

**HIGH-SILICA RESOURCE POTENTIAL OF THE UPPER  
CHILHOWEE QUARTZITE,  
McDOWELL COUNTY, NORTH CAROLINA**

**by**

**Leonard S. Wiener, Carl E. Merschat  
North Carolina Geological Survey**

**and**

**James T. Tanner, Jr.  
Minerals Research Laboratory  
North Carolina State University**

**INFORMATION CIRCULAR 26**

**NORTH CAROLINA GEOLOGICAL SURVEY**

**DIVISION OF LAND RESOURCES**

**RALEIGH**

**1990**

**NC DENR LIBRARY  
1610 MSC  
RALEIGH, NC 27699-1610  
919-715-8161**

**STATE OF NORTH CAROLINA  
JAMES G. MARTIN, GOVERNOR**

**DEPARTMENT OF ENVIRONMENT,  
HEALTH, AND NATURAL RESOURCES  
WILLIAM W. COBEY, JR., SECRETARY**

## CONTENTS

---

	Page		Page
Abstract .....	1	Summary and discussion of laboratory	
Introduction .....	1	results .....	13
Industry background .....	2	Conclusions .....	16
Previous work .....	2	Acknowledgements .....	17
Present study .....	5	References cited .....	18
Land ownership .....	5	Appendices:	
Geology .....	5	1. Industry specifications for high-silica	
Location and description of samples .....	5	materials .....	19
Site A .....	7	Silica sand for plate glass .....	20
Site B .....	8	Silica sand for plate glass (float	
Site C .....	8	composition) .....	20
Site D .....	8	Container glass .....	21
Site E .....	10	Commercially available high-purity	
Laboratory evaluation of samples .....	10	quartz .....	21
Procedure .....	10	Range of chemical composition of	
Sample A .....	11	commercially available ground silica ...	21
Sample B .....	11	Typical requirements for high-silica	
Sample CW .....	13	material for fiberglass manufacture .....	21
Sample CG .....	13	2. Selected Tyler mesh designations and	
Sample D .....	13	equivalent U.S. sieve numbers .....	22
Sample E .....	13		

## ILLUSTRATIONS

---

	Page
Figure 1. Distribution of the upper Chilhowee in McDowell and surrounding counties .....	3
2. Location of sample sites .....	6
3. East-west cross section through sample site A .....	8
4. Sampled interval, site B .....	9
5. Sampled interval, site C .....	9
6. Sampled interval, site D .....	9

## TABLES

---

	Page
Table 1. Selected chemical analyses of samples from the upper Chilhowee Group, North Carolina, Tennessee, and Virginia .....	4
2. Location of sample sites by North Carolina state plane coordinates and quadrangle ....	7
3. Petrographic analyses of selected hand samples from sample sites A, B, C, D, and E .....	7
4. Screen analyses after crushing and grinding of samples A, B, CW, CG, D, and E .....	11

**TABLES (continued)**

---

	Page
5. Chemical analyses of field samples .....	11
6. Ore dressing test data, sample A (without -150-mesh material) .....	12
7. Ore dressing test data, sample A (includes flotation of -150-mesh material) .....	12
8. Ore dressing test data, sample B .....	14
9. Ore dressing test data, sample CW .....	14
10. Ore dressing test data, sample CW, reduced reagent levels .....	15
11. Ore dressing test data, sample D .....	15
12. Ore dressing test data, sample E .....	16
13. Screen analyses of quartz concentrates .....	17
14. Chemical analyses and recovery of quartz concentrates .....	17

# HIGH-SILICA RESOURCE POTENTIAL OF THE UPPER CHILHOWEE QUARTZITE, McDOWELL COUNTY, NORTH CAROLINA

## Information Circular 26

---

By Leonard S. Wiener, Carl E. Mersch, and James T. Tanner, Jr.

### ABSTRACT

This report presents geologic and mineral-dressing data to evaluate the upper part of the Cambrian-age Chilhowee Group rocks in northern McDowell County, North Carolina, as a source of high-silica material. Previous investigations demonstrated that quartzites of the upper Chilhowee in this area are a potential silica resource.

For this study five sites were selected for thorough sampling. Representative bulk samples weighing from 35 to 60 pounds were collected from the exposures at each site. A large reserve of quartzite is present around each sample site — the total is nearly 100 million short tons.

In the laboratory a standardized, bench-scale ore-dressing procedure was used to prepare quartz concentrates. The procedure involved crushing, grinding, froth flotation, and magnetic separation.

About 50 to 60 percent of the raw material is readily recoverable as a high-silica quartz concentrate. Preliminary experimentation indicates that adjustment of reagent levels and other flotation parameters would lead to significant increases in recovery and, in some cases, improvement in grade of the concentrate.

About one half of the samples' quartz concentrate is coarse enough for use by manufacturers of plate glass and container glass. With additional grinding, the remainder of the concentrate would probably meet most market specifications for fine-ground silica.

### INTRODUCTION

This report presents the results of a field and laboratory study of quartzites from Chilhowee

Group rocks exposed near Marion in northern McDowell County, North Carolina. The study's purpose is to investigate the potential of the rocks as a source of raw material for high-silica products. The report provides new, detailed information and compares the laboratory results with industry requirements for high-silica materials.

Previously, a statewide survey of North Carolina's high-silica resources was undertaken by Broadhurst in 1949. He presented and discussed results of a sampling program from about two dozen selected localities throughout the state (Broadhurst, 1949). Broadhurst included the Chilhowee Group quartzites in his summary statement "These are probably the purest quartzite formations in all of North Carolina and offer the best possibilities as sources of high-silica quartzite" (Broadhurst, 1949, p. 6). In 1949, at the time of Broadhurst's report, sand and gravel deposits near Lilesville in Anson County and by-product quartz from one feldspar flotation plant in the Spruce Pine district of Mitchell County provided nearly all of North Carolina's high-silica output. Since then consumption of high-silica material has increased substantially and North Carolina producers responded to the growing demand by enlarging capacity and bringing new deposits into production. More recently the U.S. Bureau of Mines (Davis and Tepordei, 1986) predicted an average annual growth rate to the year 2000 of 2.8 percent for glass sand, the single largest component of the high-silica industry. This estimated growth will require ap-

proximately 300,000 tons<sup>1</sup> of additional glass sand production per year.

## INDUSTRY BACKGROUND

The use of sand for construction purposes in North Carolina undoubtedly goes back to colonial days; however, the first production figures for industrial sand, 859 tons, were recorded in 1905 (Stuckey, 1965).

Nowadays, approximately 28 million tons of industrial sand, valued at more than 360 million dollars, are produced in the United States each year. North Carolina's output exceeds 15 million dollars, thereby placing the state sixth among the 39 states reporting industrial sand production (U.S. Bureau of Mines, 1989).

About 90 percent of the state's industrial sand output is medium-grained, high-silica quartz sand. Most of this material is used in the manufacture of plate glass and glass containers and is known in the industry as glass sand. Glass sand is defined as a quartz-rich sand suitable for glassmaking because of its high silica content (93 to 99+ percent) and its low content of iron oxide, chromium, cobalt, and other colorants (Bates and Jackson, 1987). Glass sand specifications used by the glass industry of North Carolina are at the upper end of the definition. Local glassmakers require a minimum of 99.3 percent silica (Appendix 1).

Some high-silica material is further processed into very high-purity quartz which is used in the electronics industry. Also, a small amount of high silica material is ground into a fine-grained product. This fine-ground material, sometimes called silica flour, is an essential ingredient in the manufacture of fiberglass and ceramic whiteware bodies (excepting bone china), enamel, and frit. In addition it is used as an economical extender or func-

tional filler in many products such as paint, rubber, plastic, abrasive soap, and scouring pads.

High-silica material in North Carolina comes mostly from unconsolidated quartz-rich sand deposits in the Sand Hills region and the inner Coastal Plain in the southeastern part of the state. Silica is also produced as a by-product or co-product of feldspar, mica, and clay mining in the Spruce Pine and Kings Mountain districts. The ore deposits in these two areas are quartz-bearing alaskite and weathered pegmatite bodies. Some of this quartz is ground into silica flour, and some is beneficiated to attain the ultra-pure levels required by the fiber optic and electronic industries (Appendix 1).

## PREVIOUS WORK

Broadhurst (1949) included six samples of white, massive, fine-grained quartzite from the upper part of the Chilhowee Group in his statewide silica resource study. The samples were collected from roadside exposures on the west side of Linville Mountain along U.S. Route 221 in northern McDowell County (figure 1). (Broadhurst, following the then accepted stratigraphic terminology [Keith, 1903;1905], called these rocks the Erwin Quartzite). Silica content of this quartz-rich raw material ranged from 91 to 96.7 percent (table 1). However, the alumina content ranged from 2.7 to 7.2 percent, which is too high to meet specifications now set by most consuming industries (Appendix 1).

In late 1986, the Minerals Research Laboratory of North Carolina State University performed several flotation tests on grab samples from weathered Chilhowee strata along road cuts located in northern McDowell County (table 1). The Laboratory's test work indicated that the resulting quartz concentrate would be suitable for glass sand. One of the processed samples was further evaluated by a large glass-sand producing company and was found to be an acceptable raw material.

---

<sup>1</sup>Following domestic industry practice for silica sand, all tonnage values in this report refer to 2,000-pound tons.

