SUITABILITY OF PINEHURST FORMATION AS A GLASS SAND, RICHMOND COUNTY, NORTH CAROLINA

Information Circular 33

by

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By

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ABSTRACT

Split-spoon samples of six drill cores 0 to 60 feet deep within 2,800 acres from the Pinehurst Formation, Richmond County, North Carolina, were evaluated for glass sand raw material potential. The Pinehurst Formation, as mapped on the 1985 Geologic Map of North Carolina, covers approximately 120,660 acres in Richmond, Scotland, Moore and Hoke counties. Commercial glass sand has been produced from a nearby site from the Pinehurst Formation.

Minerals were identified with a binocular microscope and by powder x-ray diffraction. Trace amounts of heavy minerals found in the raw material included schorl (a member of the tourmaline group), rutile, and zircon. Less abundant trace minerals were goethite, hematite, muscovite, kaolinite, and chromite. The major mineral present in these samples was quartz, averaging 60-73% of each sample.

Several physical separation processes were necessary to make a product suitable for glass application. These included attrition scrubbing, sizing, flotation, heavy liquid separation, and magnetic separation to remove impurities such as iron and titanium minerals, mica, organic matter, feldspar, trace elements, and other impurities.

The glass sand product after attrition scrubbing, sizing, and magnetic separation contained 0.13-0.16 % Al_2O_3, 0.02 – 0.04% Fe_2O_3, < 0.01 – 0.02% TiO_2 and traces of other minor elements. Further reduction of impurities will be obtained from separation processes that include flotation. This product is well within the specifications for typical glass sand and is suitable for many glass sand applications.

INTRODUCTION

Laboratory investigations were conducted on sand samples from the Pinehurst Formation in Richmond County, North Carolina (Mensah-Biney and others, 2001) (Figures 1, 2). In general, sedimentary silica sand is a common source for commercial silica, mainly used for glass containers in the United States. The sand must be free of mica, organic matter, iron, titanium, trace elements, or other impurities that can be removed and separated by crushing, screening, scrubbing, heavy media separation, flotation, and magnetic separation.

The objective of this study was to find the most efficient physical separation scheme to produce glass sand. Standard bench-scale procedures involved scrubbing, sizing, flotation, heavy-liquid separation, and magnetic separation to remove impurities. Powder x-ray diffraction and x-ray fluorescence were utilized for identification and mineral composition. Minerals were identified with a binocular microscope.

The site under investigation has direct nearby access to convenient transportation and power. The area is served by electric power. Nearby streams are potential sources of process water. Road access to the site is provided by paved State Road 1615 that intersects State Highway 381 and U.S. Highway 74. Secondary roads provide access to north/south and east/west lines of the CSX railroad that serves the Port of Wilmington and the nearby Pilkington North America glass plant in Laurinburg, North Carolina. The glass sand plant is located on U.S. Highway 74 East, about 10 miles east of the Pinehurst glass sand site. The glass sand plant can be contacted at 910.276.5630; its mailing address is P.O. Box 969, Laurinburg, North Carolina, 28353. The plant's street address is U.S. Highway East, 13121 Rockyford Road, Laurinburg, North Carolina 28352.

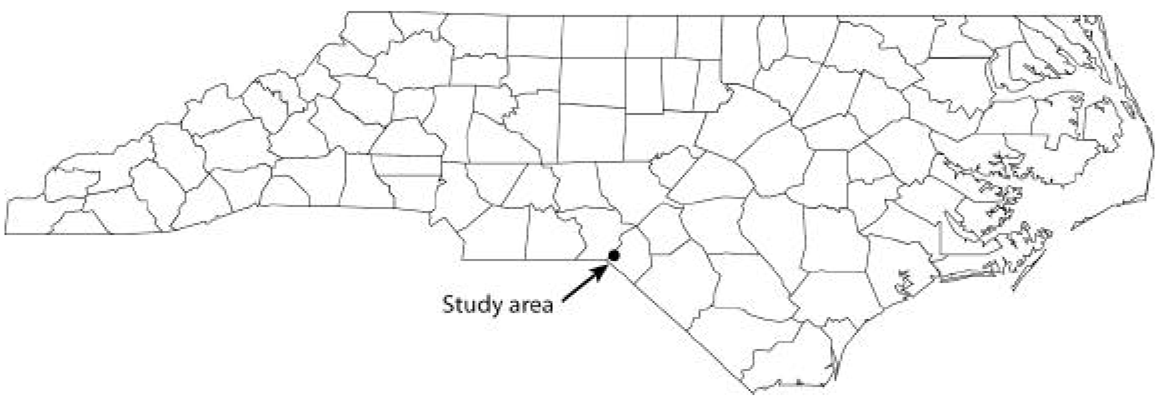

Figure 1. Site location map (black dot) in Richmond County, North Carolina.

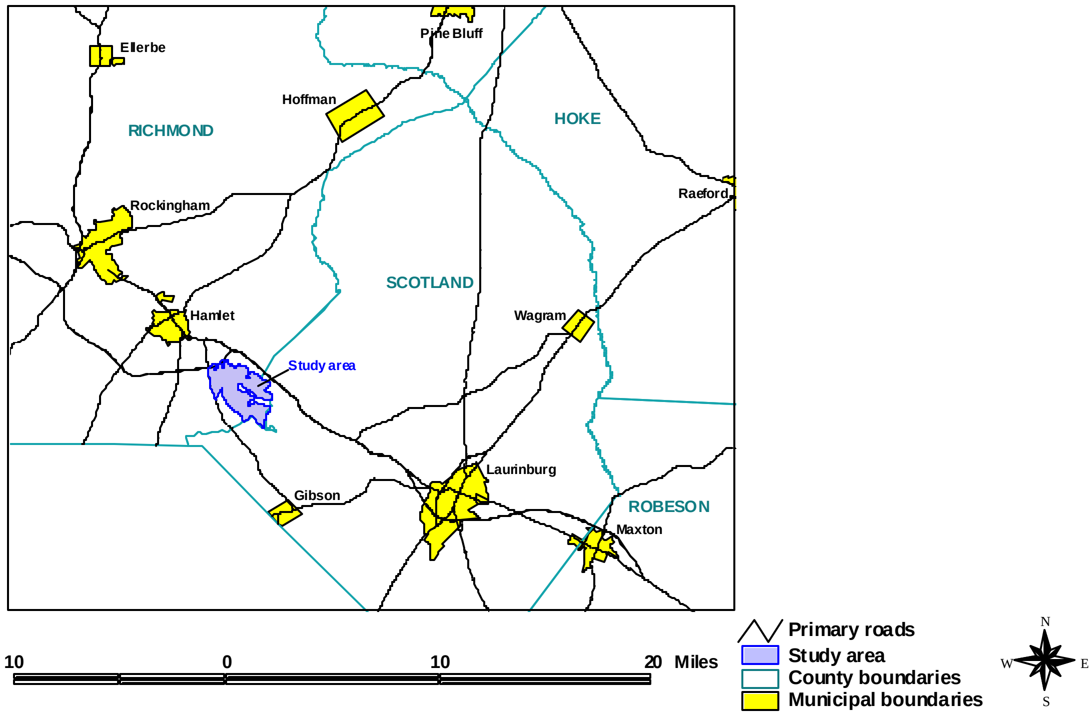

Figure 2. Site location map detail showing primary roads, and boundaries of municipalities and counties.

