide stain along joints. Scattered granules (4 mm) and pebbles (5 mm and more) occur near the top of the exposure. Bedding ranges from 4 to 48 inches (10 to 122 cm). Exposed thickness of the upper unit is 38 feet (12 m). Strike is N25°E; dip is 5°NW.

Laboratory analyses: In thin section this sandstone consists of fine to medium, with some coarse, subangular to subrounded grains. The quartz grains are bonded by quartz; some grains are sutured. Other constituents include minor amounts of muscovite and sericite. Sieve and chemical analyses of the raw material (R-5592-A) and beneficiated material (R-5592-B) are shown in Table 8. Histograms and cumulative frequency curves of the sieve analyses are shown in Figures 12 and 13. The raw material is moderately well sorted; after beneficiation the material is well to moderately well sorted.

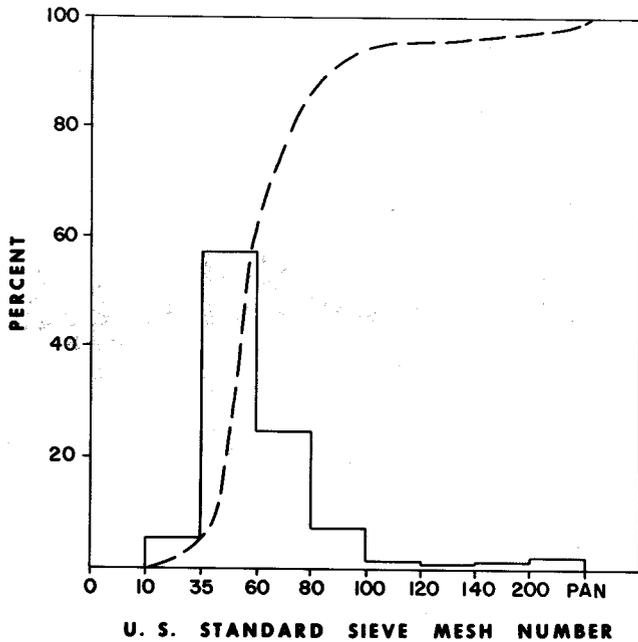


Figure 12. Histogram and cumulative frequency curve of sample R-5592-A, Keefer Sandstone.

Table 8. Sieve and chemical analyses of sample R-5592, Keefer Sandstone.

SIEVE ANALYSES

U.S. Standard Sieve Mesh No.	SAMPLE R-5592-A Percent Retained	SAMPLE R-5592-B Percent Retained
10	0	0
35	5.31	4.01
60	56.95	55.01
80	24.70	28.76
100	7.06	7.95
120	1.23	1.44
140	0.97	0.97
200	1.26	0.93
Pan	2.17	0.71

CHEMICAL ANALYSES

(Spectrum Laboratories, Inc.)

Constituents	Percent	
SiO ₂	97.5	99.3
Al ₂ O ₃	0.76	0.32
Fe ₂ O ₃	1.24	0.26
MgO	0.05	0.02
CaO	0.03	0.02
K ₂ O	0.02	0.02
CrO ₂	<0.01	<0.01
TiO ₂	<0.01	<0.01
CoO	<0.01	<0.01

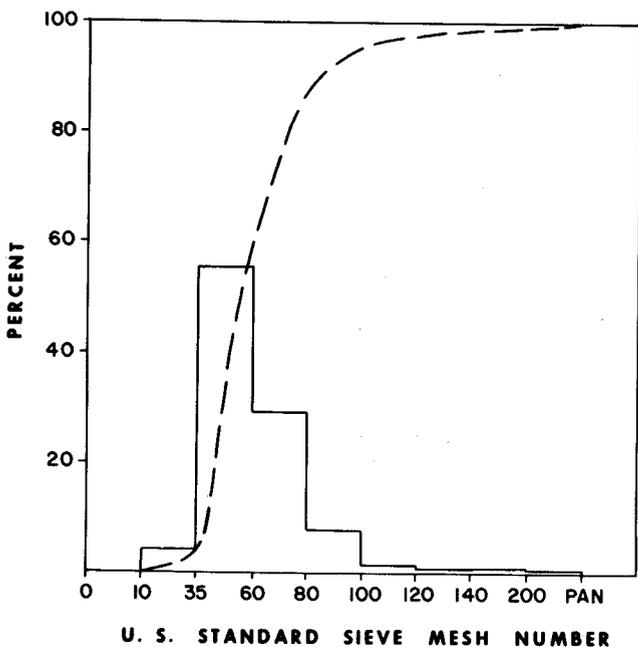


Figure 13. Histogram and cumulative frequency curve of sample R-5592-B, Keefer Sandstone.

Sample R-5593

Location: Same as for R-5592.

Description: Sandstone, white to yellowish-gray, with medium and minor amounts of coarse, subrounded to rounded grains. Sandstone ranges from friable to very friable; there is some iron-oxide stain. Bedding averages 20 inches (51 cm). Exposed thickness of the lower unit is 25 feet (8 m). Strike is N25°E; dip is 5°NW.

Laboratory analyses: The lower part of the Keefer at this locality was sampled because its friability. In thin section, the sandstone consists of fine to coarse, subrounded to rounded quartz grains bonded by quartz. Some grains show secondary quartz overgrowths.

Sieve and chemical analyses of the raw material (R-5593-A) and beneficiated material (R-5593-B) are shown in Table 9. Histograms and cumulative frequency curves of the sieve analyses are shown in Figures 14 and 15. Both raw and beneficiated material are moderately well sorted.