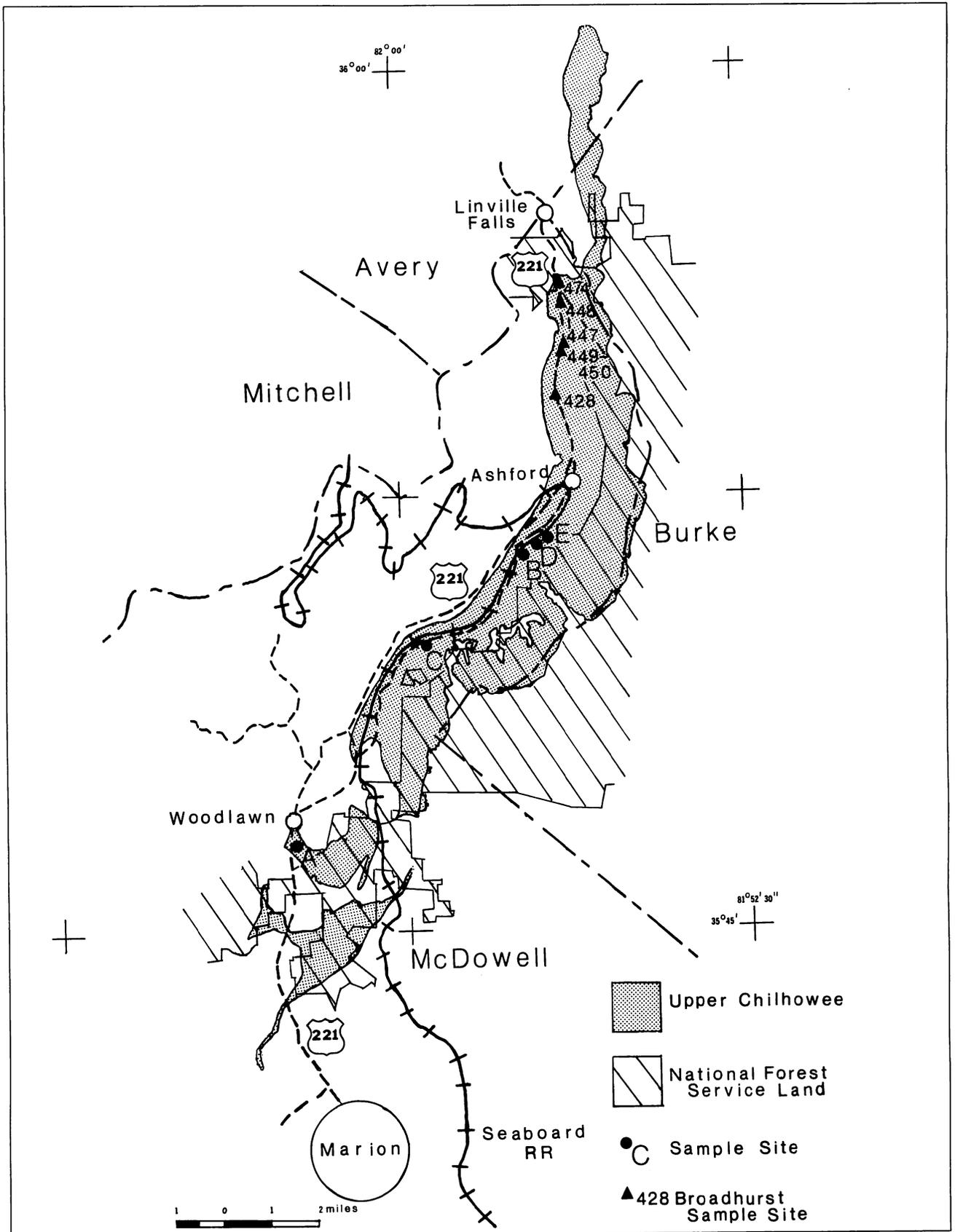


Figure 1. Distribution of the upper Chilhowee in McDowell and surrounding counties. Geology modified from Bryant and Reed (1970); Samples A-E, this study; numbered localities from Broadhurst's study (1949).

Table 1. *Selected chemical analyses (in percent) of samples from the upper Chilhowee Group North Carolina, Tennessee, and Virginia*

Sample	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	FeO	MgO	K <sub>2</sub> O	Na <sub>2</sub> O	Al <sub>2</sub> O <sub>3</sub>	CaO	TiO <sub>2</sub>	P <sub>2</sub> O <sub>5</sub>	MnO	Cr <sub>2</sub> O <sub>3</sub>	CoO	L.O.I.
1	95.6	0.19	-	-	-	-	2.7	-	-	-	-	-	-	-
2	91.0	0.17	-	-	-	-	7.2	-	-	-	-	-	-	-
3	95.0	0.27	-	-	-	-	3.7	-	-	-	-	-	-	-
4	95.4	0.12	-	-	-	-	3.6	-	-	-	-	-	-	-
5	94.9	0.16	-	-	-	-	4.1	-	-	-	-	-	-	-
6	96.7	0.12	-	-	-	-	3.0	-	-	-	-	-	-	-
7	90.3	0.74	0.60	0.27	1.6	0.08	4.1	0.05	0.66	0.01	0.00	-	-	1.00
8	94.4	2.5	0.27	0.07	0.70	0.07	1.4	0.07	0.30	0.01	0.00	-	-	0.69
9	83.4	2.81	-	0.28	3.34	0.06	7.37	0.06	0.66	-	-	-	-	1.03
10	97.04	0.25	-	0.06	0.21	0.007	1.43	0.006	0.14	-	-	-	-	0.12
11	83.79	0.63	-	0.09	0.06	0.64	12.56	<0.02	0.09	-	-	-	-	2.14
12	98.0	0.46	-	0.04	-	-	0.28	0.03	0.08	-	-	-	-	0.1
13	97.6	1.12	-	0.02	-	-	0.94	0.03	0.05	-	-	-	-	0.3
14	95.8	1.09	-	0.08	-	-	0.69	0.41	0.06	0.02	0.01	-	-	0.7
15	98.62	0.04	-	-	-	-	0.82	-	-	-	-	-	-	-
16	98.5	0.20	-	0.08	0.21	0.07	0.42	0.00	0.10	-	-	-	-	0.14
17	97.74	0.42	-	-	-	-	0.54	0.72	-	-	-	-	-	0.48
18	96.47	0.03	-	0.01	1.08	0.02	1.86	0.00	0.14	0.02	0.00	0.003	0.004	0.36
19	97.62	0.01	-	0.02	0.31	0.01	0.72	0.00	0.11	0.00	0.00	0.003	0.004	0.19
20	97.60	0.34	-	0.03	0.05	-	1.67	0.05	0.01	-	-	<0.01	<0.01	-
21	99.3	0.31	-	0.02	0.35	-	0.47	<0.01	<0.01	-	-	<0.01	<0.01	-

Samples 1-6: One-pound grab samples, upper Chilhowee quartzite, McDowell County, North Carolina (Broadhurst, 1949).

7-8: Hand samples, upper Chilhowee quartzite, Burke County, North Carolina (Bryant and Reed, 1970).

9-11: Hand samples, Chilhowee quartzite, McDowell County, North Carolina (unpublished data, Minerals Research Laboratory, 1986).

12-17: Sample collection and analyses by Tennessee Valley Authority. Data in files of North Carolina Geological Survey. 12-Composite chip sample of 30-foot section, Nebo Sandstone, Polk County, Tennessee. 13-Grab sample, Nebo Sandstone, Monroe County, Tennessee. 14-Grab sample, Hesse Sandstone, Polk County, Tennessee. 15-Hesse Sandstone, Blount County, Tennessee. 16-Hesse Sandstone, Cocke County, Tennessee. 17-Erwin Formation, manufactured sand from Holston Mountain Quarry, Carter County, Tennessee.

18-19: Hand samples, Antietam Formation, Botetourt County, Virginia (Sweet and Wilkes, 1986).

20: Hand sample, Antietam Formation, Augusta County, Virginia (Sweet, 1981).

21: Hand sample, Antietam Formation, Rockbridge County, Virginia (Sweet, 1981).

## PRESENT STUDY

Prompted by the favorable results from its flotation tests of quartzite from the Chilhowee Group, the Minerals Research Laboratory asked the North Carolina Geological Survey to participate in a more thorough study of this high-silica resource. Field work was conducted in early 1987, and the laboratory beneficiation studies and chemical analyses were finished by April.

Existing geologic maps (Bryant and Reed, 1970) were used in locating the extent of the Chilhowee's upper quartzite unit in northern McDowell County. After a brief reconnaissance, five sites were selected for sampling. Most are along state road or railroad rights-of-ways where the strata are well exposed. Measurements of stratigraphic thickness were made and representative bulk samples were collected at each site. Bench-scale flotation tests were then conducted to determine if commercially acceptable glass sand or other high-silica material could be produced from the samples. Petrographic examination of thin sections cut from a hand sample taken at each site revealed that feldspar and fine-grained muscovite or sericite are the main alumina-bearing impurities.

## LAND OWNERSHIP

The strata at each site extend into privately owned land or U.S. National Forest Service land. With the exception of the Forest Service boundary (figure 1), no effort was made to ascertain ownership or boundaries of individual tracts in the area.

## GEOLOGY

The quartzite layers sampled are within the Cambrian-age Upper Chilhowee map unit of the Geologic Map of North Carolina (North Carolina Geological Survey, 1985). These distinctive quartzites were first mapped in the area by Keith (1903; 1905) and Keith and Sterrett (1952) who correlated

them with the Erwin Formation. The Erwin Formation is named for exposures near Erwin, Tennessee, and constitutes the upper part of the Chilhowee Group. Subsequently, in more detailed work, Bryant and Reed (1970) also correlated the North Carolina rocks to Chilhowee strata of the well-studied northeast Tennessee sequence (King and Ferguson, 1960). Their correlation is based on similarities of rock types, similarity of stratigraphic sequence, and very rare trace fossils.