SOURCE OF SAMPLES

Split-spoon samples were taken from six drill cores 0 to 60 feet deep within approximately 2,800 acres of the Pinehurst Formation, Richmond County, North Carolina. The split spoon drill samples used in this study were from one of two sites selected by a sitting commission for a proposed regional low-level radioactive waste (LLRW) disposal repository. Both sites were studied in detail and many surface and subsurface investigations (including drilling) were conducted that included mineral resource potential. Following designation of another location in Wake County, North Carolina, as the preferred LLRW disposal site, site characterization investigations ceased at the Richmond county site. Subsequently, the duplicate split spoon drill samples used in this study became available for testing.

PREVIOUS WORK

The Pinehurst Formation was previously included in a study by Broadhurst (1949) who presented and discussed results from about two dozen selected localities as part of a statewide survey of North Carolina's high silica resources. Chem-Nuclear Systems, Inc. (1993) evaluated the mineral potential as a site selection criterion for a proposed regional low-level radioactive waste (LLRW) disposal site.

One criterion for selecting a LLRW disposal site requires considering the proximity to natural resources such as water, coal, oil, or other resources. Site suitability requirements call for avoiding areas with known resources. If the resource would be exploited, it would result in failure of the disposal facility to meet waste performance objectives. Studies are required under the North Carolina Administrative Code (NCAC) to determine whether or not natural resources are present whose exploitation could result in inadvertent intrusion into disposal cells after removal of active institutional control and for determining the impacts of committing a natural resource to non-retrievable status should a site be chosen to be used as a disposal facility.

Minerals were some of the natural resources studied under these criteria. Chem-Nuclear's focus was the Tertiary age Pinehurst Formation, which covered most of the surface of the Richmond County site. The waste disposal applicant evaluated the Pinehurst for heavy minerals, fine aggregate material, and glass sand (Chem-Nuclear, Inc. 1993).

Chem-Nuclear Inc. recognized the economic potential of the sand for aggregate but did not consider the resource to be viable as a glass sands resource because it was thought that the heavy mineral and other mineral content would affect the glass sand potential. Laboratory beneficiation tests were not conducted at that time.

When duplicate split spoon samples from the subsurface investigation became available for subsequent study in 2000, the North Carolina Geological Survey (NCGS) requested the North Carolina State University Minerals Research Laboratory to conduct a laboratory investigation to evaluate the sand from this formation for glass sand potential. This report, preceded by an interim reports (Mensah-Biney and others, 2001), shows the viability of this deposit as a glass sand resource.

A report by Wiener and others (1990) on high silica resource in North Carolina provides industry specifications for high silica. Glass sand specifications from that report is included in Appendix 1.

GEOLOGY

The Pinehurst Formation is described on the 1985 Geologic Map of North Carolina (North Carolina Geological Survey, 1985) as a "medium to coarse grained, unconsolidated sand (with) crossbedding and rhymthic bands of clayey sands common." The Preliminary Explanatory Text for the 1985 Geologic Map of North Carolina (North Carolina Geological Survey, 1988) provides a discussion of the stratigraphic nomenclature evolution of the Pinehurst Formation by various workers.

The uppermost unit at the site (Figure 3) is loose sand that has been mapped as the Pinehurst Formation (Burt, 1981; North Carolina Geological Survey, 1985; Owens, 1989). The Pinehurst Formation consists essentially of medium- to very coarse-grained quartz sand and is typically clean, loose, crossbedded with minor clay, muscovite, iron-oxide cement and heavy minerals (Cabe and others, 1992).

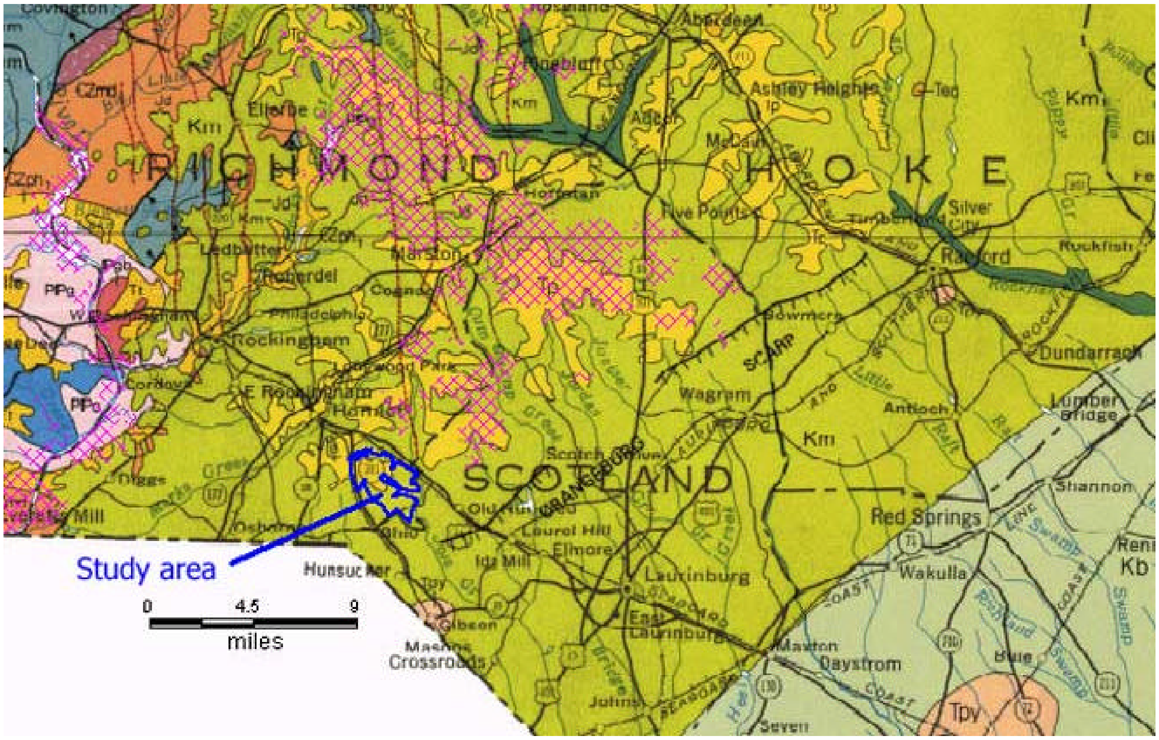

Figure 3. Generalized geologic setting showing the site (outlined in blue) superimposed on the 1985 Geologic Map of North Carolina. The primary units in the immediate area of the site are the Pinehurst Formation (Tp) [shown in yellow], and the Middendorf Formation (Km) shown in pale green. County lines are brown.

Below the Pinehurst Formation is the Middendorf Formation that contains discontinuous layers with variable pebble, sand and clay contents. Weathered feldspar grains compose some of the sand and pebble clasts. Small amounts of heavy minerals are also present.

Beneath the Middendorf Formation is the Cape Fear Formation that consists of poorly-sorted sand, silt and clay beds. The Cape Fear Formation rests on the basement complex, composed essentially of phyllic equivalents of metavolcanic and metavolcaniclastic rocks metamorphosed to greenschist facies.

METHODOLOGY

SAMPLE DESCRIPTION

The Pinehurst and the Middendorf formations crop out in the sampling area and both are potential sources for glass-quality quartz sand. Sediment samples obtained from six drill cores were used in the laboratory bench scale evaluation for glass sand. The cores were taken from both east-west and north-south directions on the site.

Split spoon samples from six core samples (Table 1, Figure 4, Figure 5) at the N.C. Geological Survey's sample repository (NCGS) in Raleigh were used for this study.

Samples were collected from drill holes shown on existing cross sections (Cross sections R1-R18 – Figure 6; and R83-R35 – Figure 7) prepared by Chem-Nuclear, Inc. (1993).