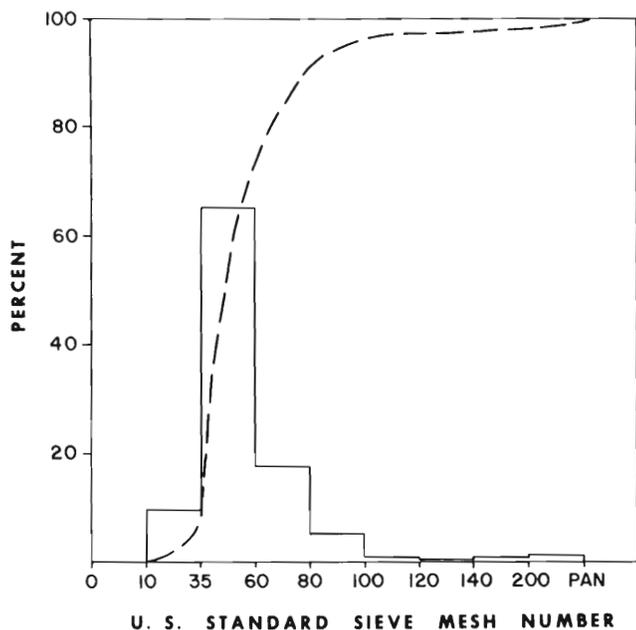


Figure 14. Histogram and cumulative frequency curve of sample R-5593-A, Keefer Sandstone.

Table 9. Sieve and chemical analyses of sample R-5593, Keefer Sandstone.

SIEVE ANALYSES

U.S. Standard Sieve Mesh No.	SAMPLE R-5593-A	SAMPLE R-5593-B
	Percent Retained	
10	0	0
35	9.48	7.42
60	64.80	59.23
80	17.50	22.20
100	5.12	7.08
120	0.70	1.24
140	0.46	0.80
200	0.58	0.92
Pan	1.10	0.95

CHEMICAL ANALYSES
(Spectrum Laboratories, Inc.)

Constituents	Percent	
SiO ₂	99.1	99.5
Al ₂ O ₃	0.15	0.13
Fe ₂ O ₃	0.49	0.13
MgO	0.01	<0.01
CaO	0.03	<0.01
K ₂ O	0.01	0.05
CrO ₂	<0.01	<0.01
TiO ₂	<0.01	<0.01
CoO	<0.01	<0.01

Sample R-5594

Location: The Keefer Sandstone (Figure 16) was sampled 5.5 miles (8.8 km) north of Rapps Mill in Rockbridge County on the northeast side of the Lexington Reservoir road, approximately 2.75 miles (4.43 km) by road northwest of its intersection with State Road 612 in the Sugarloaf Mountain, Virginia, 7.5-minute quadrangle (UTM: N 4,178, 640, E 619,860; Zone 17).

Description: Sandstone, white to brown, with medium to coarse and some fine, subangular to subrounded grains. Reddish-brown to black iron-oxide stain occurs as coating on the grains and also along fractures. Most of the stain is in the lower part of the unit. Some scattered granules are near the middle of the exposure, which also has some cross-beds. The lower 90 feet (27 m) vary from slightly indurated to friable; the top 132 feet (40 m) consist of very slightly friable to friable sandstone. Bedding ranges from 8 to 36 inches (20 to 91 cm), averaging 20 inches (51 cm); beds are thicker toward the top. A good exposure of the Rose Hill Formation is present at the base of the unit. Exposed thickness of the Keefer is 222 feet (68 m), including 25 feet (8 m) of covered interval at the base of the exposure. Strike is N7°E; dip is 30°NW to 37°NW.

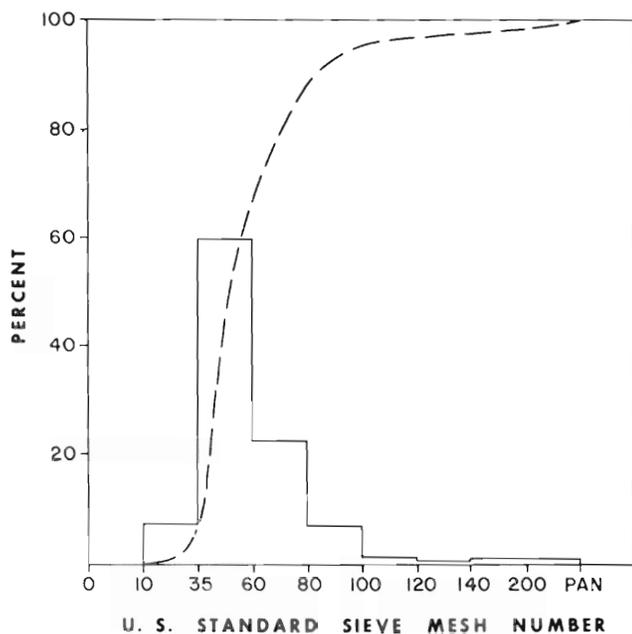


Figure 15. Histogram and cumulative frequency curve of sample R-5593-B, Keefer Sandstone.



Figure 16. Keefe Sandstone near the Lexington Reservoir, Rockbridge County (sample R-5594).

