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A REPORT ON THE

HIGH-SILICA SAND RESOURCES OF NORTH CAROLINA

BY

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HIGH-SILICA SANDS IN NORTH CAROLINA

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INTRODUCTION

Purpose and Scope

Approximately five million tons of silica sand are mined annually in North Carolina. Most of it is used for general construction purposes. Other uses are as engine sand, filler sand, blast sand, and filter sand. With the rapid industrial and economic growth of North Carolina, considerable interest has developed as to the possibility of using some of the local high-grade quartz sands in the manufacture of glass or other specialized products.

Results of earlier investigations carried out by the Division of Mineral Resources of the North Carolina Department of Conservation and Development, published as Information Circular 7[1*], indicate that the highest grade silica sands occurring in large volumes in North Carolina are those in the southeastern part of the State. The present report is a general appraisal of these sands as potential raw materials for the manufacture of glass or other high-silica products and presents data concerning their distribution, geologic occurrence, mineralogy, and amenability to beneficiation. It is the result of a cooperative project between the Division of Mineral Resources of the North Carolina Department of Conservation and Development and the North Carolina State College Minerals Research Labora-

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* References are at end of report.

tory in Asheville. The information presented portrays representative conditions and is designed as a basis for a more practical evaluation of high-silica sands in North Carolina.

Acknowledgments

Field investigation of the high-silica sands was carried out by geologists of the Division of Mineral Resources of the North Carolina Department of Conservation and Development. Staff members of the North Carolina State College Minerals Research Laboratory in Asheville performed chemical and screen analyses and made beneficiation tests. The project was supervised by the writer and was under the general guidance of Dr. Jasper L. Stuckey, State geologist.

HIGH-SILICA SANDS

Definitions

Sand is a term applied to an aggregate of unconsolidated particles of mineral matter in which the size of individual particles ranges from 2 mm. to 0.05 mm. (1/12 to 1/500 of an inch). Sands may be natural or artificial. Most natural sands are composed largely of the mineral quartz (silica), but small amounts of other minerals are often present. The term "high-silica" is applied to quartz sands of extreme purity to distinguish them from more impure varieties commonly used for construction and other general purposes. To meet the high-silica standard, a sand should contain 98 percent or more silica and have a very low iron and clay mineral content.

Origin and Occurrence

Naturally occurring sands are formed by the disintegration of rocks and minerals through various processes of mechanical and chemical weathering.

Residual deposits are formed by the breakdown of the original rock in place. Sands are often transported considerable distances by water and wind and may be deposited many times along flood plains of rivers and streams, in lakes, along beaches, and in the ocean adjacent to the coast. After deposition, some sands become consolidated to form sandstones, others remain unconsolidated.

Important commercial deposits of high-silica sands are of both consolidated and unconsolidated types. Many of the glass sand deposits now being worked consist of loosely consolidated sandstones which may be disintegrated easily by simple crushing or hydraulic methods. Unconsolidated sands usually are of a younger geologic age than the consolidated types and often occur as surficial deposits, having been concentrated by wind and water action. Although deposits of unconsolidated sands are often not as large or uniform as the bedded sandstones, they have been utilized successfully in the manufacture of glass in California, New Jersey, and South Carolina. The high-silica sands occurring in volume in North Carolina are largely of this type.

Uses and Specifications

High-silica sand has a wide variety of specialized uses in the chemical and ceramic industries. It is used in the manufacture of glass, silicon carbide, solium silicate (water glass), fused optical quartz, pottery, and other products. For such uses, a sand containing 99 percent or more silica and less than 0.05 percent iron oxide is desired. Where extremely fine sizes are required, the raw sand is ground prior to being marketed. High-silica sand is a relatively cheap commodity, prices ranging from $1.50 to $5 per ton depending upon quality.

Glass Sands

One of the most important uses of high-silica sands is in the making of glass, where silica constitutes from 52 percent to 65 percent of the raw materials used in most common glass[2] and up to 96 percent in special varieties[3]. Since silica is largely responsible for transparency, luster, and hardness of the finished product, glass sands must meet rigid chemical, mineralogical, and physical standards. General requirements are given below. Actual specifications vary with individual manufacturers and with the grade of glass produced.