In the McDowell County area Bryant and Reed (1970) divide the Chilhowee into an upper quartzite unit and a lower quartzite unit separated by a thin phyllitic unit. The upper quartzite unit is of more interest as a high-silica resource because it is less feldspathic, less argillaceous, and exhibits better sorting than does the lower quartzite unit.

The upper unit consists of a distinctly bedded sequence of white to light-greenish-gray, vitreous to dull, medium- to fine-grained, thin- to thick-bedded quartzite to feldspathic quartzite. Thin interlayers of metasiltstone, slate, or phyllite are also present. Bryant and Reed (1970) estimate the thickness of the upper quartzite unit to range from 1,300 to perhaps 2,500 feet. Because this unit underlies approximately 14,000 acres in northern McDowell County (North Carolina Geological Survey, 1988), it is apparent that extremely large tonnages of quartzite are present in the study area.

## LOCATION AND DESCRIPTION OF SAMPLES

Six samples were collected from five sites located in extreme northern McDowell County (figures 1 and 2). The selected area is attractive for mineral resource development. It has convenient rail and highway transportation, available electric power, and ample water sources. Further, there is enough relatively flat ground in the vicinity to accommodate a processing plant. The sites are located where the terrain would permit development of at least a one-half-square-mile area to accommodate a quarry and plant. Based on

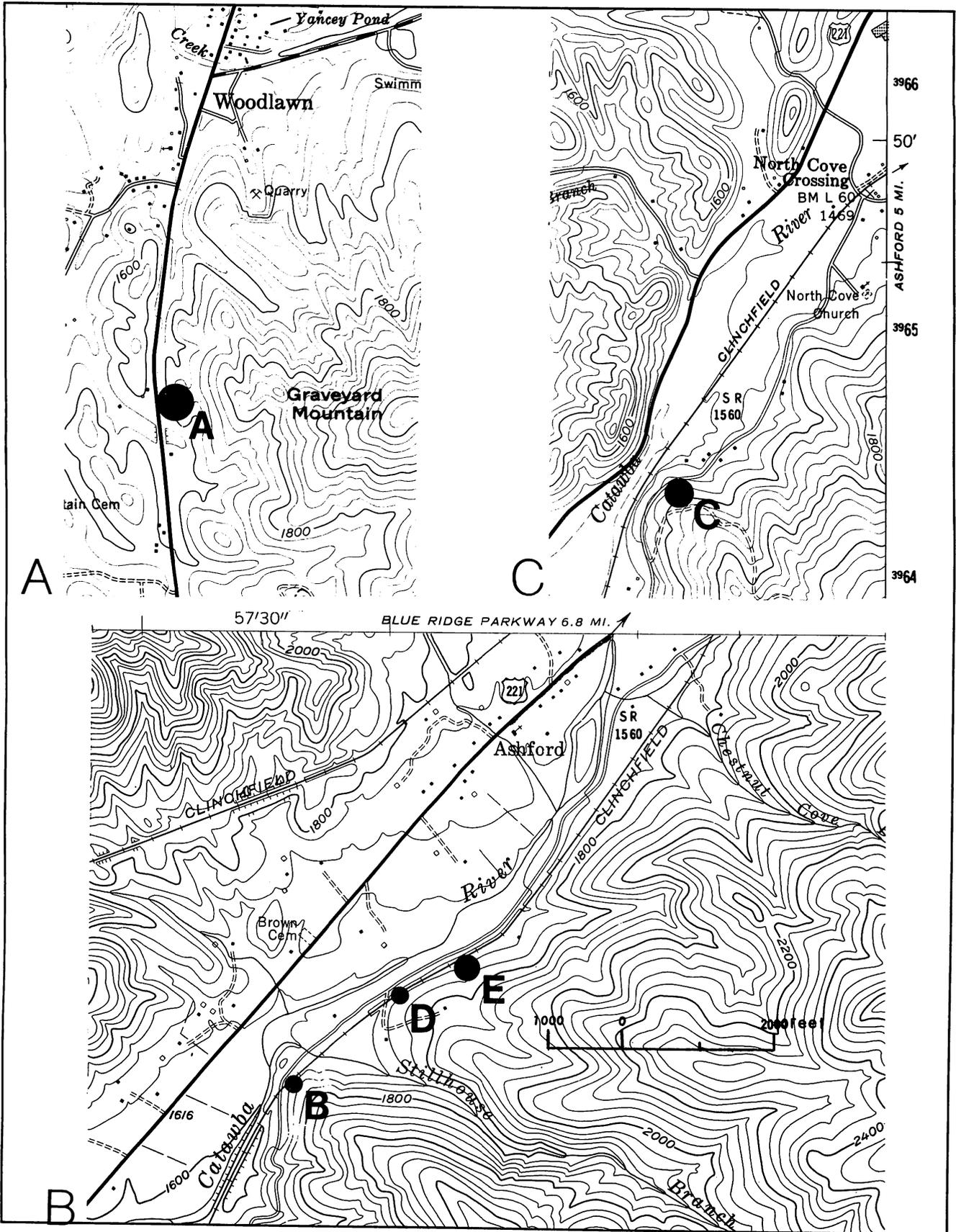


Figure 2. Location of sample sites. A - sample site A, Little Switzerland 7.5-minute Quadrangle (photorevised 1979). B - sample sites B, D, and E, Ashford 7.5-minute Quadrangle (1956). C - sample site C, Little Switzerland 7.5-minute Quadrangle. All maps are at the same scale.

Table 2. *Location of sample sites by North Carolina state plane coordinates and quadrangle*

Sample Site	North Carolina Coordinate	7.5-Minute Quadrangle
A	757,000N; 1,097,850E	Little Switzerland
B	780,500N; 1,123,950E	Ashford
C	767,250N; 1,107,900E	Little Switzerland
D	781,650N; 1,125,350E	Ashford
E	782,100N; 1,126,200E	Ashford

50-foot-deep, 100-acre quarries, the five sites have a potential quartzite resource totaling nearly 100 million tons.

Two of the sites are near the eastern edge of the Little Switzerland 7.5-minute Quadrangle; site A is in the vicinity of Graveyard Mountain and site C is about eight-tenths of a mile south of the community of North Cove Crossing. Sites B, D, and E are on the Ashford 7.5-minute Quadrangle between one-half and one mile south of the Ashford community. North Carolina state plain coordinates of the sites are listed in table 2.

The sampling procedure was designed to obtain a composite bulk sample representative of the complete exposure. At four sites the sample collected was a composite of approximately equal-sized rock chips hammered out of the outcrop. Chips were taken at two-foot intervals from along several independent traverses crossing the entire span of the exposure. Rocks at the fifth site (site A) were so friable that a shovel was used to collect the sample. The bulk samples ranged in weight from about 35 to 60 pounds.

In addition to the bulk samples, a hand sample of quartzite was collected at each site for petrographic study. The results of the petrographic analyses are presented in table 3.

#### SITE A

Sample site A is located along the east side of U.S. Route 221 approximately one mile south of the Woodlawn community on the Little Switzerland 7.5-minute Quadrangle (figure 2-A). The site, covering about four acres, had previously been

Table 3. *Petrographic analyses of selected hand samples from sample sites A, B, C, D, and E*

	Modal analysis (in percent)					
	A	B	*CW	*CG	D	E
Quartz	97.5	93.0	85.0	60.0	97.5	89.5
Plagioclase	1.0	5.0	10.0	21.0	2.0	6.5
Microcline	0.5	1.5	1.5	2.5	trace	1.0
Muscovite	1.0	0.5	2.5	14.0	0.5	2.5
Chlorite	trace	trace	-	-	-	-
Zircon	-	trace	trace	trace	-	-
Limonite	trace	trace	1.0	1.5	trace	0.5
Black Opaque	-	-	-	1.0	-	-

#### Grain size range (in millimeters)

Quartz	*0.005 - 0.22	*0.005 - 0.22	*0.005 - 0.22	*0.005 - 0.16	0.03 - 0.16	0.03 - 0.22
Feldspar	0.05 - 0.22	0.05 - 0.22	0.05 - 0.22	0.05 - 0.14	0.03 - 0.16	0.03 - 0.22
Muscovite	0.02 - 0.05	0.02 - 0.05	0.02 - 0.05	0.02 - 0.08	0.005 - 0.03	0.01 - 0.05

\*CW — White-colored sample from site C; \*CG — gray-colored sample from site C.

\*Extremely small size caused by secondary granulation resulting from mylonitization.

cleared and graded, exposing an 80-foot thickness of southwest-dipping beds. White, weathered layers of medium- to fine-grained quartzite predominate. The terrain at this site consists of two west-facing slopes of different steepness separated by a 40-foot-wide flat bench (figure 3). The cleared area is about 850 feet long and 200 feet wide. The potential resource of high-silica material above the level of the adjoining highway, U.S. 221, is estimated to be about 300,000 tons. The upper Chilhowee is extremely friable here, which may be partially attributed to weathering and thorough decomposition of feldspar grains in the quartzite. Granulation associated with local faulting may also have enhanced the quartzite's friability at this locality.

#### SITE B

Sample site B, located on the Ashford 7.5-minute Quadrangle, is a low, 135-foot-long railroad excavation along the west side of the Seaboard Railroad tracks (identified as the Clinchfield Railroad in figure 2). The locality is 100 feet north of the intersection of the tracks with State Route 1560, and 1,000 feet south of where Stillhouse Branch passes beneath the railroad (figure 2-B).