Laboratory analyses: In thin section the sandstone consists of fine to coarse, subangular to subrounded, slightly iron-oxide-stained quartz grains bonded by quartz. Sieve and chemical analyses of the raw material (R-5594-A) and beneficiated material (R-5594-B) are shown in Table 10. Histograms and cumulative frequency curves of the sieve analyses are shown in Figures 17 and 18. Both raw and beneficiated material are moderately well sorted.

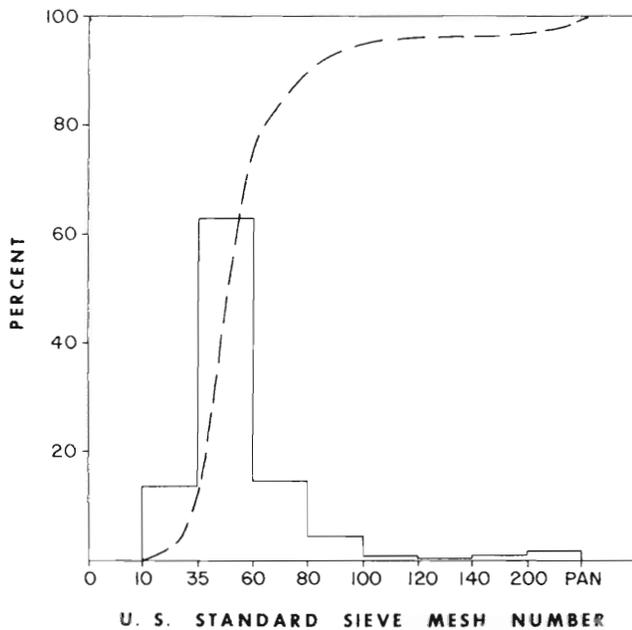


Figure 17. Histogram and cumulative frequency curve of sample R-5594-A, Keefe Sandstone.

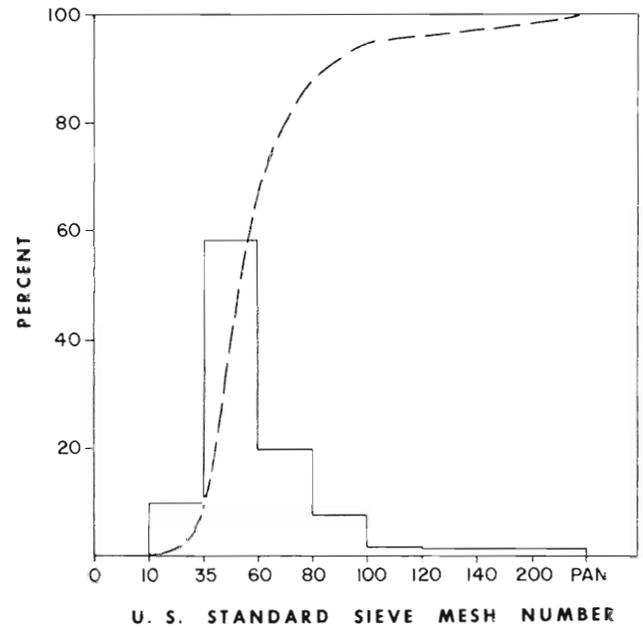


Figure 18. Histogram and cumulative frequency curve of sample R-5594-B, Keefe Sandstone.

Table 10. Sieve and chemical analyses of sample R-5594, Keefe Sandstone.

SIEVE ANALYSES

U.S. Standard Sieve Mesh No.	SAMPLE R-5594-A Percent Retained	SAMPLE R-5594-B Percent Retained
10	0	0
35	13.84	9.83
60	62.67	57.98
80	14.20	19.62
100	4.49	6.79
120	0.87	1.59
140	0.72	1.35
200	0.97	1.35
Pan	1.88	1.32

CHEMICAL ANALYSES
(Spectrum Laboratories, Inc.)

Constituents	Percent	
SiO ₂	98.6	99.2
Al ₂ O ₃	0.28	0.21
Fe ₂ O ₃	0.60	0.31
MgO	0.02	0.01
CaO	0.02	0.04
K ₂ O	0.02	0.01
CrO ₂	<0.01	<0.01
TiO ₂	<0.01	<0.01
CoO	<0.01	<0.01

RIDGELEY SANDSTONE

The Ridgeley Sandstone (Devonian) is a white to light- to dark-gray and brown, medium- to coarse-

grained, subangular to rounded sandstone. There is clayey carbonate matrix near the lower part of the unit at many localities and hematitic cement at several localities. The sandstone is very friable after carbonate is leached out. Where the material is well indurated, the grains are usually bonded by a simple quartz weld; there is some cementation by secondary quartz overgrowths. Small fragments of white to light-brown feldspar occur at some localities. White, rounded quartz pebbles up to 20 mm in length form conglomeratic masses locally; one is 12 inches (30 cm) thick. Brachiopods are in the rock at most localities. Yellowish-brown to gray to reddish-black iron-oxide stains are on most weathered surfaces; manganese mineralization was observed along fracture surfaces and on bedding planes in Highland and Bath counties. Results of partial chemical analyses on materials from these counties are in Table 11.

Table 11. Partial chemical analyses of the Ridgeley Sandstone in Bath and Rockbridge counties, Virginia (Carter, 1968, p. 353). Analyzed by the U.S. Geological Survey.