Chemical Character: Glass sands are required to be of a uniform high purity, and few containing less than 98 percent silica are acceptable. Most consumers request more than 99 percent silica. Iron, one of the most objectionable impurities, is a strong colorizing agent and when present in very small quantities will color glass green and yellow. An iron oxide content of 0.3 percent is permissible in some grades of green glass, but for most white varieties, it must be less than 0.04 percent. An iron oxide content of 0.035 percent or less is specified by most manufacturers. Alumina in the form of colloidal clay minerals is objectionable if present in quantity, since it tends to produce a cloudiness in glass. An alumina content of 0.1 percent is maximum for sand to be used in optical glass, although up to 0.5 percent may be tolerated for container ware. Other objectionable impurities which should be kept at a minimum include magnesia, titania, and organic matter. Usually magnesia is not present to any large degree in silica sands, this contamination often being introduced into the mix with limestone. Titania is frequently associated with clay as stain and small mineral grains. Table I. presents general chemical specifications for sands used in various grades of glass as recommended by the American Ceramic Society and the

National Bureau of Standards[4].

Table I. Specifications for Chemical Composition of Glass Sands
Percentage Composition Based on Ignited Samples

Qualities	SiO_2 Minimum	Al_2O_3 Maximum	Fe_2O_3 Maximum	CaO+MgO Maximum
First quality, optical glass	99.8	0.1	0.02	0.1
Second quality, flint-glass containers and tableware	98.5	0.5	0.035	0.2
Third quality, flint glass	95.0	4.0	0.035	0.5
Fourth quality, sheet glass, rolled and polished plate	98.5	0.5	0.06	0.5
Fifth quality, sheet glass, rolled and polished plate	95.0	4.0	0.06	0.5
Sixth quality, green glass containers and window glass	98.0	0.5	0.3	0.5
Seventh quality, green glass	95.0	4.0	0.3	0.5
Eighth quality, amber glass containers	98.0	0.5	1.0	0.5
Ninth quality, amber glass	95.0	4.0	1.0	0.5

Mineralogical Composition: The high-purity standards necessary for glass manufacture make the mineralogical composition of glass sands an extremely important factor. Normally, a high-silica sand will contain more than 98 percent silica in the form of quartz. The remaining material consists of small amounts of various minerals which are considered to be impurities. Of these impurities, iron-bearing minerals present the most difficult problems, and those commonly occurring with quartz sands include limonite, hematite, magnetite, ilmenite, titanite, hornblende, anatase(?), garnet, and glauconite. Other minerals frequently present are feldspar, mica, clay minerals, zircon, kyanite, monazite, and epidote. When present in objectionable quantities, these impurities must be removed economically. The mineralogical composition of a sand will determine the feasibility of beneficiation and will indicate the most practical processing methods to be used.

Physical Character: To meet specifications, a quartz sand must have the proper distribution of grain sizes, a uniform density, and be free from harmful inclusions. Of particular importance is the distribution of grain sizes. Normal design of glass furnaces makes excessively fine sands undesirable because of extreme dust losses, which not only reduce the available materials for processing but also block regenerators, necessitating excessive shutdowns. Large grains are also undesirable, since they do not melt rapidly and result in slowing down the fusing process with a consequent increase in the cost of manufacturing the glass. Although the problem has been studied in detail, manufacturers do not agree on what are the most effective grain sizes for glass sands. It is generally conceded that the sand should pass No. 20 sieve (0.8 mm.) and most of it be retained on No. 100 sieve (0.15 mm.). The size distribution in an ideal glass sand as recommended by the Owens-Illinois Glass Company is shown as Table II[5]. Particle shape, at one time considered to be of importance, is not a major factor, although some manufacturers prefer a sharp angular grain to a well rounded one. A uniform density and white color is highly desirable in a glass sand.

Table II. Ideal Glass Sand

Mesh Size	Percentage Weight
+35	1 to 2
35 to 48	25 to 30
48 to 80	30 to 40
80 to 100	36*
100 to 200	
-200	

* Minus 80-mesh material with not more than 1 to 2 percent minus 200-mesh material. The minus 80-mesh material should not exceed 40 percent. If possible to conform with the other size requirements, it is desirable to keep the amount of minus 80-mesh material below 30 percent.