Table 1. Drill hole data from Pinehurst Formation.

Drill Hole	Depth Below Ground Surface (meters)	Number of Samples in Drill Hole	Number of Samples used in Composite	Entire Depth of Sample (meters)
R42	9.14	15	6	1.07 – 2.90
R63	18.29	37	11	0.30 – 6.10
R83	8.53	43	29	0.00 – 5.94
R41	9.14	24	16	0.30 – 5.94
R9	9.14	45	7	0.30 – 4.27
R18	10.97	53	48	0.00 – 10.36

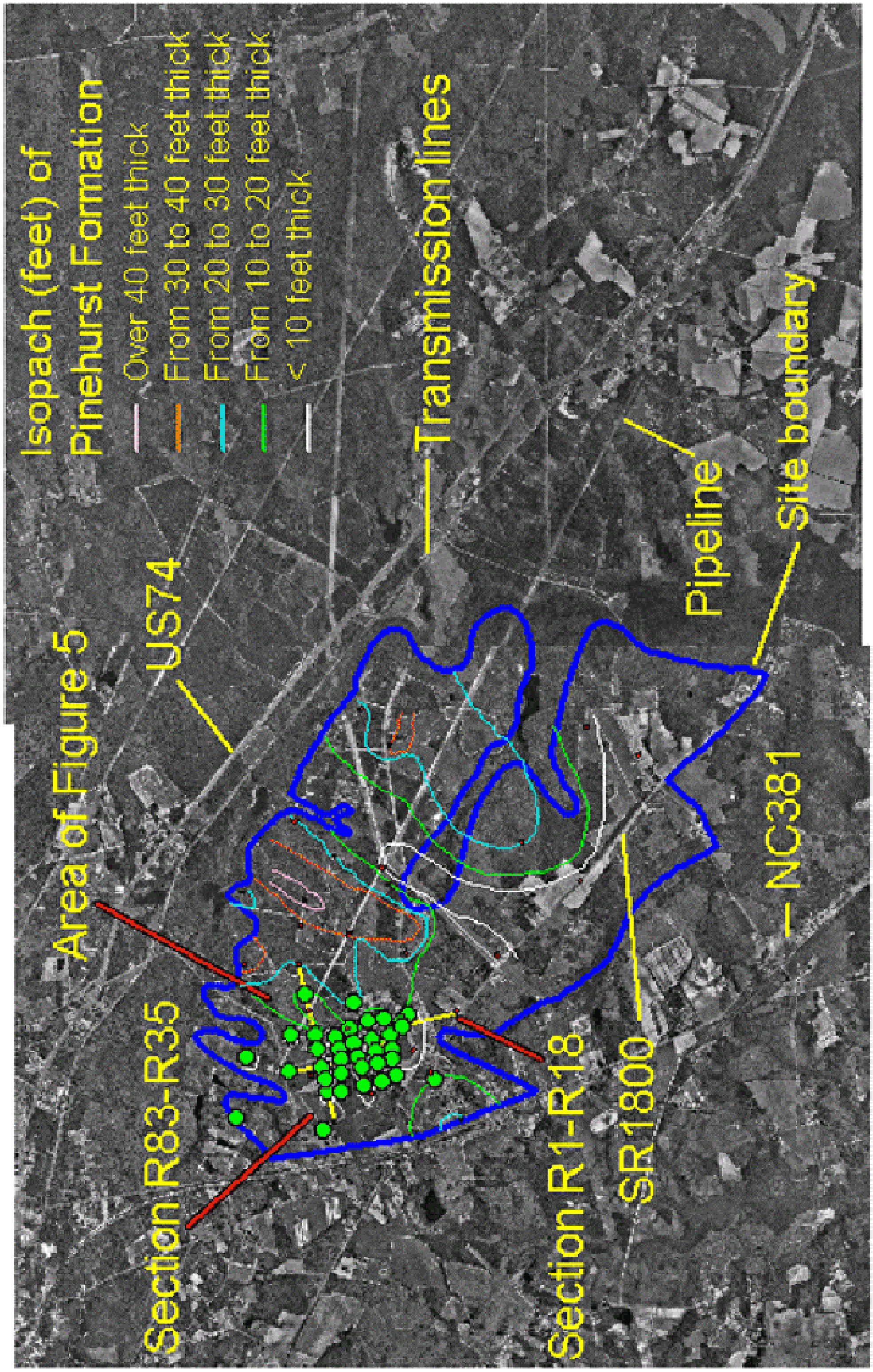

Figure 4. Site footprint with drill hole locations (green dots) on digital orthophoto-quarter quadrangle. Cross sections with drill holes used in this study have yellow labels. The site footprint is outlined in dark blue. Sand isopachs are in feet; Figure 5, an enlargement of this image, has the same isopach color scheme.