Locality	Percent		
	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃
Healing Springs, Bath Co.	97.4	0.48	0.0
Hotchkiss, Bath Co.	94.9	0.72	1.5
Millboro Springs, Bath Co.	96.1	0.34	1.2
Warm Springs, Bath Co.	96.1	0.38	0.94
Goshen, Rockbridge Co.	93.4	4.9	1.4

Sample R-5595

Location: The Ridgeley Sandstone was sampled in Augusta County on a forest service road, approximately 1 mile (1.6 km) south of Deerfield, 850 feet (259 m) and N9°W from the junction of State Road 600 and State Road 692 in the Deerfield, Virginia, 7.5-minute quadrangle (UTM: N 4,226,940, E 639, 690; Zone 17).

Description: Sandstone, white to yellowish-gray, with medium, subrounded to rounded grains. Sandstone ranges from very friable to slightly friable. There is yellowish-orange and reddish iron-oxide stain on the grains and there is black iron stain along some fractures and bedding planes. Gray coloration is especially prominent near the base of the unit as are scattered granules. The top 10 feet (3 m) of the exposure is a clean, white sand with minor black iron stain. "*Spirifer*" molds occur throughout the unit. Bedding ranges from 6 to 24 inches (15 to 61 cm); it averages 12 to 16 inches (30 to 41 cm). Exposed thickness is 22 feet (7 m). Strike is N26°E;

dip is 23°SE.

Laboratory analyses: In thin section the sandstone consists of fine to medium, subrounded to rounded quartz grains bonded by quartz. There is some iron-oxide stain on the surface of the grains. Some sutured contacts occur along grain boundaries and secondary quartz overgrowths are com-

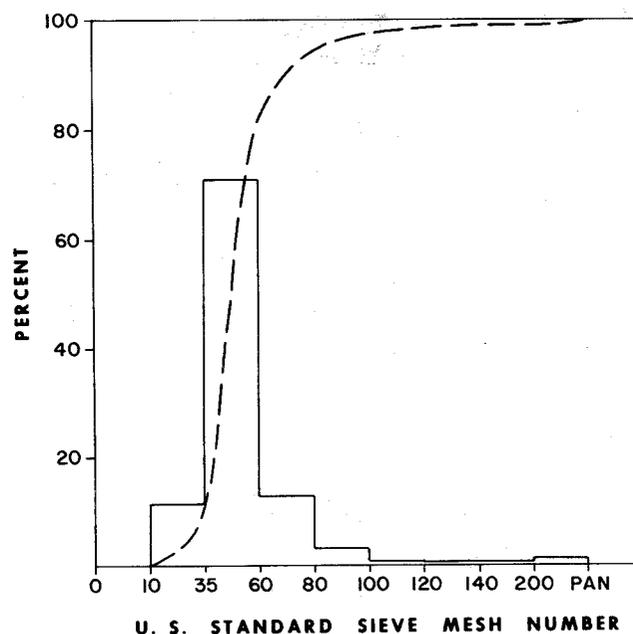


Figure 19. Histogram and cumulative frequency curve of sample R-5595-A, Ridgeley Sandstone.

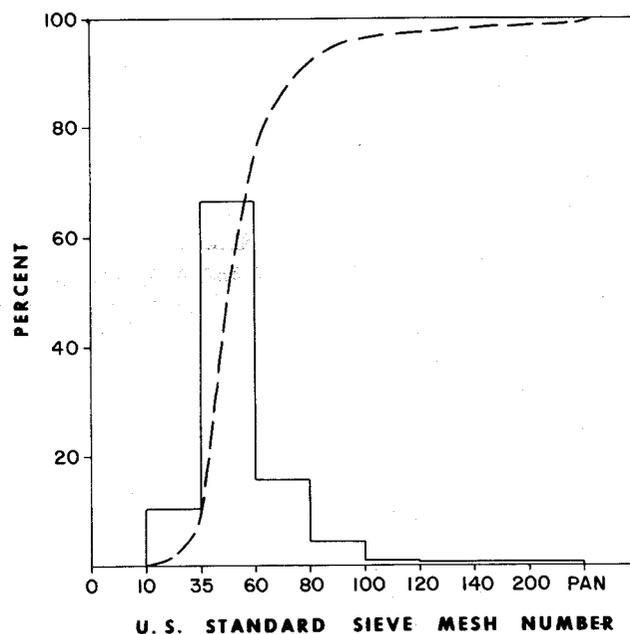


Figure 20. Histogram and cumulative frequency curve of sample R-5595-B, Ridgeley Sandstone.

mon. The matrix contains sericite, hematite and magnetite(?).

Sieve and chemical analyses of the raw material (R-5595-A) and beneficiated material (R-5595-B) are shown in Table 12. Histograms and cumulative frequency curves are shown in Figures 19 and 20. Both raw and beneficiated material are moderately well sorted.

Table 12. Sieve and chemical analyses of sample R-5595, Ridgeley Sandstone.

SIEVE ANALYSES

U.S. Standard Sieve Mesh No.	SAMPLE R-5595-A	SAMPLE R-5595-B
	Percent Retained	
10	0	0
35	11.53	10.31
60	70.37	66.07
80	12.61	15.84
100	3.05	4.38
120	0.61	1.08
140	0.43	0.70
200	0.43	0.70
Pan	0.82	0.68

CHEMICAL ANALYSES

(Spectrum Laboratories, Inc.)