Although considerable tolerance can be allowed for many types of glass, as is indicated by the general specifications presented above, most manufacturers demand top-quality sand regardless of grade of glass being produced. This allows a close control of the finished product and assures manufacturers of the best sands within a district.

HIGH-SILICA SANDS IN NORTH CAROLINA

Geographic Distribution

In North Carolina the major occurrences of high-silica sand are in the southeastern part of the State and are confined largely to Moore, Hoke, Cumberland, Bladen, Robeson, Scotland, Anson, Columbus, and New Hanover Counties. Deposits are scattered throughout an irregular zone about 50 miles wide, which extends from near Eagle Springs, Moore County, to just north of Carolina Beach, New Hanover County, a distance of approximately 125 miles. (See accompanying map.)

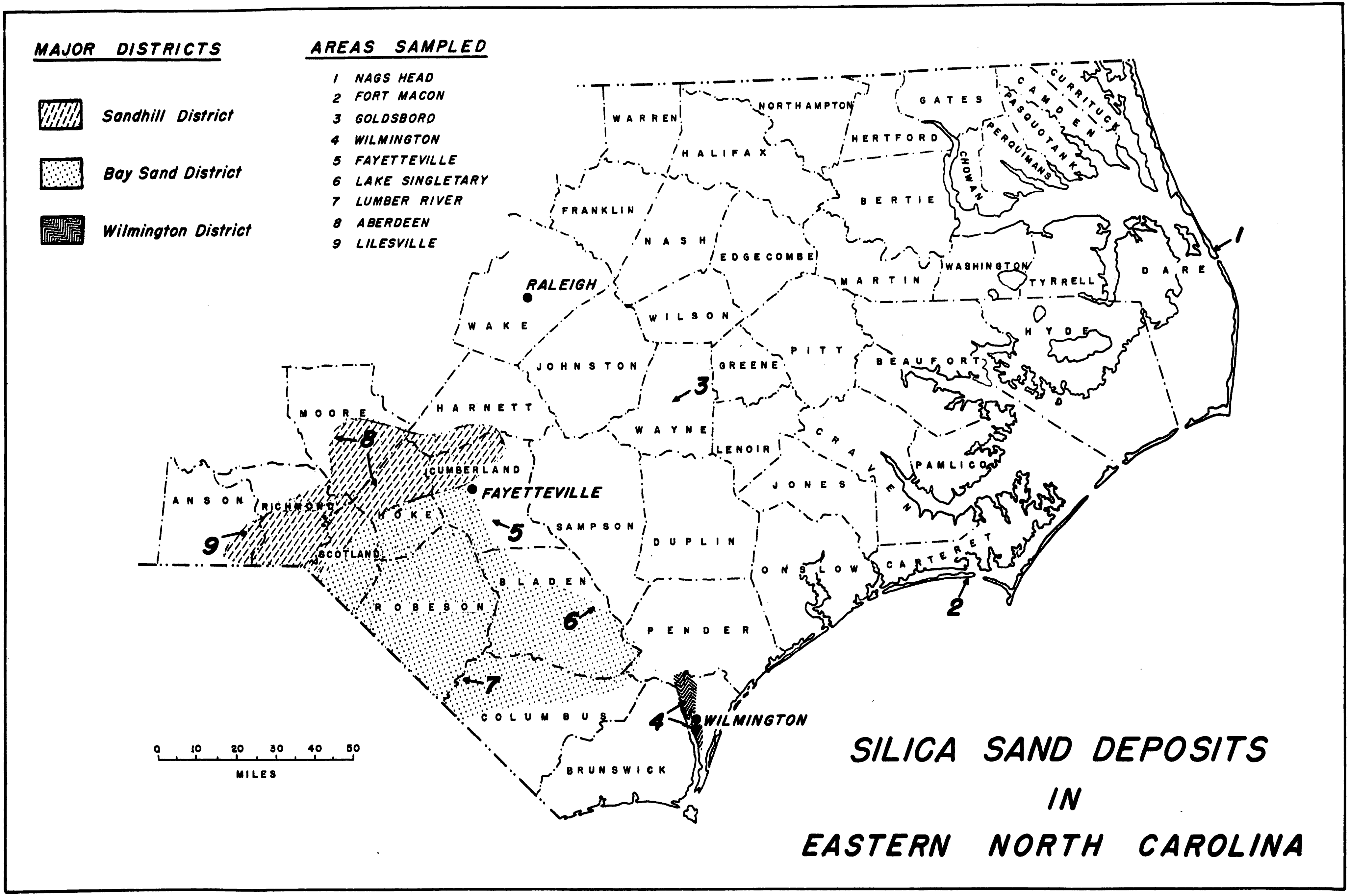
Within this zone the sand occurrences may be divided into three geographic and geologic districts. The northernmost is the well known "Sandhills" area along the western border of the Coastal Plain. It includes the southern half of Moore County, the northern half of Hoke County, and smaller parts of Anson, Richmond, Scotland, and Cumberland Counties. The most important deposits are in the Moore-Hoke area and in eastern Anson County. Southeast of the Sandhills is a series of rather widely scattered quartz sand deposits occurring along interstream divides and adjacent to certain topographic depressions, known as "bays." These deposits comprise the second district and occur sporadically in parts of Hoke, Robeson, Bladen, and Columbus Counties. The third district is in New Hanover County and includes an area near Wilmington in which considerable amounts of dune sand occur. In both the Sandhills and Wilmington districts there are sizable volumes of high-quality quartz sand. Between the two, deposits of excellent sand occur at intervals, but the volume in any one deposit is usually limited.