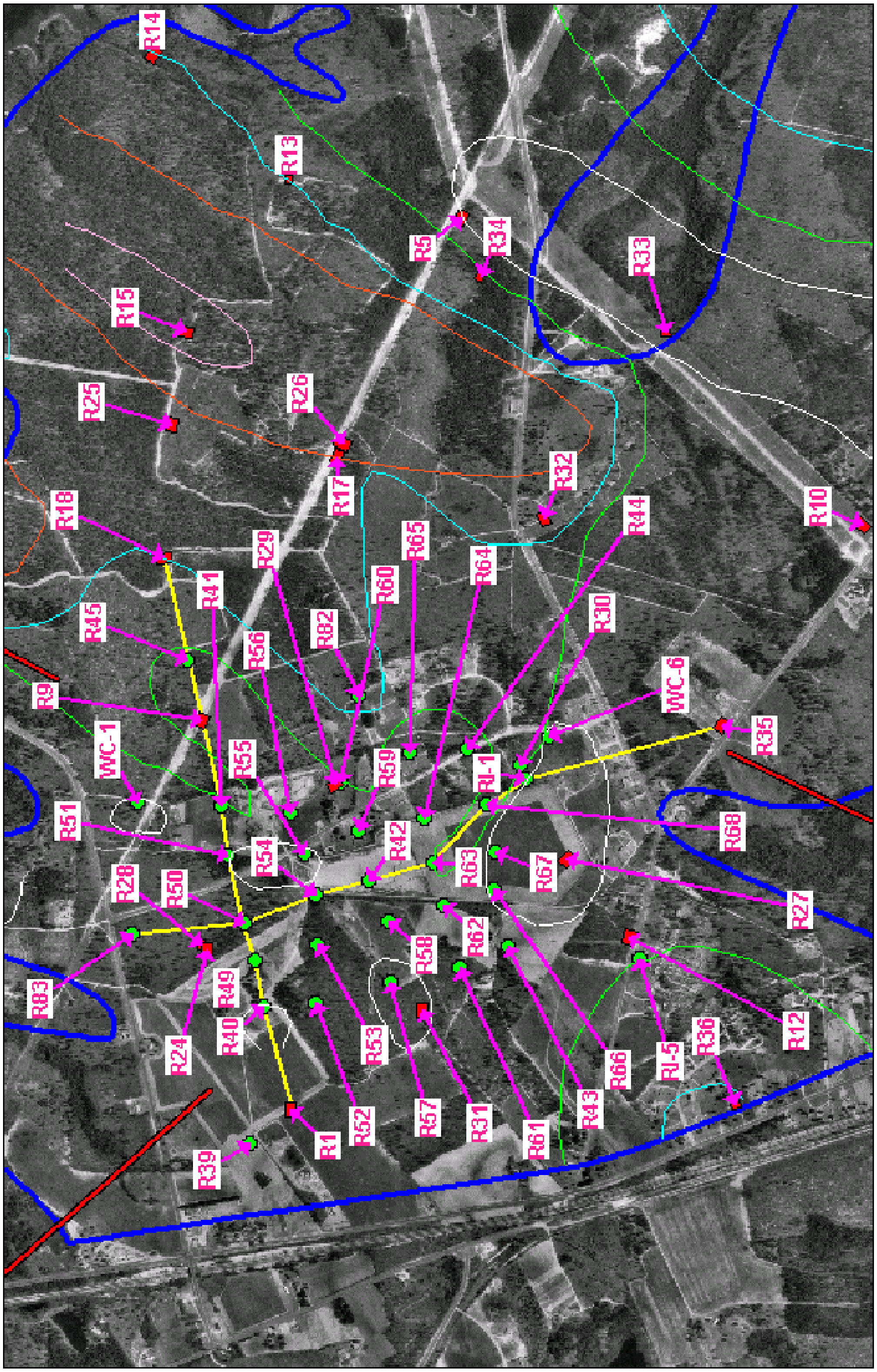

Figure 5. Detail of Figure 4 showing location of cross sections with sampled drill holes. Refer to Figure 4 for isopach color explanation. Yellow lines show cross sections of Figures 6 and 7. Refer to Figures 6 and 7 for specific drill holes used in this study.

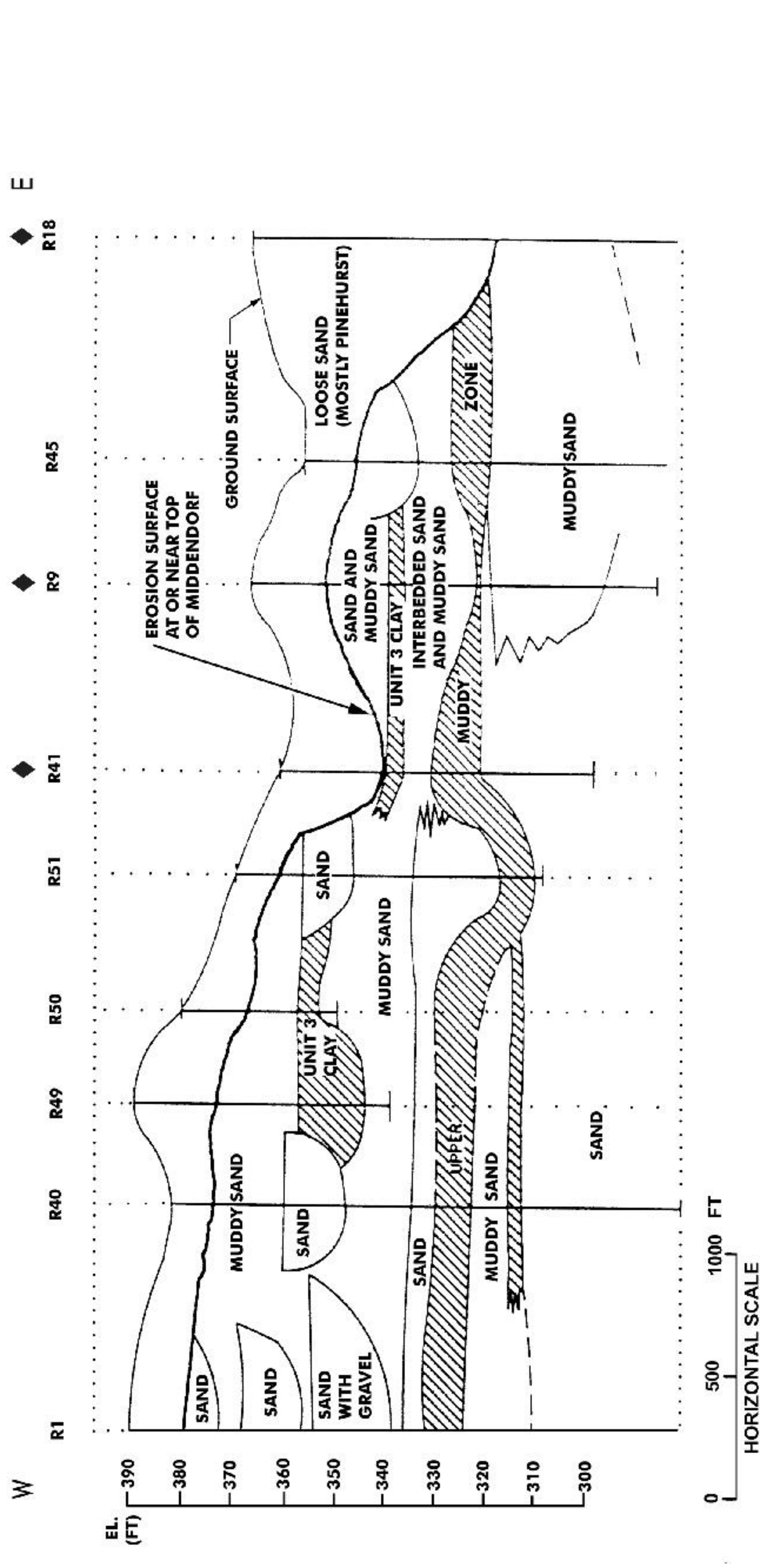

Figure 6. Generalized cross section – R1—R18. A black diamond symbol designates drill holes used in this study. Refer to Figure 5 for the location of this cross section.