Constituents	Percent	
SiO ₂	98.0	98.9
Al ₂ O ₃	1.21	0.18
Fe ₂ O ₃	0.44	0.11
MgO	0.02	0.01
CaO	0.08	0.55
K ₂ O	0.01	0.03
CrO ₂	<0.01	<0.01
TiO ₂	<0.01	<0.01
CoO	<0.01	<0.01

Sample R-5596

Location: The Ridgeley Sandstone was sampled 2.65 miles (4.27 km) north of Warm Springs in Augusta County on the southwest side of U.S. Highway 220 approximately 0.15 mile (0.24 km) by road southeast of its intersection with State Road 621 in the Warm Springs, Virginia, 7.5-minute quadrangle (UTM: N 4,215,670, E 606,320; Zone 17).

Description: Sandstone, white to orange to dark-brownish-orange, with fine to medium, subangular to rounded grains. Sandstone is highly friable; iron-oxide stain is scattered throughout the exposure. Manganese is concentrated near the middle and towards the base of the exposure. There are "Spirifer" molds near the lower part of the unit. Bedding varies from 10 to 36 inches (25 to 91 cm), and aver-

ages 20-24 inches (51-61 cm). Exposed thickness of the unit is 75 feet (23 m). Strike is N35°E; dip is 12°NW.

Laboratory analyses: No section was prepared for this sample as the material would crumble apart upon contact. Extremely friable sandstone consists of fine to medium, subrounded to rounded quartz

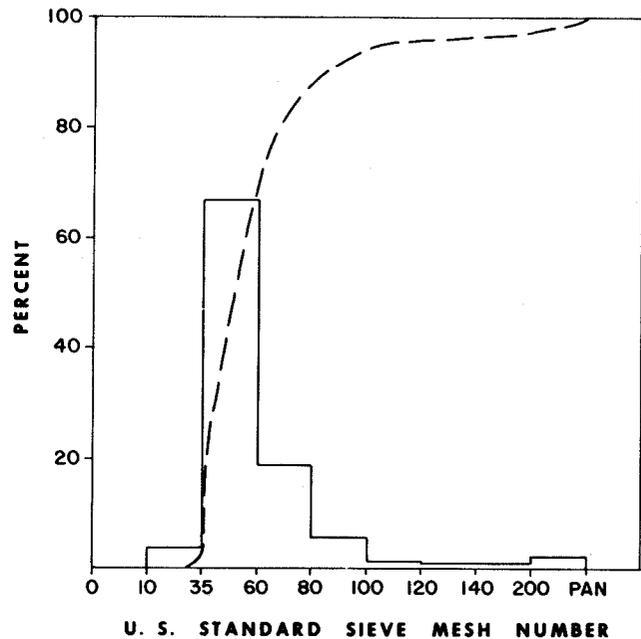


Figure 21. Histogram and cumulative frequency curve of sample R-5596-A, Ridgeley Sandstone.

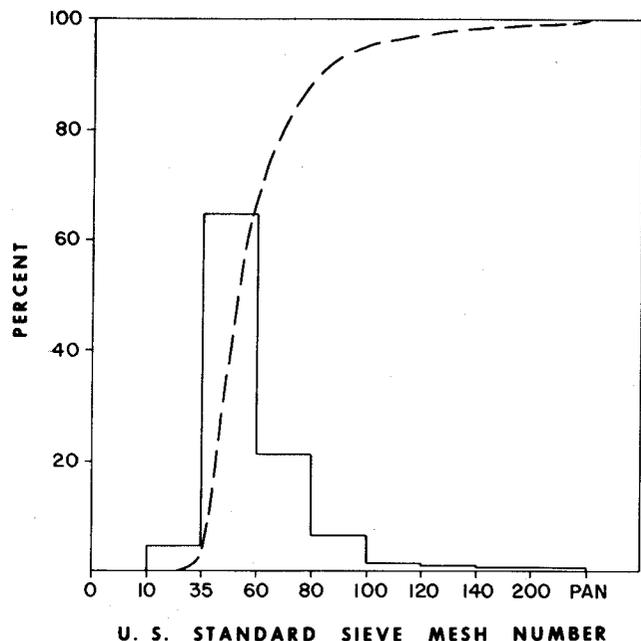


Figure 22. Histogram and cumulative frequency curve of sample R-5596-B, Ridgeley Sandstone.

grains. Minor feldspar and sericite is present.

Sieve and chemical analyses of the raw material (R-5596-A) and beneficiated material (R-5596-B) are shown in Table 13. Histograms and cumulative frequency curves are shown in Figures 21 and 22. Both raw and beneficiated material are moderately well sorted.

Table 13. Sieve and chemical analyses of sample R-5596, Ridgeley Sandstone.

SIEVE ANALYSES		
U.S. Standard Sieve Mesh No.	SAMPLE R-5596-A	SAMPLE R-5596-B
	Percent Retained	
10	0	0
35	3.70	4.28
60	66.38	64.27
80	18.58	21.09
100	5.54	6.11
120	1.29	1.42
140	1.12	1.07
200	1.06	0.87
Pan	2.08	0.77

CHEMICAL ANALYSES
(Spectrum Laboratories, Inc.)

Constituents	Percent	
SiO ₂	98.8	99.4
Al ₂ O ₃	0.63	0.15
Fe ₂ O ₃	0.87	0.03
MgO	0.04	<0.01
CaO	<0.01	0.04
K ₂ O	0.06	0.05
CrO ₂	<0.01	<0.01
TiO ₂	<0.01	<0.01
CoO	0.01	<0.01

Sample R-5597

Location: The Ridgeley Sandstone was sampled 0.75 mile (1.21 km) southeast of Bath Alum in Bath County on the west side of State Road 683 approximately 0.3 mile (0.15 km) by road south of its intersection with State Highway 39 in the Bath Alum, Virginia, 7.5-minute quadrangle; (UTM: N 4,211,310, E 613,490; Zone 17).