The stratigraphic interval sampled is about 54 feet thick. White to very light-gray, thin- to medium-layered quartzite dominates. Minor, very

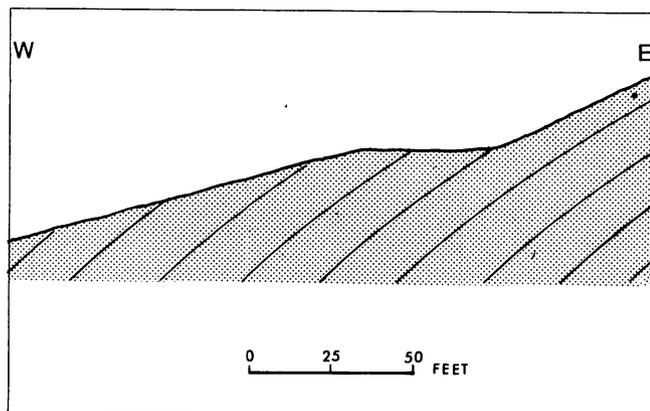


Figure 3. East-west cross section through sample site A.

thinly layered muscovite-bearing metasilstone to slate are also present. The sampled interval is shown in figure 4.

#### SITE C

Sample site C is located on the Little Switzerland 7.5-minute Quadrangle along a sharp curve in a 450-foot-long road cut on the east and southeast side of State Route 1560 (figure 2-C). The south end of the road cut is dominated by white quartzite and the north end by gray quartzite.

Two samples were collected from this site. One sample, designated CW, is a composite from white quartzite beds similar to those at the other sample sites. It represents a 29.5-foot-thick stratigraphic sequence at the south end of the exposure.

The rock sequence at the north end of the exposure is much more heterogeneous, although gray feldspathic quartzite beds dominate. The sample from this part of the exposure is designated CG. It represents 34 feet of interlayered gray feldspathic quartzite, white quartzite, and minor amounts of silty slate (figure 5). Petrographic examination (table 3) and chemical analysis indicate this sample is of low quality.

#### SITE D

Sample site D is located on the Ashford 7.5-minute Quadrangle. It is a 135-foot-long railroad cut along the west side of the Seaboard Railroad tracks, approximately 1,300 feet north of where Stillhouse Branch crosses beneath the railroad (figure 2-B). Average dip of the beds here is about 22 degrees to the southwest. Sample D represents 39.5 feet of stratigraphic thickness. Ninety percent is very light-gray quartzite; minor interlayers of metasilstone and dark-gray slate make up the remainder (figure 6).

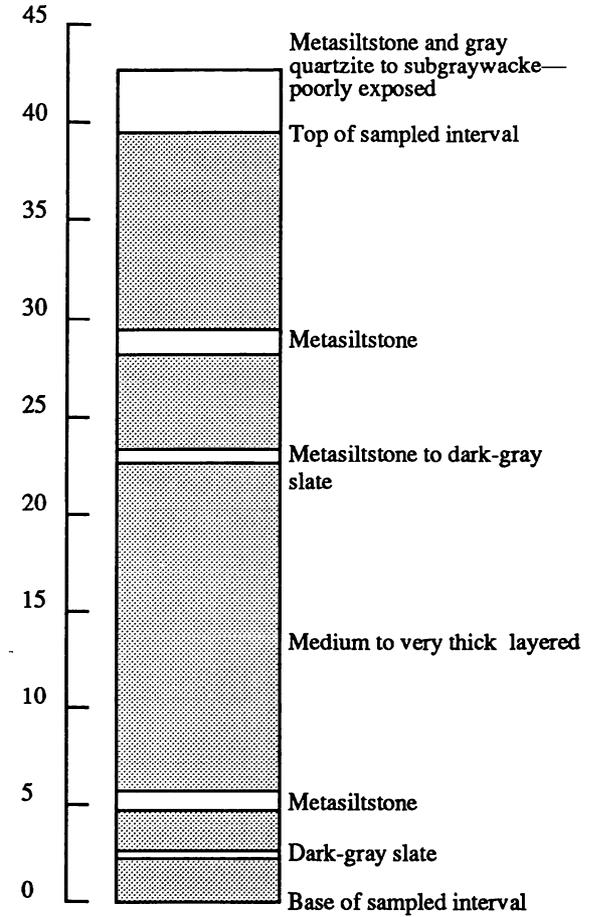
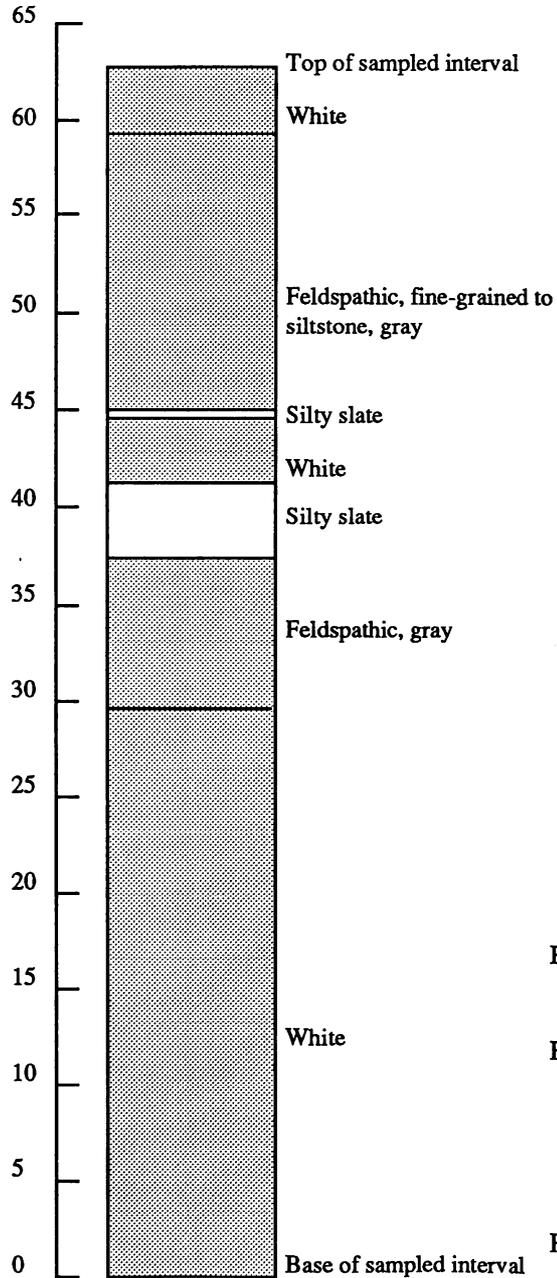
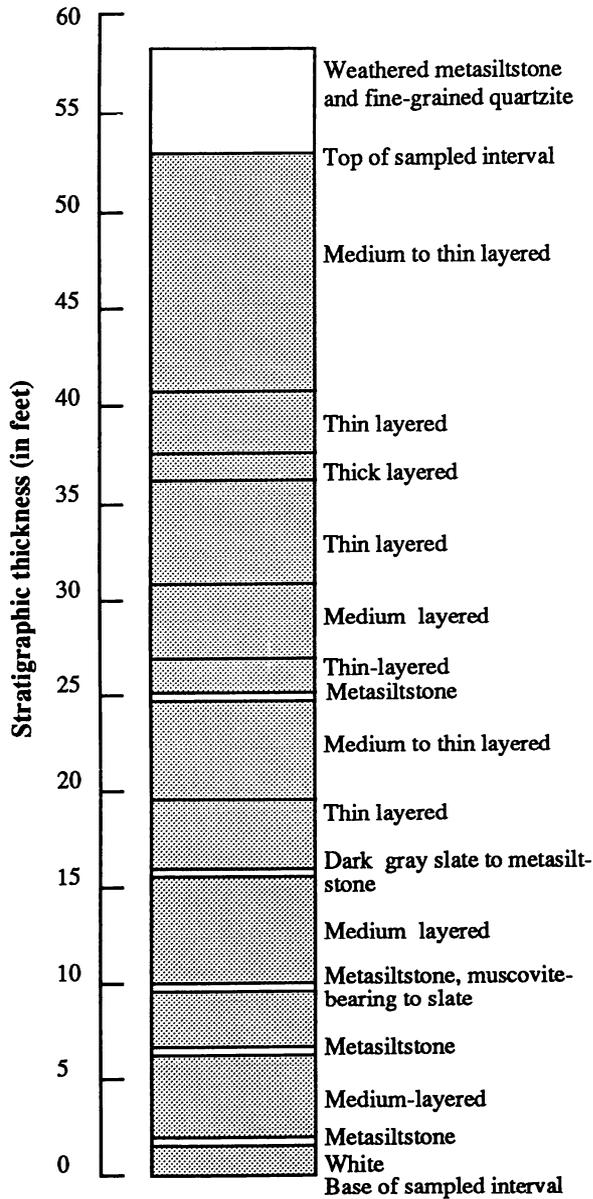


Figure 6. Sampled interval, site D above. Quartzite layers shown by dot pattern.

Figure 5. Sampled interval, site C to left. Sample CW represents the lower part of the interval (0-29.5 feet); sample CG represents the upper part of the interval (29.5-63.5 feet). Quartzite layers shown by dot pattern.

Figure 4. Sampled interval, site B far left. Quartzite layers shown by dot pattern.

## SITE E

Sample site E, a 200-foot-long railroad cut located on the Ashford 7.5-minute Quadrangle, is approximately 2,500 feet north of where Stillhouse Branch crosses beneath the railroad (figure 2-B). The quartzite is white, medium- to thick-layered and is fresh to partially weathered. A calculated stratigraphic thickness of 105 feet is present; however, the rocks are locally covered so a completely continuous interval could not be sampled.