Other occurrences of quartz sands, particularly those in the immediate coastal areas, are known to exist but their lack of purity, or volume, or accessibility makes them appear less favorable for specialized commercial development. Among the larger deposits are the dunes near Kitty Hawk, Dare County, and near Atlantic Beach, Carteret County. In the Spruce Pine district of Mitchell and Yancey Counties, a high-silica sand is produced as a byproduct of feldspar and kaolin concentration and sold to industrial firms in Tennessee and Virginia.

Geologic Aspects

The sands described in this report occur as surficial deposits in the southern Coastal Plain region of the State. They are referred to as Sandhills sands, bay sands, and coastal sands, designations which reflect differences in their occurrence and geologic histories. Although varying locally, they exhibit an overall uniformity of texture and composition.

The sands are principally crystalline quartz and seldom contain sufficient clay to make the grains cohere. In most deposits they are a light yellowish-tan to white, medium grained, and subangular to subrounded. The tan color results largely from small amounts of iron oxides which stain individual quartz grains. Where deposits have been subjected to excessive natural leaching, much of the stain has been removed and the sand is exceptionally white. Grain sizes vary from very fine to coarse, but most particles are in the medium and lower coarse size ranges. Analyses of



SILICA SAND DEPOSITS IN EASTERN NORTH CAROLINA typical sands from the various districts show that from 15 percent to 25 percent of the grains are larger than 0.5 mm. in diameter, from 50 percent to 75 percent are between 0.5 mm. and 0.25 mm. and from 10 percent to 20 percent are between 0.25 mm. and 0.125 mm. Sizes finer than 0.125 mm. constitute less than 2 percent of most sands. The grains have a rather uniform two-dimension circularity but differ as to roundness and degree of frosting. Although most of the sands are relatively free from excessive clay contamination, small amounts of other impurities are present as individual mineral grains. These include magnetite, ilmenite, hematite, limonite, hornblende, tourmaline, epidote, mica, feldspar, zircon, rutile, kyanite, and anatase(?). Seldom do these impurities constitute more than 1.5 percent of a sand, and most are present in relatively fine sizes.

Deposits are of both residual and dune types and show little stratification or other structure. Occasional pebbles are scattered throughout the sand, but gravel accumulations are rare and are usually near the bottom of a deposit. Since deposits represent surface concentrations, they are quite shallow and of limited areal extent. Depths seldom exceed 15 feet, most being less than 10 feet.