Description: Sandstone, white to light-yellowish-orange to dark-yellowish-orange, with fine to medium, subrounded to rounded grains. The middle of the unit is gray. There are a few white, rounded granules near the base of the unit. The sandstone, which ranges from very friable to fairly well indurated, has iron stain on grains, especially along fracture surfaces. There are some brachiopod casts and molds. Bedding varies from 12 to 18 inches (30.5 to 45.5 cm). Exposed thickness is 63 feet (19 cm)

including several covered intervals. Strike is N12°E; dip is 17°SE.

Laboratory analyses: In thin section the sandstone consists of fine to coarse, subangular to subrounded slightly iron-oxide-stained quartz grains bonded by quartz. Some grains are sutured together. Sericite is in the clay matrix.

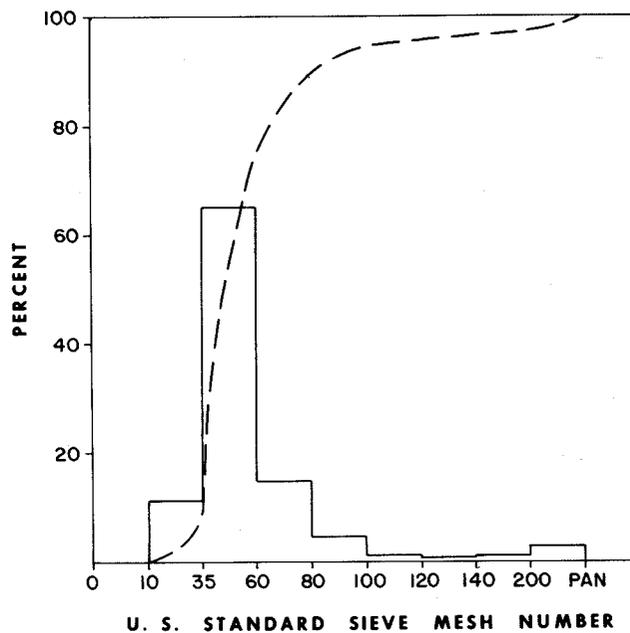


Figure 23. Histogram and cumulative frequency curve of sample R-5597-A, Ridgeley Sandstone.

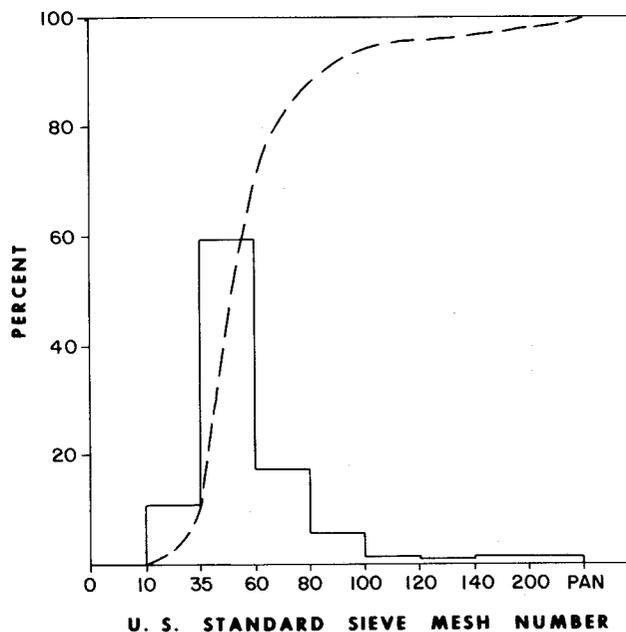


Figure 24. Histogram and cumulative frequency curve of sample R-5597-B, Ridgeley Sandstone.

Sieve and chemical analyses of the raw material (R-5597-A) and beneficiated material (R-5597-B) are shown in Table 14. Histograms and cumulative-frequency curves are shown in Figures 23 and 24. Both raw and beneficiated material are moderately well sorted.

Table 14. Sieve and chemical analyses of sample R-5597, Ridgeley Sandstone.

SIEVE ANALYSES

U.S. Standard Sieve Mesh No.	SAMPLE R-5597-A	SAMPLE R-5597-B
	Percent Retained	
10	0	0
35	11.20	10.99
60	64.14	59.69
80	14.38	17.45
100	4.51	5.96
120	1.04	1.56
140	0.90	1.24
200	1.10	1.49
Pan	2.43	1.48

CHEMICAL ANALYSES

(Spectrum Laboratories, Inc.)

Constituents	Percent	
SiO ₂	97.2	99.5
Al ₂ O ₃	0.33	0.12
Fe ₂ O ₃	1.64	0.25
MgO	0.04	0.01
CaO	0.30	<0.01
K ₂ O	0.01	0.10
CrO ₂	<0.01	<0.01
TiO ₂	0.01	<0.01
CoO	<0.01	<0.01

POCONO FORMATION

The Mississippian-age Pocono Formation consists of light-yellowish-orange to olive-gray to dark-grayish-red, very fine- to very coarse-grained, well-indurated sandstone and interbedded shales. Generally the rock is composed of subangular to rounded, poorly sorted quartz grains, and contains feldspar, muscovite and light-gray to dark-brown and black shale interbeds as well as some iron-oxide stain. One locality contains about 7-10 percent white to yellowish-gray feldspar.