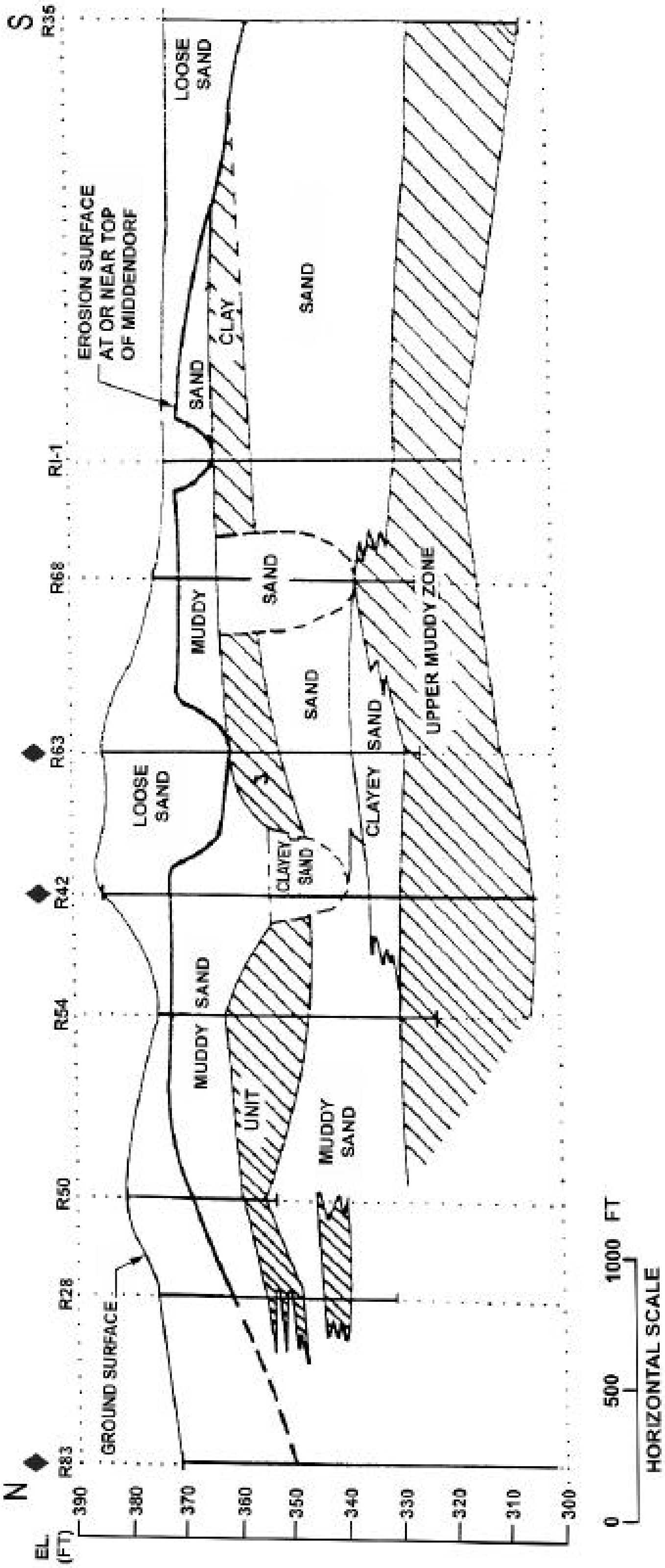

Figure 7. Generalized cross section – R83—R35. A black diamond symbol designates drill holes used in this study. Refer to Figure 5 for the location of this cross section.

The composite sample from drill hole R42 was composed of fine- to very coarse-grained light tan sand. This sample contained very coarse quartz with a slight orange stain. The sample from drill hole R63 was composed of medium to very fine-grained, light tan sand. The quartz was cleaner in this sample compared to the more prominent iron stains on other samples. The whiter color might have been an indication of kaolin present in the sample.

Drill hole R83 sample contained fine to medium-grained tan sand with a small amount of mica. The drill hole R41 sample contained very fine to medium-grained, white to light tan sand with a slight orange stain. The sample from this hole was lighter in color with less stain than most of the other samples. The drill hole R9 sample consisted of fine to coarse-grained, medium to dark tan sand with small amounts of orange and dark brown stain. This sample had a deeper brown color compared to the other samples with visible organic material.

The sample from drill hole R18 consisted of fine to coarse-grained, orange to red-stained sand with a deep brown stain. From 0.00 to 5.33 meters depth, the sand appeared to be light orange to light brown color whereas from 5.33 to 10.36 meters depth, the color was a deep red. Owing to the apparent contrast between the samples from these two depths, tests were done utilizing the first 5.33-meter depth (a total of twenty-three samples combined) and the next 5.03-meter depth (a total of twenty-five samples combined). Tests were also performed with samples from the combined depth of 10.36 meters.

EXPERIMENTAL PROCEDURES

SAMPLE PREPARATION

Bench-scale tests were conducted at the North Carolina State University's Mineral Research Laboratory. The composite sample from each hole was ground in a laboratory rod mill with three rods for 30 seconds to one minute to loosen large clumps and thoroughly mix the sample. Then the sample was split into approximately 700-gram equal portions for subsequent testing. Approximately 500-gram sample from these splits was used for testing.

SCRUBBING AND DESLIMING

The 500-gram samples were scrubbed at 70% solids at 1200 RPM for five minutes in an attrition scrubber. The pulp pH was maintained at less than three with sulfuric acid (10 wt. %). After scrubbing, the samples were deslimed on a 200-mesh screen. The deslimed products were advanced to the subsequent tests while the slimes were flocculated, settled, filtered, dried, weighed and discarded as waste. The influence of pulp density as percent solids, pH, and scrubbing time on the yield and quality of sand was evaluated

SIZING/SCREEENING

The scrubbed products after desliming were filtered and dried at 110°C overnight. Each sample was screened on a Ro-Tap for 15 minutes using US Standard 30-, 40-, 60-, 100-, 140-, 200-, and – 200-mesh. These size fractions were weighed, and the weight distribution was calculated. The size fractions were kept separate.

MAGNETIC SEPARATION

Size fractions from 40- to 140-mesh were combined and used for magnetic separation. All samples went through three passes on the magnetic separator (Permroll) at 150 RPM. Tests 6719-2, -4, and -6 combined 40-, 60-, and 100-mesh size fractions whereas tests 6719-3, -5, and –7 combined 40-, 60-, 100-, and 140-mesh sizes for the magnetic separation. Only samples with the largest weight percentages were used for magnetic separation.

HEAVY LIQUID SEPARATION

The composite samples from the individual drill hole were subjected to heavy liquid separation to remove heavy minerals as sink product and the glass sand as float product. The heavy-liquid separation test was carried out in a 500 ml. separatory funnel with tetrabromoethane (TBE) with a nominal density of 2.96 g/cc. The procedure was to add about 150 g of the dried product to the heavy liquid in the separatory funnel. The mixture was shaken gently manually and placed on a ring stand to allow the particles to separate as sink and float layers (about 30 minutes). The two separated layers were stirred gently to free entrapped particles and allow them to separate to their proper layers. Next, the sink product (heavies) was drained from the bottom of the funnel with the clear heavy liquid and filtered in a buchner filter apparatus to remove the entrained heavy liquid. The filtrate (TBE) was removed from the buchner flask and the filtered solids on the filter paper were washed several times with alcohol to remove excess TBE adsorbed on the particles. Finally the washed sink product was dried in an oven and weighed. The float product (light) was drained from the separatory funnel and treated as above.

FLOTATION PROCESS

The flotation process consisted of conditioning the material at 60-70% solids with a petroleum sulfonate collector for approximately five minutes at a pH <3 maintained with sulfuric acid. The conditioned pulp was adjusted to 25% solids and the iron mineral impurities were removed as the float product. The machine discharge was dewatered and conditioned at approximately 40% solids for one minute with an amine and a frother at a maintained pH less than three. The conditioned pulp was adjusted to 25% solids and the mica removed as the float product. The machine discharge was dewatered and conditioned at around 40% solids for one minute with an amine, hydrofluoric acid (HF), and frother at a pH less than three. The conditioned pulp was adjusted to 25% solids and the feldspar impurities removed as the float product leaving the machine discharge as the final glass sand product. All flotation products were filtered, dried, weighed, and assayed (Table 3).

CHEMICAL ANALYSIS

The standard chemical analysis for glass sand by XRF (Fe_2O_3, Al_2O_3, CaO, MgO, TiO_2, K_2O, SiO_2, ZrO_2, Na_2O, P_2O_5) and LOI (Loss on Ignition) was completed on six product samples by The Mineral Lab, Inc., Lakewood, Colorado.

MINERAL IDENTIFICATION – QUALITATIVE ANALYSIS

The flotation products were further analyzed by powder x-ray diffraction (XRD) to confirm the mineral identification of the samples. The feldspar float products generated by the flotation tests were not sufficient for XRD analysis. In fact, no feldspar was visible in the samples under the microscope. Powdered samples were scanned at 0.2° 2θ/sec with a generator tension of 45 kV and 40 mA.

RESULTS

Results of the attrition scrubbing tests for samples from individual drill holes are summarized in Table 2. Table 3 lists the results of the flotation tests, and Table 4 shows the summary of the attrition scrubbing tests for the composite samples. The results of the heavy liquid separation tests are tabulated in Table 5.

Table 2. Attrition scrubbing tests* – Samples from individual drill holes.