## LABORATORY EVALUATION OF SAMPLES

Field-collected samples of the upper Chilhowee were characterized and evaluated by the Minerals Research Laboratory of North Carolina State University. A routine quartz beneficiation scheme involving crushing, grinding, flotation, and magnetic separation was followed. Chemical and grain size analyses were made at appropriate places during beneficiation. The results are discussed relative to some industry requirements for high-silica materials.

## PROCEDURE

Samples were homogenized by crushing using a jaw crusher and roll crusher to pass through a 9-mesh sieve. (See Appendix 2 for table of sieve sizes.) Further size reduction of the quartzite samples was by rod milling, except for samples B and CW. These two samples were reduced to grain sizes amenable to flotation in the initial crushing stages. Screen analyses of the crushed and ground material are presented in table 4. A 10-gram sample of the homogenized raw material was extracted for chemical analysis; these results are presented in table 5.

The minus 9-mesh material was split into 500-gram batches for bench flotation tests. To obtain the desired grain size of minus 30 mesh with

a minimum of minus 150-mesh material, a 500-gram sample of each of the samples was either ground in a small 8.5-inch-diameter x 9-inch-long rod mill using a 13-kilogram rod load or screened on a 30-mesh screen. Rod milling was followed by screening on a 30-mesh sieve. The plus 30-mesh material was reground in the same mill. The ground material was concentrated to 70 percent solids and scrubbed for 15 minutes at 1,000 rpm in the presence of 0.5 pounds per ton of sodium hydroxide. It was deslimed twice by washing on a 325-mesh sieve and then concentrated to 65-percent solids. This was followed by conditioning at 700 rpm for 6 minutes at a pH of about 2.5 in the presence of sulfuric acid, HM-70 petroleum sulfonate, Armac-T amine, No. 2 fuel oil, and H-26 frother. Mica and iron-bearing minerals were removed by flotation in a 2-liter Denver laboratory flotation cell operated at 1,200 rpm. The machine discharge from this float was deslimed by washing on a 325-mesh sieve and conditioned in the float cell at 30 percent solids and 1,200 rpm for two minutes in the presence of Armac-T amine, No. 2 fuel oil, H-26 frother, and hydrofluoric acid. Feldspar was then removed by flotation. Tables 6 through 12 provide details for reagent levels and other parameters.

The resulting quartz concentrate was dewatered and prepared for magnetic separation by scrubbing at 65-percent solids in the presence of sulfuric acid followed by washing on a 325-mesh screen. Magnetic separation was accomplished at 7,500 gauss in an Eriez magnetic separator.

The quartz concentrate was then filtered and dried. A small sample was split out for chemical analysis which was done by conventional atomic absorption methods. These final results are presented in table 13.

Heavy minerals were quantitatively determined by stirring a 100-gram sample of the quartz concentrate in a separatory funnel containing S-tetra-bromoethane (specific gravity = 2.96) and allowing the sample to stand overnight. Normally

Table 4. *Screen analyses after crushing and grinding of samples A, B, CW, CG, D, and E*

Tyler Sieve Size	Percent Weight Retained					
	A	B	CW	CG	D	E
9 Mesh	-	-	-	-	-	-
-9 +20 Mesh	0.3	2.7	4.1	19.8	9.8	14.4
-20 +30 Mesh	1.2	2.6	3.7	17.0	8.0	6.0
-30 +40 Mesh	2.0	2.4	3.3	12.4	6.4	3.8
-40 +60 Mesh	6.9	4.4	4.2	13.0	9.0	6.1
-60 +100 Mesh	30.3	11.4	9.9	9.1	11.5	13.8
-100 +150 Mesh	21.6	15.5	16.2	4.5	10.5	12.8
Pan	37.7	61.0	58.6	24.2	44.8	43.1
Total	100.0	100.0	100.0	100.0	100.0	100.0

Table 5. *Chemical analyses (in percent) of field samples*

Sample	Fe <sub>2</sub> O <sub>3</sub>	K <sub>2</sub> O	Na <sub>2</sub> O	CaO	TiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	L.O.I.	SiO <sub>2</sub> (by difference)
A	0.54	0.17	0.006	<0.01	0.20	0.63	0.4	98.04
B	0.72	1.24	0.02	<0.01	0.8	2.34	0.62	94.25
CG	3.34	7.33	0.10	<0.01	0.84	9.17	1.23	77.98
CW	0.26	0.42	0.01	<0.01	0.10	0.62	0.24	98.34
D	1.25	2.74	0.04	<0.01	0.9	4.33	0.08	90.65
E	0.19	0.73	0.01	<0.01	0.06	0.68	0.18	98.14

the amount of material that sinks to the bottom of the funnel after this length of time is removed, dried, and weighed. In the case of the upper Chilhowee, however, no heavy minerals were present in any of the quartz concentrates.

This material's chemical analysis and heavy mineral content meets or exceeds glass sand specifications. In the second flotation test of sample A, the minus 150 mesh was left in the flotation feed and recovery increased to 74 percent (table 7).

### Sample A

Two flotation tests were performed on sample A; in one the minus 150-mesh material, approximately 27 percent, was screened out prior to flotation (table 6). The conventional iron-mica flotation procedure was followed by feldspar flotation. Forty-seven percent of the initial material was recovered as a plus 150-mesh quartz concentrate.

### Sample B

Flotation of sample B yielded a 53-percent recovery (table 8), and the quartz concentrate contained 67 percent minus 150-mesh material (table 13), leaving only 33 percent suitable in size for manufacturing plate glass. The Fe<sub>2</sub>O<sub>3</sub> and TiO<sub>2</sub> content was slightly high and does not meet most industry specifications.

Table 6. Ore dressing test data, sample A (without -150 mesh material)

Flotation product	Distribution (percent)	Chemical analysis (in percent)								
		Fe <sub>2</sub> O <sub>3</sub>	MgO	K <sub>2</sub> O	Na <sub>2</sub> O	Al <sub>2</sub> O <sub>3</sub>	CaO	L.O.I.	SiO <sub>2</sub>	TiO <sub>2</sub>
+30 Mesh	0.8	-	-	-	-	-	-	-	-	-
+150 M Qtz. Conc.	47.3	0.02	0.002	0.009	0.002	0.04	<0.003	0.09	99.84	0.03
Spar	7.6	-	-	-	-	-	-	-	-	-
Iron-Mica	13.4	-	-	-	-	-	-	-	-	-
-150 Mesh Tails	26.7	-	-	-	-	-	-	-	-	-
Slime	4.2	-	-	-	-	-	-	-	-	-
Eriez Magnetics	trace	-	-	-	-	-	-	-	-	-
Total	100.0									

Process	Conditions			Reagents (in pounds per ton of feed)							RPM
	Time (min.)	Percent solids	pH	2.5% NaOH	2.5% H <sub>2</sub> SO <sub>4</sub>	2.5% HM-70	2.5% Ar-T	No. 2 Fuel Oil	H-26	HF	
Rod Mill 500 gms	1	40	-	0.5	-	-	-	-	-	-	55
Screen 30 Mesh	-	-	-	-	-	-	-	-	-	-	-
Conc. to 70%	-	-	-	-	-	-	-	-	-	-	-
Scrub	15	70	-	0.5	-	-	-	-	-	-	1000
Deslime 2X 325 M	-	-	-	-	-	-	-	-	-	-	-
Screen on 150 M	-	-	-	-	-	-	-	-	-	-	-
Cond. (Iron-Mica)	6	65	2.5	-	0.6	0.5	0.2	0.1	0.1	-	700
Float	-	-	-	-	-	-	-	-	-	-	1200
Deslime 325 M	-	-	-	-	-	-	-	-	-	-	-
Cond. in Cell	2	15	2.5	-	-	-	0.1	0.1	0.1	1.2	1200
Float	-	-	-	-	-	-	-	-	-	-	-
Eriez 3X	-	-	-	-	-	-	-	-	-	-	-

Note: 3X means 3 times through Eriez magnetic separator.

Table 7. Ore dressing test data, sample A (includes flotation of -150 mesh material)

Flotation product	Distribution (percent)	Chemical analysis (in percent)							
		Fe <sub>2</sub> O <sub>3</sub>	K <sub>2</sub> O	Na <sub>2</sub> O	Al <sub>2</sub> O <sub>3</sub>	CaO	L.O.L.	SiO <sub>2</sub>	TiO <sub>2</sub>
Quartz Conc.	74.1	0.044	0.015	0.002	0.055	<0.003	0.07	99.8	0.04
Spar	12.2	-	-	-	-	-	-	-	-
Iron-Mica	8.9	-	-	-	-	-	-	-	-
Slime	4.7	-	-	-	-	-	-	-	-
Eriez Magnetics	0.1	-	-	-	-	-	-	-	-
Total	100.0								

Process	Conditions			Reagents (in pounds per ton of feed)							RPM
	Time (min.)	Percent solids	pH	2.5% NaOH	2.5% H <sub>2</sub> SO <sub>4</sub>	2.5% HM-70	2.5% Ar-T	No. 2 Fuel Oil	H-26	HF	
Rod Mill	0.5	40	-	0.5	-	-	-	-	-	-	55
Screen on 325 M	-	-	-	-	-	-	-	-	-	-	-
Scrub	15	70	-	0.5	-	-	-	-	-	-	1000
Deslime 2X 325 M	-	-	-	-	-	-	-	-	-	-	-
Cond. (Iron-Mica)	6	65	2.5	-	0.6	0.5	0.2	0.1	0.1	-	700
Float	-	-	-	-	-	-	-	-	-	-	-
Deslime 325 M	-	-	-	-	-	-	-	-	-	-	-
Cond. in Cell	2	15	2.5	-	-	-	0.1	0.1	0.1	1.2	700
Eriez 3X	-	-	-	-	-	-	-	-	-	-	-

Note: 3X means 3 times through Eriez magnetic separator.