These sands are associated with sedimentary formations which range from Cretaceous to Pleistocene in age. In most instances true age relationships are obscure, since many of the deposits have been altered by varying degrees of water and wind action subsequent to original deposition. With the exception of the immediate coastal areas, the largest accumulations of sand are in those areas underlain by a series of intermixed sands, clays, and gravels, considered to be Cretaceous in age. Where the underlying sediments are of a calcareous or argillaceous nature, surficial sands are very thin or absent. Although there is evidence that the sands are related genetically to Cretaceous sediments, the present position and character of deposits indicate diverse geologic histories. Within each major sand district most deposits have a common origin and overall similarity of character; between districts, there are differences.

Along the western border of the southern part of the Coastal Plain, surficial sands occur over a large well dissected upland known as the Sandhills. Deposits are of a residual type, having formed from a reddish-brown clayey sand, into which the high-quality sand grades. The clay content of the original sediments was relatively small, and its removal was probably effected by means of downward percolating waters. The sands are generally incoherent and quite uniform throughout much of the district. The most conspicuous structures are thin discontinuous horizontal layers of brown clayey sand which are present in many deposits. These layers, usually only 1 to 3 inches thick and seldom more than 1 foot long, are composed principally of sand with just enough clay binder to make the quartz grains cohere. Narrow zones of small gravels sometimes are present near the bottom of many deposits. Underlying the high-silica sands of the Sandhills and in places apparently grading into them is a series of strongly cross-bedded continental arenaceous sediments of Cretaceous age. Since the Sandhills sands are at elevations higher than the known advance of Pleistocene seas and do not show the prominent structures displayed by the underlying continental sediments, their true age is in doubt; they are, however considered to be of Cretaceous age.

The eastern border of the rolling Sandhills district is often indicated by a topographic break which is quite prominent in some places but is difficult to discern at others. From the Sandhills scarp, the land surface slopes gently eastward as a series of broad low terraces which were formed during the gradual cyclic withdrawal of shallow Pleistocene seas. The terraces are composed of unconsolidated sands, clayey sands, and silts and probably represent reworked Cretaceous formations. One of the most outstanding surface features on the terraces are shallow oval depressions known as bays. Because of the widespread occurrence of the bays in this district, the sands are referred to as bay sands. Although deposits are very limited in volume, there are some localities in which exceptionally high-grade sand occurs. One of the most outstanding sands is that classified by the United States Soil Conservation Service as the St. Lucie. This white sand forms low circular rims around parts of the bays and irregular mounds and ridges along some of the rivers. Deposits show no prominent structures although small irregular areas of brown to tan sand are often completely surrounded by the white sand. The St. Lucie is considered to be Pleistocene in age and to have formed from underlying tan Norfolk sands by wind or a combination of wind and water action.

In the Wilmington district the high-silica sands have accumulated as large dunes and are quite uniform in size and mineral content. Although many of the dunes along the immediate coast contain considerable amounts of calcareous materials, those inland are relatively free from such impurities. Underlying the sands between the Cape Fear and Northeast Cape Fear Rivers is a series of brown sands and small gravels which may be Cretaceous in age. The large dunes were formed probably in late Pleistocene time and represent reworked phases of the underlying formations.

Sandhills District

The Sandhills region comprises the most important source of silica sand in the State. Lying along the western border of the Coastal Plain, it is accessible to markets by rail and highway. The principal production is from deposits near Lilesville in Anson County, between Raeford and Aberdeen in Hoke County, and between Aberdeen and Eagle Springs in Moore County. Most of the sand is sold for general construction and filler purposes, but some very pure silica materials are produced for special uses.

The highest quality sand occurs as unconsolidated surficial deposits from 5 to more than 20 feet deep and overlies a series of relatively impure sands, clayey sands, and gravels. These upper sands are residual, apparently having been derived as a result of the removal of clay and other minerals from the original sediments by downward percolating waters or other agents. They consist principally of very clean sand with little or no gravel being present. Structures are not common within individual deposits, but occasional thin, discontinuous, relatively parallel, dark streaks of clayey sand are present in most of the sand pits. These layers or streaks are horizontal generally and are usually less than 2 inches thick and 10 inches long. They consist of small amounts of dark brown clay, binding an otherwise incoherent sand. The deposits are best developed along the low rolling hills and ridges which form the principal uplands in the area.