In Augusta County there are good exposures of rocks of the Pocono Formation at North River Gap on the north side of State Road 718, 0.5 mile (0.8 km) by road northwest of its junction with State Road 730. At this locality and along the forest service road near Camp Flather, portions of the Pocono are estimated to be up to 700 feet (213 m) thick (Rader, 1969,

p. 16). There are also exposures at the North River campground and on the top of Grindstone Mountain.

OTHER OCCURRENCES

Localities of other good exposures of Antietam, Tuscarora, Keefer, Pocono and Ridgeley sandstone and quartzite are indicated in Figures 25-28. These localities are designated as "A15, B13", etc; the numbers correspond to information in an open-file report by Sweet (1978b).

MANGANESE MINERALIZATION

Mining and prospecting for manganese ore has been conducted at several localities in the study area. Most of the zones of mineralization are in sandstones and quartzites. Manganese mineralization is probably associated with groundwater flow. Manganese distribution throughout the area is shown in Figure 1. Varying amounts of cobalt are associated with iron and manganese prospects along the west side of the Blue Ridge in Augusta and Rockbridge counties and north-northeast and south-east of Warm Springs in Bath County (Pierce, 1944, p. 274). Manganese mineralization and associated cobalt may decrease value of high-silica resources at certain locations. McLaws (1971, p. 7) reports that as little as 0.0002 percent cobalt produces a distinct tint in glass; specifications of one manufacturer states that the weight of coloring oxides other than Fe₂O₃ (e.g., oxides of chromium, manganese, nickel, cobalt, copper) is not to exceed 0.0001 percent.

CONCLUSIONS

Four formations in Augusta, Bath, Highland and Rockbridge counties have potential economic value as high-silica resources. Chemical and sieve analyses of selected sandstone and quartzite samples reflect this potential.

The Antietam Formation contains an upper unit of thin- to medium-bedded sandstones and quartzites and a lower unit of clean, well-indurated, massive quartzite. Spectrum Laboratories, Inc. reports two samples of the Antietam contain 97.6, and 99.3 percent silica; the silica content of the first sample was raised to 99.3 percent by simple beneficiation.

The Tuscarora Formation consists of very fine- to coarse-grained, friable sandstones to well-indurated quartzites. Spectrum Laboratories, Inc. reports that five samples of the Tuscarora contain 98.6, 98.6, 99.3, 99.0 (99.3 beneficiated), and 98.9 (99.4 beneficiated) percent silica.

The Keefer Sandstone consists of a very fine- to medium-grained, indurated to friable sandstone with some quartz-pebble conglomeratic lenses. Spectrum Laboratories, Inc. reports that three