Test Number	6719-1	6719-2	6719-3	6719-4	6719-5	6719-6	6719-7
Sample ID	R83	R83	R41	R18	R63	R9	R42
	Scrubbed Product Cumulative % Retained						
US 40 mesh	28.0	26.5	41.0	33.6	37.2	45.3	52.9
US 60 mesh	58.1	56.9	69.2	62.9	57.2	73.9	75.2
US 100 mesh	84.8	84.7	91.0	88.7	76.3	92.6	91.4
US 140 mesh	91.4	91.4	95.7	94.4	81.1	96.2	95.7
Scrub Yield, Wt. % **(Note 1)**	80.1	80.3	73.8	77.3	62.4	71.9	63.0
Final Non-magnetic Yield, Wt. % **(Note 2)**	72.7	70.1	70.2	69.5	59.3	66.9	59.8
	Final Product Chemical Analysis %						
Fe_2O_3		0.02	0.02	0.01	0.02	0.04	0.02
Al_2O_3		0.15	0.13	0.14	0.13	0.34	0.16
MnO		0.01	0.01	0.01	0.01	0.01	0.01
TiO_2		0.01	0.01	0.01	0.01	0.02	0.01
K_2O		0.01	0.01	0.01	0.01	0.01	0.01
Na_2O		0.05	0.05	0.05	0.05	0.05	0.05
MgO		0.05	0.05	0.05	0.05	0.05	0.05
CaO		0.01	0.01	0.01	0.01	0.01	0.01
P_2O_5		0.05	0.05	0.05	0.05	0.05	0.05
SiO_2		99.6	99.8	98.7	99.1	97.2	98.8
LOI		0.01	0.1	0.07	0.09	0.1	0.1

*Attrition scrubbed at 70 % solids with H_2SO_4

Note 1 - The yield of sand after scrubbing and slime removal.

Note 2 - The yield after magnetic separation of the sized product.

Table 3. Flotation Test Results – Samples from individual drill holes.

Test Number	6719-8	6719-9	6719-10	6719-11	6719-12
Sample ID	R83	R18	R18	R41	R18
Depth (meters)	0.00 – 5.94	5.33-10.36	0.0-10.36	0.00 – 5.94	0.0 -5.33
	Feldspar Tailings Cum. % Retained				
US 40 mesh	30.7	28.1	33.2	39.4	37.8
US 60 mesh	60.7	57.3	62.1	68.1	66.2
US 100 mesh	86.4	85.5	88.2	91.0	90.9
US 140 mesh	93.3	93.5	94.6	96.3	96.3
Float Yield, Wt.% (Note 1)	80.1	81.0	78.0	74.9	75.5
Final Non-magnetic Yield, Wt. % (Note 2)	78.3	78.9	76.7	73.8	74.1

Note 1 - The yield of sand after removal of mica, iron minerals and feldspar.
Note 2 - The yield after magnetic separation of the sized feldspar tailings.

Table 4. Attrition Scrubbing Tests – Composite Sample from all drill holes.

Test Number	6719-13	6719-14	6719-15	6719-16	6719-17	6719-18
Scrub % Solids	70	70	65	65	70	70
Scrub Reagent	NaOH	H_2SO_4	H_2SO_4	NaOH	None	H_2SO_4
Scrub Time (min.)	5.0	5.0	5.0	5.0	5.0	3.0
	Scrubbed Product- Cumulative % Retained					
US 40 mesh	28.5	33.2	33.0	34.2	31.0	31.3
US 60 mesh	56.7	62.4	62.1	62.8	61.1	60.4
US 100 mesh	84.4	87.8	87.7	87.7	87.2	86.7
US 140 mesh	92.0	94.2	94.1	93.8	94.1	93.4
Scrub Yield, Wt. % (Note 1)	79.1	78.5	78.3	76.9	80.9	78.6
Final Non-magnetic Yield, Wt. % (Note 2)	75.2	76.9	76.5	74.6	78.8	76.5
	Final Product Chemical Analysis. %					
Fe_2O_3	0.02	0.03	0.03	0.02	0.04	0.03
Al_2O_3	0.16	0.22	0.23	0.14	0.22	0.21
MnO	0.01	0.01	0.01	0.01	0.01	0.01
TiO_2	0.02	0.03	0.02	0.02	0.02	0.02
K_2O	0.01	0.01	0.01	0.01	0.01	0.01
Na_2O	0.05	0.05	0.05	0.05	0.05	0.05
MgO	0.05	0.05	0.05	0.05	0.05	0.05
CaO	0.01	0.01	0.01	0.01	0.01	0.01
P_2O_5	0.05	0.05	0.05	0.05	0.05	0.05
SiO_2	98.0	96.5	97.0	97.2	98.4	98.2
LOI	0.08	0.07	0.09	0.1	0.08	0.1

Note 1 - The yield of sand after scrubbing and slime removal.
Note 2 - The yield after magnetic separation of the sized product.

Table 5. Heavy liquid separation test results – Raw samples from individual drill holes.

	Float Product		Sink Product		Total	
Drill Hole	Wt- grams	Wt. %	Wt- grams	Wt. %	Wt- grams	Wt. %
R18	158.6	99.5	0.8	0.5	159.4	100.0
R42	152.7	99.5	0.8	0.5	153.5	100.0
R9	152.0	99.5	0.7	0.5	152.7	100.0
R63	162.2	99.8	0.4	0.2	162.6	100.0
R83	153.8	99.6	0.5	0.4	154.3	100.0
R41	148.8	99.4	0.9	0.6	149.7	100.0

The particle size analysis showed that majority of sand recovered were in the +40 and +140 US Standard mesh size fractions (51 – 80%). The specifications for glass sand usually require the largest amount of material to be between 40 and 140 mesh.

In general, the yield of sand after attrition scrubbing of samples from the individual drill holes was between 62.4 and 80.3% by weight whereas the final yield of sand after magnetic separation (the non-magnetic product) ranged from 59.3 to 72.7% (Table 2). The yield of sand after flotation and magnetic separation ranged from 73.8 to 78.9% (Table 3). The final yield of non-magnetic product from the composite sample by attrition scrubbing ranged from 74.6 to 78.8% (Table 4).

The influence of such variables, such as pH, scrubbing time, and % solids on the final yield of sand was not significant (Table 4).

Raw samples contained an insignificant amount of heavy minerals. All of the heavy liquid separations yielded float products greater than 99% of the weight and less than 0.5% in the sink product.

Chemical analysis is of the samples from individual drill holes revealed that all the major impurities associated with sand were low and within the chemical specifications for glass sand (Table 4). Iron was below 0.04% Fe_2O_3, magnesium was below the detection limit of 0.05% MgO, aluminum ranged from 0.34% to 0.13% Al_2O_3 and titanium ranged from 0.03% TiO_2 to less than the detection limit of 0.01% TiO_2. For the composite samples, titanium and aluminum impurities were slightly higher but were still well within specifications for glass sand. Trace elements such as Zn, Pb, Mo, Cu, and Cr in all of the samples also were very low and measured in parts-per-million.

The iron minerals products from the flotation tests were used for the x-ray diffraction analysis. These samples contained mostly quartz and minute amounts of other heavy minerals. After separation of the quartz from the bulk of the sample under a microscope, the x-ray analysis of the remaining sample indicated the presence of schorl (tourmaline), zircon, and rutile. When viewed under the microscope, most of the grain sizes had a dark reddish-brown color. This could have been an indication that fractions of the quartz were stained with goethite and hematite, or the color could have indicated the presence of the minerals mentioned above, schorl, zircon, and rutile. The mica flotation product also contained a fair amount of quartz (40%), but trace minerals such as kaolinite and muscovite were also detected. Feldspar was not detectable in the sample as indicated by XRD or binocular microscopy.