However, adjustment of the standardized flotation procedure would likely improve quality and yield of material from this site.

### Sample CW

A 53-percent quartz concentrate recovery was achieved from sample CW (table 9) which included about 80 percent minus 150 mesh. This material met all of the chemical requirements of glass sand, except the percent  $\text{TiO}_2$  was slightly higher than industry specifications. In a second flotation test (table 10), it was shown that a greater yield of high-grade silica could be obtained from this material. In the second test, flotation reagent levels were reduced, and recovery increased to 62 percent. Comparison of tables 9 and 10 shows that the grade was also improved.

### Sample CG

Sample CG was not floated because of the large amount of contaminants present (tables 3 and 5).

### Sample D

Only 37 percent of quartz concentrate was recovered from sample D (table 11). Also, the percentage of  $\text{Fe}_2\text{O}_3$  and  $\text{TiO}_2$  in the concentrate was relatively high. Initial analysis showed this sample to be less pure than most of the other samples (table 5), which may account for the poor results. Also, during flotation it was observed that too much quartz floated with the iron-mica minerals and the feldspar. Experimentation and adjustment of flotation parameters would probably lead to improvement of both quality and yield of the quartz concentrate.

### Sample E

Sample E yielded a 56-percent recovery of quartz concentrate (table 12). This included 52 percent minus 150-mesh material (table 13). The

chemical analysis of the concentrate was well within glass sand specifications. Once again, it is believed that adjustment of the standardized flotation parameters should result in higher yields from this as well as the other samples.

## SUMMARY AND DISCUSSION OF LABORATORY RESULTS

Six samples of Chilhowee quartzite were beneficiated by the standard iron-mica and feldspar flotation procedure as shown in tables 6 through 12 to determine if it is possible to produce glass-grade sand or other high-silica commodity from this resource.

The samples were first crushed to minus 30 mesh to prepare them for flotation. All of the samples readily crushed to a fine size, some of them more so than others. Approximately 60 percent of samples B and CW crushed to minus 150 mesh, while samples A, D, and E crushed to approximately 40 percent minus 150 mesh. Sample CG crushed to the coarsest size (24 percent minus 150 mesh); however, with a silica content of less than 78 percent, it was the least pure of the six samples. Since the maximum amount of minus 150-mesh sand allowed by plate glass or container glass manufacturers is only a few percent (Appendix 1), about half of the raw material must be eliminated from consideration for glassmaking prior to flotation.

Inclusion of fine-size material in the flotation procedure does not significantly degrade the chemical quality of the resulting quartz concentrate, but substantially increases the yield. This is shown by comparing results from the two tests on Sample A (table 14). In the first test, minus 150-mesh material was screened out prior to flotation; in the second test the minus 150-mesh material was included in the flotation procedure. The quartz concentrate recovery increased from 47 percent to 74 percent. This increase is commensurate with the 38 percent minus 150-mesh material in Sample A's flotation head feed (table 4).

Table 8. Ore dressing test data, sample B

Flotation Product	Distribution (percent)	Chemical analysis (in percent)								
		Fe <sub>2</sub> O <sub>3</sub>	MgO	K <sub>2</sub> O	Na <sub>2</sub> O	Al <sub>2</sub> O <sub>3</sub>	CaO	L.O.I.	SiO <sub>2</sub>	TiO <sub>2</sub>
+30 Mesh	8.6	-	-	-	-	-	-	-	-	-
Quartz Conc.	53.4	0.06	0.007	0.05	0.002	0.1	0.003	0.17	99.57	0.04
Spar	14.8	0.3	-	3.00	0.06	-	-	-	-	-
Iron-Mica	15.4	-	-	-	-	-	-	-	-	-
Slime	7.7	-	-	-	-	-	-	-	-	-
Eriez Magnetics	0.1	-	-	-	-	-	-	-	-	-
Total	100.0									

Process	Conditions			Reagents (in pounds per ton of feed)							
	Time (min.)	Percent solids	pH	2.5% NaOH	2.5% H <sub>2</sub> SO <sub>4</sub>	2.5% HM-70	2.5% Ar-T	No. 2 Fuel Oil	H-26	HF	RPM
Screen 30 Mesh	-	-	-	-	-	-	-	-	-	-	-
Conc. on 325 M	-	-	-	-	-	-	-	-	-	-	-
Scrub	15	70	-	0.5	-	-	-	-	-	-	1000
Deslime 2X 325 M	-	-	-	-	-	-	-	-	-	-	-
Cond. (Iron-Mica)	6	65	2.5	-	0.6	0.5	0.2	0.1	0.1	-	700
Float	-	-	-	-	-	-	-	-	-	-	1200
Deslime 325 M	-	-	-	-	-	-	-	-	-	-	-
Cond. in Cell	2	15	2.5	-	-	-	0.1	0.1	0.1	1.2	1200
Float	-	-	-	-	-	-	-	-	-	-	-
Scrub Tails	10	65	-	-	3.0	-	-	-	-	-	-
Eriez 3X	-	-	-	-	-	-	-	-	-	-	-

Note: 3X means 3 times through Eriez magnetic separator.

Table 9. Ore dressing test data, sample CW

Flotation product	Distribution (percent)	Chemical analysis (in percent)								
		Fe <sub>2</sub> O <sub>3</sub>	MgO	K <sub>2</sub> O	Na <sub>2</sub> O	Al <sub>2</sub> O <sub>3</sub>	CaO	L.O.I.	SiO <sub>2</sub>	TiO <sub>2</sub>
+30 Mesh	10.2	-	-	-	-	-	-	-	-	-
Quartz Conc.	53.1	0.03	0.005	0.03	0.002	0.06	<0.003	0.1	99.73	0.04
Spar	16.4	-	-	-	-	-	-	-	-	-
Iron-Mica	19.1	-	-	-	-	-	-	-	-	-
Slime	1.2	-	-	-	-	-	-	-	-	-
Eriez Magnetics	trace	-	-	-	-	-	-	-	-	-
Total	100.0									

Process	Conditions			Reagents (in pounds per ton of feed)							
	Time (min.)	Percent solids	pH	2.5% NaOH	2.5% H <sub>2</sub> SO <sub>4</sub>	2.5% HM-70	2.5% Ar-T	No. 2 Fuel Oil	H-26	HF	RPM
Screen 30 Mesh	-	-	-	-	-	-	-	-	-	-	55
Conc. on 325 M	-	-	-	-	-	-	-	-	-	-	-
Scrub	15	70	-	0.5	-	-	-	-	-	-	1000
Deslime 2X 325 M	-	-	-	-	-	-	-	-	-	-	-
Cond. (Iron-Mica)	6	65	2.5	-	0.6	0.5	0.2	0.1	0.1	-	700
Float	-	-	-	-	-	-	-	-	-	-	-
Deslime 325 M	-	-	-	-	-	-	-	-	-	-	-
Cond. in Cell	2	15	2.5	-	-	-	0.1	0.1	0.1	1.2	1200
Float	-	-	-	-	-	-	-	-	-	-	-
Scrub Tails	10	65	-	-	3.0	-	-	-	-	-	-
Eriez 3X	-	-	-	-	-	-	-	-	-	-	-

Note: 3X means 3 times through Eriez magnetic separator.

Table 10. Ore dressing test data, sample CW, reduced reagent levels

Flotation product	Distribution (percent)	Chemical analysis (in percent)							
		Fe <sub>2</sub> O <sub>3</sub>	K <sub>2</sub> O	Na <sub>2</sub> O	Al <sub>2</sub> O <sub>3</sub>	CaO	L.O.L.	SiO <sub>2</sub>	TiO <sub>2</sub>
+30 Mesh	0.4	-	-	-	-	-	-	-	-
Quartz Conc.	62.3	0.02	0.02	0.002	0.05	<0.003	0.07	99.81	0.03
Spar	20.7	-	-	-	-	-	-	-	-
Iron-Mica	9.8	-	-	-	-	-	-	-	-
Slime	6.6	-	-	-	-	-	-	-	-
Eriez Magnetics	0.2	-	-	-	-	-	-	-	-
Total	100.0								

Process	Conditions			Reagents (in pounds per ton of feed)							
	Time (min.)	Percent solids	pH	2.5% NaOH	2.5% H <sub>2</sub> SO <sub>4</sub>	2.5% HM-70	2.5% Ar-T	No. 2 Fuel Oil	H-26	HF	RPM
Rod Mill	2	40	-	0.5	-	-	-	-	-	-	55
Screen on 30 M	-	-	-	-	-	-	-	-	-	-	-
Screen on 325 M	-	-	-	-	-	-	-	-	-	-	-
Scrub	15	70	-	0.5	-	-	-	-	-	-	-
Deslime 2X 325 M	-	-	-	-	-	-	-	-	-	-	-
Cond. (Iron-Mica)	6	65	2.5	-	0.6	0.2	0.1	0.1	0.1	-	700
Float	-	-	-	-	-	-	-	-	-	-	-
Deslime 325 M	-	-	-	-	-	-	-	-	-	-	-
Cond. in Cell	2	15	2.5	-	-	-	0.1	0.1	0.1	1.2	1200
Float	-	-	-	-	-	-	-	-	-	-	-
Scrub Tails	10	65	-	-	3.0	-	-	-	-	-	-
Eriez 3X	-	-	-	-	-	-	-	-	-	-	-

Note: 3X means 3 times through Eriez magnetic separator.