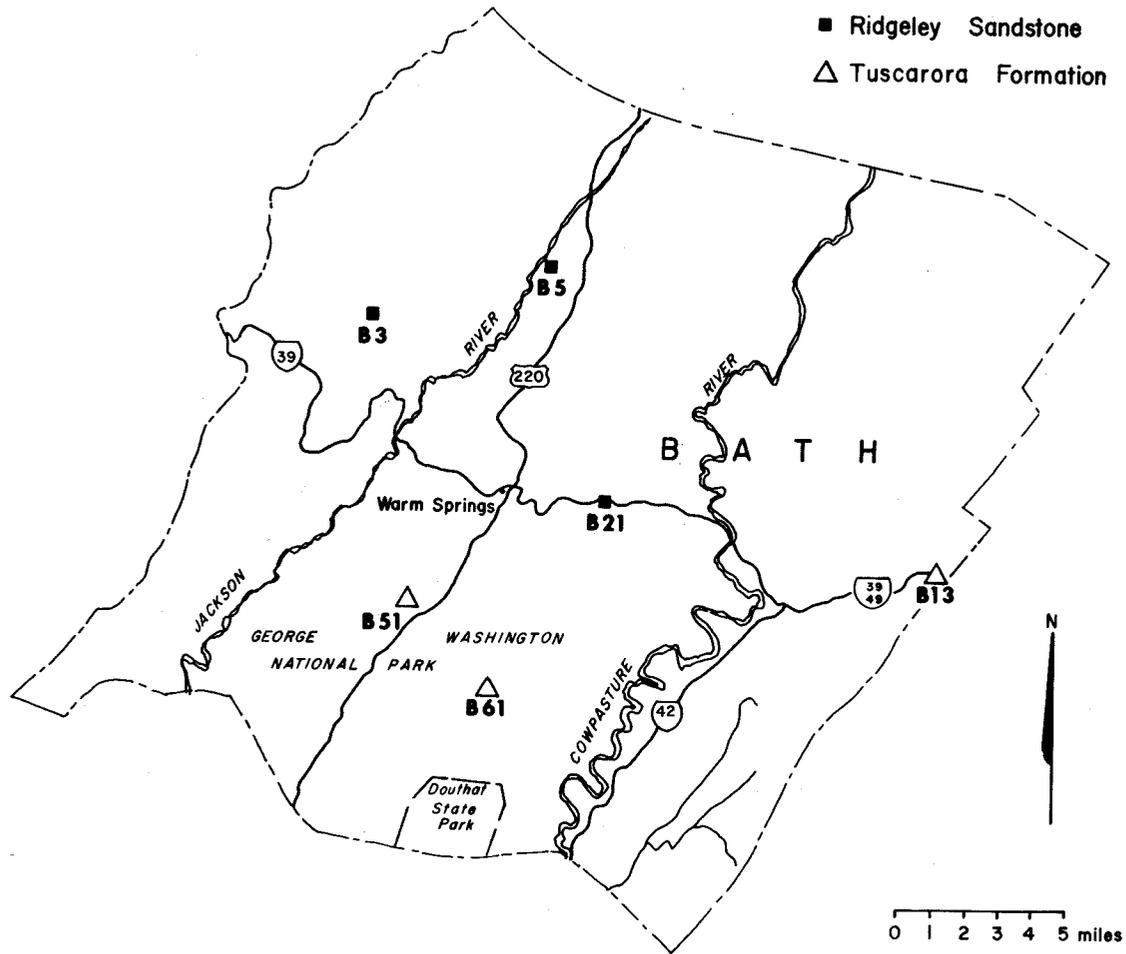


Figure 26. Outcrop location map of high-silica resources in Bath County; localities not sampled.

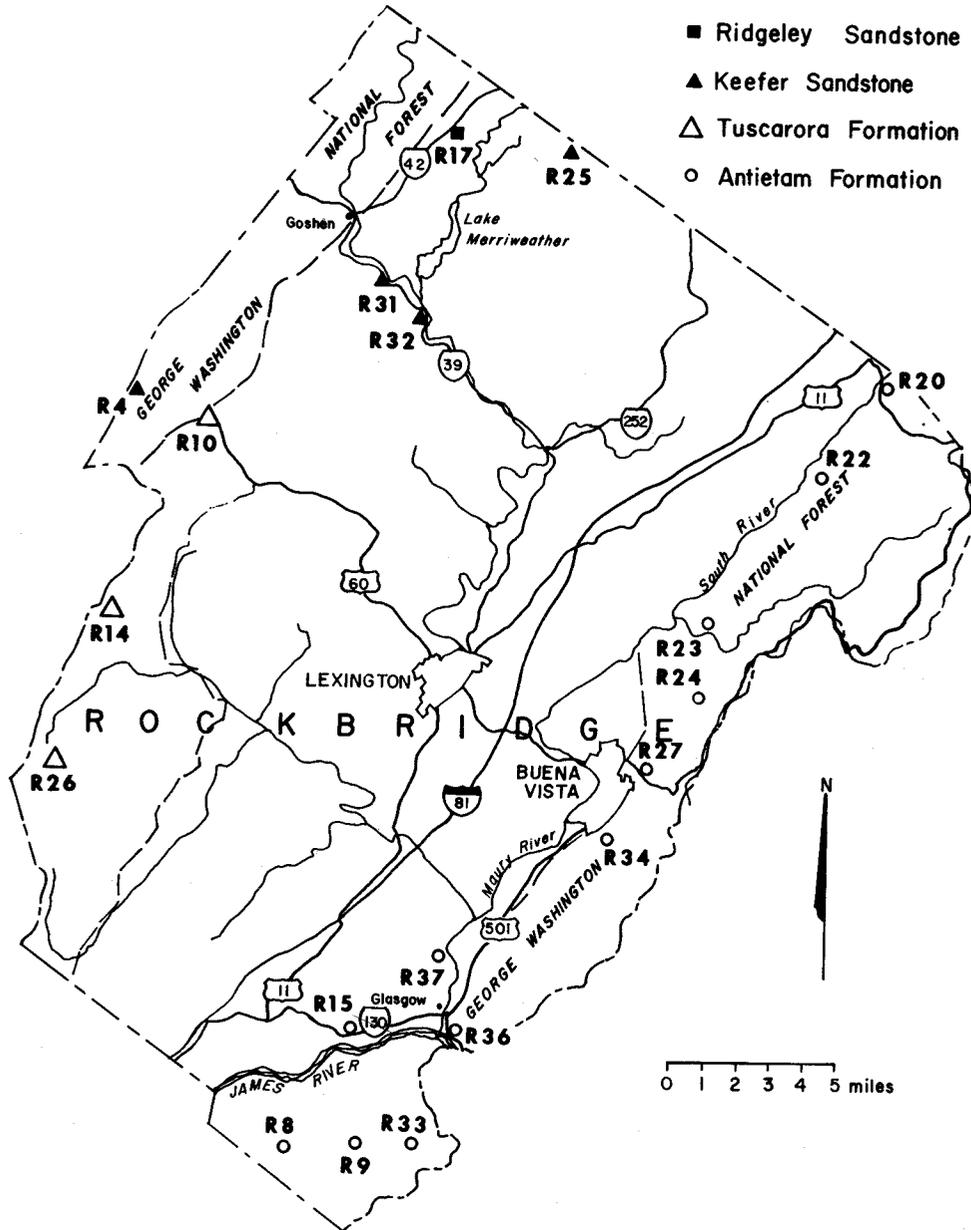


Figure 28. Outcrop location map of high-silica resources in Rockbridge County; localities not sampled.

samples of the Keefer contain 97.5, 99.1 and 98.6 percent silica; upon simple beneficiation, these samples contain 99.3, 99.5 and 99.2 percent silica, respectively.

The Ridgeley Sandstone is a white to dark-brown medium- to coarse-grained sandstone that is friable

at many places and well indurated at few. Spectrum Laboratories, Inc. reports that three samples of the Ridgeley contain 98.0, 98.8 and 97.2 percent silica. Upon beneficiation, these three samples contain 98.9, 99.4 and 99.5 percent silica, respectively.

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