RESOURCE POTENTIAL

GLASS SAND RESOURCES

The Pinehurst Formation, as mapped on the 1985 Geologic Map of North Carolina, covers approximately 120,660 acres in Richmond, Scotland, Moore and Hoke counties. Some Pinehurst outcrop underlies North Carolina Game Lands. Commercial glass sand is being produced from a nearby site operated by the Unimin Corporation from the Pinehurst Formation (see Figure 8). Because of the large area of game lands, the available land for glass sand exploration is substantially restricted.

Indicated and measured reserves can be determined in many parts of the site because many drill holes are spaced at approximately 500 feet. Inferred reserves can be mapped elsewhere on the site where drill hole spacing is greater.

Laboratory analysis from this study indicates sand from the deposit can be beneficiated to glass sand specifications. Chem-Nuclear (1993) determined a total gross tonnage of 36.6 million short tons in the area. Details of Chem-Nuclear's sand reserve calculation is included here because the report was not widely distributed.

Sand thickness ranges from 0 to more than 50 feet (Figure 4). Areas with sand thickness greater than 20 feet occur in several areas. One of these in the northern part of the site has 695 acres. The second largest deposit of Pinehurst sand is located in the eastern part of the site in the vicinity of borehole R7. A small abandoned sand mine is on the western edge of this deposit. A smaller sand deposit is situated to the south in the vicinity of borehole R8. Other deposits of Pinehurst Formation sand 20 or more feet thick in the site are relatively small.

The largest deposit is north of the pipeline and east of Secondary Road 1615 and covers 411 acres. Thicknesses of sand in this area include 25 acres of 20-30 feet, 153 acres of 30-40 feet, 107 acres of 40-50 feet, and 26 acres of 50 feet.

The gross tonnage of sand in the larger area can be estimated as follows:

Assumption: Pounds per cubic	=	115
foot		
Knowns: Pounds per short ton	=	2,000
Cubic feet per acre foot	=	43,560
Short tons sand per acre foot	=	2,505

(115 x 43,560)/2000

Calculation tonnage (short tons) = 2,505 x acres x sand thickness (average feet):

20' - 30' (25') area tonnage	= 2,505 x 125 x 25	=	7,828,125
30' - 40' (35') area tonnage	= 2,505 x 153 x 35	=	13,414,275
40' - 50' (45') area tonnage	= 2,505 x 107 x 45	=	12,061,575
50' + area tonnage	= 2,505 x 26 x 55	=	3,582,15
Total gross tonnage (short tons) in area		=	36,886,125

The glass sand product obtained by attrition scrubbing, sizing, and magnetic separation contained 0.13 to 0.16% Al_2O_3, 0.02 to 0.04% Fe_2O_3, less than 0.02% TiO_2, and traces of other minor elements such as Zn, Pb, Mo, Cu, and Cr. This product was found suitable for glass sand application and the physical and chemical characteristics were well within the specifications for typical glass sand (see Appendix).

HEAVY MINERALS

During site characterization, both the heavy mineral content and tonnage of sand were evaluated. The heavy mineral species in the –35 mesh to +325 mesh fraction of borehole samples to a depth of 40 feet consists of ilmenite, tan opaques, leucoxene, rutile, zircon/xenotime, monazite, staurolite and kyanite (Chem-Nuclear Systems, 1993, Table 2.7.1-10). The potential heavy minerals of economic interest is less than one percent of total heavy minerals recovered. Other minerals identified during this study included schorl and lesser amounts of goethite, hematite, muscovite, [add comma] and magnetite.

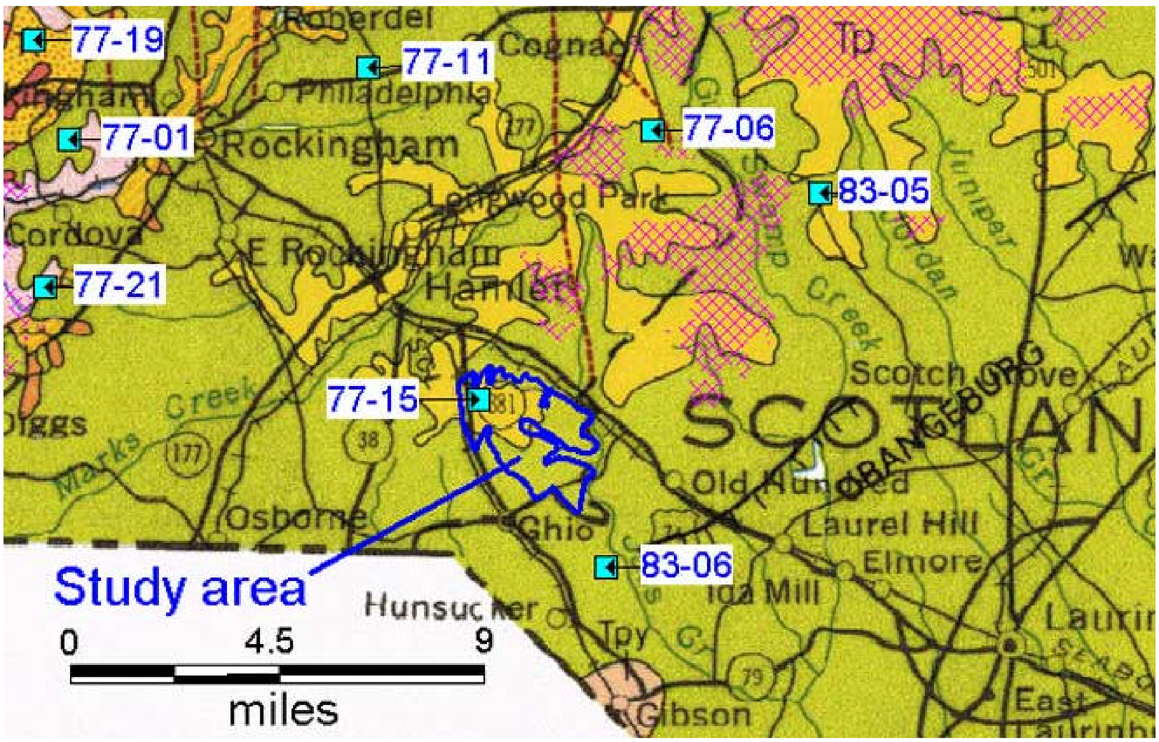

Figure 8. Map showing the distribution of Pinehurst Formation relative to the North Carolina Game Land (violet ruled lines) and other permitted mines. The site footprint is shown in dark blue. The five permitted mines visible in this view are: 77-06 – Unimin's Marston Plant, 83-05 – Morgan Sand Mine, 83-06 – Mudd Land Mine, 77-15 – Hamlet Plant, and 77-11 – Southeastern Sand and Clay Pit. The 1985 Geologic Map of North Carolina serves as the base.

Most of the silica sand consumption in the United States goes toward making glass containers and flat pieces of glass used for windows. Silica sand is also used for the manufacture of fiberglass and specialty glass. Non-glass applications for silica sand include foundry, refractory, and metallurgical purposes, chemical production, abrasives, and hydraulic fracturing. Recent data shows that silica sand sells for $8-$25 per ton, depending on the quality and location of the site (Harben, 1999, p.190). Maximum profit could depend on nearby transportation such as railroads, and road access. Silica sand should not be shipped great distances to minimize cost (Brady and Clauser, 1977, p. 671). The proximity of the Pilkington glass plant in Laurinburg, North Carolina, readily available rail and truck access to that plant or the Port of

Wilmington, along with suitable feedstock chemistry, and a nearby operating glass sand mine, make these deposits of potential economic interest.