Table 11. Ore dressing test data, sample D

Flotation product	Distribution (percent)	Chemical analysis (in percent)								
		Fe <sub>2</sub> O <sub>3</sub>	MgO	K <sub>2</sub> O	Na <sub>2</sub> O	Al <sub>2</sub> O <sub>3</sub>	CaO	L.O.I.	SiO <sub>2</sub>	TiO <sub>2</sub>
+30 Mesh	7.8	-	-	-	-	-	-	-	-	-
Quartz Conc.	36.9	0.07	0.01	0.15	0.003	0.18	<0.003	0.09	99.46	0.04
Spar	16.8	0.67	-	5.4	0.1	-	-	-	-	-
Iron-Mica	26.6	-	-	-	-	-	-	-	-	-
Slime	11.4	-	-	-	-	-	-	-	-	-
Eriez Magnetics	0.5	-	-	-	-	-	-	-	-	-
Total	100.0									

Process	Conditions			Reagents (in pounds per ton of feed)							
	Time (min.)	Percent solids	pH	2.5% NaOH	2.5% H <sub>2</sub> SO <sub>4</sub>	2.5% HM-70	2.5% Ar-T	No. 2 Fuel Oil	H-26	HF	RPM
Rod Mill	15 secs	40	-	0.5	-	-	-	-	-	-	55
Screen 30 Mesh	-	-	-	-	-	-	-	-	-	-	-
Conc. on 325 M	-	-	-	-	-	-	-	-	-	-	-
Scrub	15	70	-	0.5	-	-	-	-	-	-	1000
Deslime 2X 325 M	-	-	-	-	-	-	-	-	-	-	-
Cond. (Iron-Mica)	6	65	2.5	-	0.6	0.5	0.2	0.1	0.1	-	700
Float	-	-	-	-	-	-	-	-	-	-	-
Deslime 325 M	-	-	-	-	-	-	-	-	-	-	-
Cond. in Cell	2	15	2.5	-	-	-	0.1	0.1	0.1	1.2	1200
Float	-	-	-	-	-	-	-	-	-	-	-
Scrub Tails	10	65	-	-	3.0	-	-	-	-	-	-
Eriez 3X	-	-	-	-	-	-	-	-	-	-	-

Note: 3X means 3 times through Eriez magnetic separator.

Table 12. Ore dressing test data, sample E

Flotation product	Distribution (percent)	Chemical analysis (in percent)								
		Fe <sub>2</sub> O <sub>3</sub>	MgO	K <sub>2</sub> O	Na <sub>2</sub> O	Al <sub>2</sub> O <sub>3</sub>	CaO	L.O.I.	SiO <sub>2</sub>	TiO <sub>2</sub>
+30 Mesh	8.7	-	-	-	-	-	-	-	-	-
Quartz Conc.	56.3	0.02	0.006	0.05	0.002	0.08	<0.003	0.08	99.74	0.02
Spar	13.5	-	-	-	-	-	-	-	-	-
Iron-Mica	17.3	-	-	-	-	-	-	-	-	-
Slime	3.8	-	-	-	-	-	-	-	-	-
Eriez Magnetics	0.4	-	-	-	-	-	-	-	-	-
Total	100.0									

Process	Conditions			Reagents (in pounds per ton of feed)							RPM
	Time (min.)	Percent solids	pH	2.5% NaOH	2.5% H <sub>2</sub> SO <sub>4</sub>	2.5% HM-70	2.5% Ar-T	No. 2 Fuel Oil	H-26	HF	
Rod Mill	15	40	-	0.5	-	-	-	-	-	-	55
Screen 30 Mesh	-	-	-	-	-	-	-	-	-	-	-
Conc. on 325 M	-	-	-	-	-	-	-	-	-	-	-
Scrub	15	70	-	0.5	-	-	-	-	-	-	1000
Deslime 2X 325 M	-	-	-	-	-	-	-	-	-	-	-
Cond. (Iron-Mica)	6	65	2.5	-	0.6	0.5	0.2	0.1	0.1	-	700
Float	-	-	-	-	-	-	-	-	-	-	-
Deslime 325 M	-	-	-	-	-	-	-	-	-	-	-
Cond. in Cell	2	15	2.5	-	-	-	0.1	0.1	0.1	1.2	1200
Float	-	-	-	-	-	-	-	-	-	-	-
Scrub Tails	10	65	-	-	3.0	-	-	-	-	-	-

Note: 3X means 3 times through Eriez magnetic separator.

Table 13 summarizes screen analyses of the quartz concentrates. The size distributions shown in this table reemphasize that for most of the samples less than half the concentrate is coarse enough for plate- or container-glass makers. But the fine-size material can be further ground to minus 200 mesh and meet specifications of the ceramic industry, fiberglass producers, or serve as a high-silica functional filler or inert extender (Appendix 1).

With only one exception, a uniform reagent-level scheme was followed in the flotation procedure. The exception was a flotation test of sample CW in which the collecting reagent, HM-70 petroleum sulfonate, was used at a reduced level. Compared to the standard flotation test on sample CW, the quartz concentrate was of higher quality. There was also an increase in yield from about 53 to 62 percent (table 14). These results indicate that additional experimentation would be helpful to

establish reagent levels and flotation parameters necessary for optimum recovery of high-grade silica concentrates.

## CONCLUSIONS

This study demonstrates that quartzite of the upper Chilhowee Group from northern McDowell County can be processed to yield a quartz concentrate which meets industry specifications for high-silica commodities. Immense quantities of quartzite are present in the region. At just the five sites sampled during this project, the quartzite resource is estimated to be nearly 100 million tons.

Principal deleterious minerals in the Chilhowee quartzite are feldspar and muscovite. Feldspar and muscovite grains are most abundant in readily identifiable minor interbeds of gray feldspathic quartzite, metasiltstone, and slate. Zircon, the only refrac-

Table 13. *Screen analyses (in percent) of quartz concentrates*

Tyler sieve sizes	A	A <sup>1</sup>	B	CW	D	E
+30 Mesh	trace	trace	trace	trace	trace	trace
-30 +100 Mesh	26.5	48.9	14.2	5.3	27.1	20.3
-100 +150 Mesh	27.7	50.1	19.2	14.9	22.6	27.3
Pan	45.8	1.0	66.6	79.8	50.3	52.4
Total	100.0	100.0	100.0	100.0	100.0	100.0

Note: <sup>1</sup> Minus 150-mesh material removed prior to flotation.

Table 14. *Chemical analyses and recovery (in percent) of quartz concentrates*

Sample	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	MgO	K <sub>2</sub> O	Na <sub>2</sub> O	Al <sub>2</sub> O <sub>3</sub>	CaO	TiO <sub>2</sub>	L.O.L.	Recovery
A <sup>1</sup>	99.84	0.02	0.002	0.01	0.002	0.04	<0.003	0.03	0.09	47.3
A	99.8	0.04	—	0.01	0.002	0.05	<0.003	0.04	0.07	74.1
B	99.57	0.06	0.007	0.05	0.002	0.1	0.003	0.04	0.17	53.4
CW	99.73	0.03	0.005	0.03	0.002	0.06	<0.003	0.04	0.1	53.1
CW <sup>2</sup>	99.81	0.02	—	0.02	0.002	0.05	<0.003	0.03	0.07	62.3
D	99.46	0.07	0.01	0.15	0.003	0.18	<0.003	0.04	0.09	36.9
E	99.74	0.02	0.006	0.05	0.002	0.08	<0.003	0.02	0.08	56.3

Notes: <sup>1</sup> Minus 150-mesh material removed prior to flotation.

<sup>2</sup> Flotation procedure used reduced reagent levels.

tory mineral in the raw material (table 3), was removed during beneficiation and was not found in any of the quartz concentrates.

The rocks at sample site A are notably friable, probably as a result of weathering and natural leaching. These rocks crushed extremely easily and the quartz concentrate was of higher grade than that of most of the other samples.

To identify prospective mine sites with the fewest undesirable beds and the most suitable raw material, additional sampling, detailed geologic mapping, and systematic core drilling should be done.

Using a standard mineral dressing flotation procedure, about 50 to 60 percent of the raw material represented by the samples is readily recoverable as a high-silica quartz concentrate. Adjustment of reagent levels and other flotation parameters to suit specific head feeds would significantly

increase the recovery and, in some cases, improve the grade.

The concentrates generally meet chemical requirements of the glass-making industry, fiberglass industry, and ceramic manufacturers. They also compare well with chemical specifications of currently marketed fine-ground silica. A little less than half of the concentrate is sufficiently coarse to be suitable as raw material for plate glass and container glass manufacturing plants. After being ground to finer sizes, the remainder would probably meet most market specifications for ground silica.

## ACKNOWLEDGEMENTS

We are pleased to acknowledge the assistance of many people. Immo Redeker, Director of the Minerals Research Laboratory, and Jeff Reid, Chief

Geologist of the North Carolina Geological Survey, strongly supported the project. Both also examined outcrops in the study area with us at the start of our work. Johnny Lawrence of the Minerals Laboratory performed most of the flotation testing. Larry Zarra, Bill Wilson, Jeff Reid, and Al Carpenter of the North Carolina Geological Survey provided us with thorough and useful reviews of the manuscript. Sigrid Ballew handled the painstaking work of preparing the manuscript, including the many tables, for the printer. In addition, she helped with proofreading and pointed out many ways to improve the report's clarity and syntax.

### REFERENCES CITED

- Bates, R. L., and Jackson, J. A., *editors*, 1987, Glossary of geology, 3rd edition: American Geological Institute, Alexandria, Virginia, 788 p.
- Broadhurst, S. D., 1949, A general survey of some high-silica materials in North Carolina: North Carolina Division of Mineral Resources Information Circular 7, 34 p.
- Bryant, Bruce, and Reed, J. C., Jr., 1970, Geology of the Grandfather Mountain window and vicinity, North Carolina and Tennessee: U.S. Geological Survey Professional Paper 615, 195 p.
- Davis, L. L., and Tepordei, V. V., 1986, Sand and gravel chapter, p. 689-703, *in* Mineral Facts and Problems, 1985 edition: U.S. Bureau of Mines Bulletin 675, 956 p.
- Keith, Arthur, 1903, Description of the Cranberry Quadrangle [North Carolina-Tennessee]: U.S. Geological Survey Atlas, Folio 90, 9 p.
- \_\_\_\_\_ 1905, Description of the Mount Mitchell Quadrangle [North Carolina-Tennessee]: U.S. Geological Survey Atlas, Folio 124, 10 p.
- Keith, Arthur, and Sterrett, D. B., 1952, Geologic map of the Morganton Quadrangle, compiled by P. B. King: U.S. Geological Survey Open-File map, 1 sheet, scale 1:125,000.
- King, P. B., and Ferguson, H. W., 1960, Geology of northeasternmost Tennessee, with a section on the description of the basement rocks by Warren Hamilton: U.S. Geological Survey Professional Paper 311, 136 p.
- North Carolina Geological Survey, 1985, Geologic map of North Carolina: North Carolina Department of Natural Resources and Community Development, Raleigh, North Carolina, 1 sheet, scale 1:500,000.
- \_\_\_\_\_ 1988, Preliminary explanatory text for the 1985 geologic map of North Carolina, appendices: North Carolina Geological Survey unpublished Contractual Report 88-1, 271 p.
- Stuckey, J. L., 1965, North Carolina: Its geology and mineral resources: North Carolina Department of Conservation and Development, 550 p.
- Sweet, P. C., 1981, High-silica resources in Augusta, Bath, Highlands, and Rockbridge Counties, Virginia: Virginia Division of Mineral Resources Publication 32, 22 p.
- Sweet, P. C., and Wilkes, G. P., 1986, High-silica resources in Alleghany, Botetourt, Craig, and Roanoke Counties, Virginia: Virginia Division of Mineral Resources Publication 67, 22 p.
- U.S. Bureau of Mines, 1989, Minerals Yearbook 1987, v. 1, Metals and Minerals: Washington, D.C., 990 p.

## **APPENDIX 1. INDUSTRY SPECIFICATIONS FOR HIGH-SILICA MATERIALS**

This appendix presents tables listing some currently used industrial specifications for high-silica materials. Principally, the specifications set limits on the raw material's chemical composition, deleterious mineral components, and grain sizes.

These tables provide sets of criteria useful to evaluate high-silica resources. But to industry, cost, availability, and uniformity of raw materials

are also significant. In light of these factors, some consumers may adjust their processes to accommodate material with slightly different properties than those listed in this appendix.

The data in the tables were obtained through the courtesy of company personnel at a number of operating mines and plants in the eastern United States.

**MANUFACTURER'S SPECIFICATION  
Silica Sand for Plate Glass**

Critical Oxides, Maximum Limit (in percent)

Fe <sub>2</sub> O <sub>3</sub>	0.08	Co <sub>3</sub> O <sub>4</sub>	0.0002
Al <sub>2</sub> O <sub>3</sub>	0.30	MnO <sub>2</sub>	0.002
Cr <sub>2</sub> O <sub>3</sub>	0.0002	H <sub>2</sub> O	0.05

Total Refractory Content per 100 pounds

Cumulative Retained on U.S. 70-Mesh

Maximum Limit  
.200 grams = .00044%

Undesired Refractory Minerals

Chromite <sup>1</sup>	FeCr <sub>2</sub> O <sub>4</sub>	Sillimanite	Al <sub>2</sub> SiO <sub>5</sub>
Corundum	Al <sub>2</sub> O <sub>3</sub>	Zircon	ZrSiO <sub>4</sub>
Andalusite	Al <sub>2</sub> SiO <sub>5</sub>	Zirconia	ZrO <sub>2</sub>
Kyanite	Al <sub>2</sub> SiO <sub>5</sub>		

<sup>1</sup> Also other spinels.

Acceptable Size Distribution (in percent)

Cumulative retained on: No. 16	Not one piece
Cumulative retained on: No. 20	0.1% max.
Cumulative retained on: No. 40	5.0-15.0% max. <sup>2</sup>
Cumulative retained on: No. 140	92.9% min.
Cumulative retained on: No. 200	99.5% min.
Cumulative retained on: No. 325	100.0% min.

<sup>2</sup> The amount of +40 material acceptable is generally dependent on the amount of +70 refractory particles contained in the product.

**MANUFACTURER'S SPECIFICATION  
Silica Sand for Plate Glass  
(Float Composition)**

Description

The material required under this specification is a fine grade of silica sand processed for use in non-solar glass manufacturing.

Specifications

Other than iron, the sand may contain no substance which will color the glass. Neither may it contain minerals or other materials that are so refractory that, in the sizes specified, they cannot be readily dissolved and incorporated.

A. Chemical Composition (in percent)

			Permitted variability
SiO <sub>2</sub>	99.50	min.	±0.30
Fe <sub>2</sub> O <sub>3</sub>	0.05	max.	±0.01
Cr <sub>2</sub> O <sub>3</sub>	0.004	max.	
Loss on Ignition	0.30	max.	

B. Physical Properties

Heavy Minerals

Total +60 mesh heavy minerals (density greater than 2.96 g/ml.) 0.008% max.

Total +40 mesh heavy minerals 0.001% max.

Exceptions will depend on specific mineral identity.

Magnetic Iron 0.0001% max.

Size Distribution

Retained on U.S. 30:	1% max.
Retained on U.S. 40:	7% max.
Through U.S. 200:	1% max.

**MANUFACTURER'S SPECIFICATION  
Container Glass**

Chemical Composition (in percent)

SiO <sub>2</sub>	99.3 min.
Fe <sub>2</sub> O <sub>3</sub>	0.04 max.
Al <sub>2</sub> O <sub>3</sub>	.5 ± .05
CaO	.01 ± .005
TiO <sub>2</sub>	.03 max.
Na <sub>2</sub> O	.01 max.
L.O.I.	.15 ± .05
Color	White
Heavy Minerals	0.2 max.

Typical Sizing (in percent)

Retained on U.S. 20	0.0
Retained on U.S. 30	1.0 max.
Passing U.S. 10	40 (average)
Passing U.S. 150	5.0 max.

**COMMERCIALY AVAILABLE HIGH-PURITY  
QUARTZ**

<u>Element</u>	<u>Range or Limit<sup>1</sup> (in parts per million)</u>	
Al	14	25 <sup>2</sup>
Fe	0.3	1 <sup>3</sup>
Na	0.7	2
K	0.4	1.3
Li	0.4	1
Na+ K+ Li	3.0	max.
Ca	0.7	2.0
Mg	0.05	0.5
Ti	1.0	1.2
Mn	0.05	1.2
Zr	1.0	2.0
Cu	0.05	max.
Ni	0.05	max.
Co	0.05	max.
Cr	0.05	max.
Mo	0.1	max.
P	0.3	max.

Size Specification (in percent)

Retained on U.S. 50	3 (max.)
Passing U.S. 140	8 (max.)

<sup>1</sup> Data is a composite of six different products manufactured by one company.

<sup>2</sup> Desirable 10 ppm

<sup>3</sup> Desirable 0.7 ppm

**RANGE OF CHEMICAL COMPOSITION OF  
COMMERCIALY AVAILABLE GROUND SILICA  
(IN PERCENT)**

SiO <sub>2</sub>	99.59 - 99.81
Fe <sub>2</sub> O <sub>3</sub>	0.030 - 0.017
MgO	<0.01 - <0.01
Al <sub>2</sub> O <sub>3</sub>	0.200 - 0.055
CaO	<0.01 - <0.01
TiO <sub>2</sub>	0.034 - 0.012
L.O.I.	0.180 - 0.100

Notes:

1. Data presented is a composite from seven mines and plants.
2. Commercially available ground silica grades (silica flour) range in size from at least 98 percent passing 60 mesh to at least 98 percent passing 400 mesh.
4. Material is advertised for use in paints, plastics, rubber, polishes, and cleansers in addition to ceramics, fiberglass, castings, and others.

**TYPICAL REQUIREMENTS FOR  
HIGH-SILICA MATERIALS FOR FIBERGLASS  
MANUFACTURE**

Chemical Composition

SiO <sub>2</sub>	99.0 ± 0.5
Fe <sub>2</sub> O <sub>3</sub>	0.1 max.

Size Specification (for "E" fiberglass)

<u>Sieve</u>	<u>Percent</u>
Retained on U.S. 100	0
Retained on U.S. 200	1
Retained on U.S. 325	3
Passing U.S. 325	96

*Typically, 28 to 30 percent of the raw material for fiberglass is quartz.*

**APPENDIX 2. SELECTED TYLER MESH DESIGNATIONS AND  
EQUIVALENT U.S. SIEVE NUMBERS**

<u>Sieve opening (in millimeters)</u>	<u>Tyler Series</u>	<u>U.S. Series</u>
2.00	9 Mesh	No. 10
1.18	14 Mesh	No. 16
.850	20 Mesh	No. 20
.600	28 Mesh	No. 30
.425	35 Mesh	No. 40
.300	48 Mesh	No. 50
.250	60 Mesh	No. 60
.212	65 Mesh	No. 70
.180	80 Mesh	No. 80
.150	100 Mesh	No. 100
.106	150 Mesh	No. 140
.075	200 Mesh	No. 200
.053	270 Mesh	No. 270
.045	325 Mesh	No. 325
.038	400 Mesh	No. 400

---