CONCLUSIONS

Laboratory beneficiation methods were successful in producing a glass sand product using split-spoon samples of six drill cores, 0.0 to 60.0 feet deep within approximately 2,800 acres underlain by the Pinehurst Formation, Richmond County, North Carolina. Indicated reserves by drilling were approximately 36.8 million short tons in this study area.

XRF analysis demonstrated that each processed sample was glass grade quality according to The Industrial Minerals HandyBook (Harben, 1999) standards. This specific type of glass sand could be used for the following: glass grade, ceramic grade, foundry grade silica, filtration sand, and possibly sodium silicate feedstock and silica flour.

All of the beneficiation methods were successful in producing glass sand that met the physical and chemical specifications. The chemical analysis focused on impurities in the samples and the percent difference of silica, rather than the actual silica content. All of the major and minor element requirements for glass grade sand were met, including the most crucial aluminum, iron, titanium, potassium, chromium, and zircon standards.

The glass sand product obtained by attrition scrubbing, sizing, and magnetic separation contained 0.13 to 0.16% Al_2O_3, 0.02 to 0.04% Fe_2O_3, less than 0.02% TiO_2, and traces of other elements such as Zn, Pb, Mo, Cu, and Cr. This product was found suitable for glass sand application, and the physical and chemical characteristics were well within the specifications for typical glass sand.

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APPENDIX 1 – GLASS SAND SPECIFICATIONS

Specification overview
Manufacturer's specification - Silica sand for plate glass

- Critical oxides, maximum limit (in percent)
- Total refractory content per 100 pounds
- Undesirable refractory minerals
- Acceptable size distribution (in percent)

Manufacturer's specification - Silica sand for plate glass (float composition)

- Description
- Specifications
- Chemical composition (in percent
- Physical properties
    - + Heavy minerals
    - + Magnetic iron
    - + Size distribution

Manufacturer's specification - Container glass

- Chemical composition (in percent)
- Typical sizing (in percent)
- Commercially available high purity quartz
- Range of chemical composition of commercially available ground silica (in percent)

Typical requirements for high-silica materials for fiberglass manufacture

- Chemical composition
- Size specification (for "E" fiberglass)

SPECIFICATION OVERVIEW

This appendix presents tables listing some currently used industrial specification for high-silica materials based on chemical composition, deleterious mineral components, and grain sizes. These data are reproduced from Wiener and others (1990).

These tables provide sets of criteria useful for evaluation of high silica resources, but cost, availability, and uniformity of raw materials are also significant to industry. 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 mines and plants in the eastern United States.

MANUFACTURURE'S SPECIFICATION – SILICA SAND FOR PLATE GLASS

Critical oxides, maximum limit (in percent)

Fe_2O_3	0.08	Co_3O_4	0.0002
Al_2O_3	0.30	MnO_2	0.002
Cr_2O_3	0.0002	H_2O	0.05

Total refractory content per 100 pounds

- Cumulative Retained on U. S. 70-Mesh Maximum Limit: 0.200 grams = 0.00044%

Undesirable refractory minerals

Chromite	$FeCr_2O_4$	Sillimanite	Al_2O_3
Corundum	Al_2O_3	Zircon	$ZrSiO_4$
Andalusite	Al_2SiO_5	Zirconia	ZrO_2
Kyanite	Al_2SiO_5		

[1] Also other spinels

Acceptable size distribution (in percent)

Cumulative retained on:		
16 US Mesh	Not one piece	Not one piece
20 US Mesh	0.1%	Maximum
40 US Mesh	5.0 – 15.0%	Maximum[2]
140 US Mesh	92.9%	Minimum
200US Mesh	99.5%	Minimum
325 US Mesh	100.0%	Minimum

[2] The amount of +40 mesh material acceptable is generally dependent on the amount of +70 mesh 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 that 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.

Chemical composition (in percent)

			Permitted variability
SiO_2	99.50	Minimum	± 0.30
Fe_2O_3	0.05	Maximum	± 0.01
Cr_2O_3	0.004	Maximum	
Loss on ignition	0.30	Maximum	

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 US 30 Mesh – 1% Maximum
- Retained on US 40 Mesh – 7% Maximum
- Through US 200 Mesh – 1% Maximum

MANUFACTURER'S SPECIFICATION – CONTAINER GLASS

Chemical composition (percent)

SiO_2	>99.3
Fe_2O_3	<0.04
Al_2O_3	0 .5 ±0 .005
CaO	0.01 ± 0.005
TiO_2	<0 .03
Na_2O	<0 .01
Loss on ignition (LOI)	0 .15 ±0 .05
Color	White
Heavy minerals	<0 .2

Typical sizing (in percent)

- Retained on US 20 mesh 0.0
- Retained on US 30 mesh 1.0 max
- Passing US 10 mesh 40 (average)
- Passing US 150 mesh 5.0 max

Commercially available high-purity quartz (ppm)

Al	14 - 25[2]
Fe	0.3 - 1[3]
Na	0.7 - 2
K	0.4 – 1.3
Na + K + Li	<3.0
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
Ni	<0.05
Co	<0.05
Cr	<0.05
Mo	<0.1
P	<0.3

[1] Data is a composite of six different products manufactured by one company.
[2] Desirable 10 ppm
[3] Desirable 0.7 ppm

Size specification (in percent)

- Retained on US 50 mesh – 3 (max.)
- Passing US 140 mesh – 8 (max.)

RANGE OF CHEMICAL COMPOSITION OF COMMERCIALLY AVAILABLE GROUND SILICA (IN PERCENT)

SiO_2	99.59 – 99.81
Fe_20_3	0.030 – 0.017
MgO	<0.01
Al_2O_3	0.200 – 0.055
TiO_2	0.034 – 0.012
Loss on Ignition (L.O.I.)	0.180 – 0.100

Notes:

- Data presented is a composite from seven mines and plants.
- 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.
- 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_2 – 99.0 ± 0.5
- Fe_2O_3 – 0.1 max.

Size specification (for "E" fiberglass)

Sieve	Percent
Retained on a US 100 mesh	0
Retained on a US 200 mesh	1
Retained on a US 325 mesh	3
Passing a US 325 mesh	96

Note: 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

Sieve opening (millimeters)	Tyler series		U. S. Series No.
2.00	9	Mesh	10
1.18	14	Mesh	16
0.850	20	Mesh	20
0.600	28	Mesh	30
0.425	35	Mesh	40
0.300	48	Mesh	50
0.250	60	Mesh	60
0.212	65	Mesh	70
0.180	80	Mesh	80
0.150	100	Mesh	100
0.106	150	Mesh	140
0.075	200	Mesh	200
0.53	270	Mesh	270
0.045	325	Mesh	325
0.038	400	Mesh	400

APPENDIX 3 – ADDITIONAL SPECIFICATION FOR GLASS SAND (FROM HARBEN, 1999)

Specifications for glass-sand	**Typical glass-sand**
Scrub product PSA, Wt. %	
+30 mesh	< 2.0
-30 +40 mesh	< 20.0
-140 mesh	< 5.0
-200 mesh	
Chemical analysis %	
Na_2O	< 0.10
K_2O	< 0.10
MgO	< 0.01
Al_2O_3	< 0.15
Fe_2O_3	< 0.03
S	
Cl	
CaO	< 0.01
TiO_2	< 0.03
P_2O_5	
MnO_2	< 0.002
BaO	
ZrO_2	20 ppm (Zr)
Cr_2O_3	0.15 ppm (Cr)
Ni	0.39 ppm (Ni)
Cu	ppm Cu
Loss on ignition (L.O.I.)	< 0.15

Reference: Peter W. Harben, The Industrial Minerals HandyBook, 3rd Edition, 1999