The sand is rather uniform throughout most of the Sandhills district. It is light tan to pale yellow, fine- to medium-grained, and generally subangular. In most deposits it is quite clean, although very thin films of clay and iron oxide sometimes coat individual grains. Analyses of typical sands from five localities in the Sandhills averaged 97.1 percent SiO_2, 1.8 percent Al_2O_3, 0.25 percent Fe_2O_3, 0.06 percent CaO+MgO, and 0.67 percent ignition loss. After a preliminary wash with water, two of the sands representing mine-run material analyzed 98.5 percent SiO_2, 1.25 percent Al_2O_3, 0.25 percent Fe_2O_3. The principal impurities include mica, clay minerals, kyanite, tourmaline, epidote, anatase(?), zircon, augite, hornblende, hematite, and magnetite. With the exception of the clay minerals and limonite, most of the impurities occur as relatively free grains. More than 45 percent of the total iron content consists of these small mineral grains, the remainder occurring as surface staining on quartz. Some of the iron-bearing minerals are included in quartz grains.

Although differences occur locally most of the sand grains are subrounded and more than 80 percent are between 0.8 mm. (20 mesh) and 0.175 mm. (80 mesh). A general indication of size distribution is given in the following screen analyses:

Screen Analyses of Sands from the Sandhills Area

Location	Percent Retained on Mesh							
	20	28	35	48	60	80	100	150
Near Aberdeen	9.4	15.6	22.4	20.5	7.5	10.1	7.5	1.6
Near Lilesville	1.9	6.3	20.8	23.8	21.9	17.3	8.1	6.5

Underlying these surficial sands and in places appearing to grade into them is a series of multicolored sands, gravels, and sandy clays. This formation has pronounced cross-bedding, contains considerable gravel, and ranges in color from white through brown to red and purple. Mica is relatively abundant, and lenses of white to pink clay and sandy clay are common. Although the surficial sands appear to grade into the material below, there is a rather obvious lack of clay lenses, gravels, cross-bedding, and other structures in them. The transition zone between the two is often very narrow, sometimes being marked by a pink to brown clayey sand or thin layer of small gravel.

In eastern Anson County, approximately 2 miles southeast of Lilesville, important deposits of gravels are concentrated in the underlying formation which extends over an area of several square miles. The sediments are at the top of a well dissected upland adjacent to the valley of the Pee Dee River and rest directly upon crystalline rocks. Sands and gravels are present at upper levels along both sides of the river valley, but those of commercial importance appear to be restricted to the western side. Deposits are from 10 to more than 30 feet deep and consist of interlayered lenses of well rounded quartz gravels, light tan to brown clayey sands, and multicolored clays. Cross-bedding is pronounced. Individual gravel lenses seldom exceed more than 10 feet in thickness but often are continuous laterally over wide areas. Where exposed by mining, the gravels appear as a series of discontinuous layers, and two or more such layers are present in most pits. These deposits constitute the largest known occurrences of high-quality silica gravels in the State and currently are being mined on a large scale. Chemical analyses of 4 washed samples taken from commercial stockpiles are, as follows:

Sample	SiO_2	Al_2O_3	Fe_2O_3
1	98.4	1.02	0.17
2	98.9	0.76	0.13
3	98.8	0.92	0.13
4	98.9	1.08	0.13

Typical Sandhills sand overlies parts of the Lilesville area, and a brown clayey sand occurs associated with or immediately overlying the gravel formations. These sands are also produced commercially. A washed sample taken from a stockpile was light tan in color and contained small amounts of mica, clay, and various dark minerals. It analyzed 98.6 percent SiO_2, 1 percent Al_2O_3, 0.13 percent Fe_2O_3, and 0.20 percent ignition loss. After removal of the heavy minerals by use of tetrabromoethane (sp. gr. 2.96), the iron content was lowered from 0.13 percent to 0.032 percent. The iron distribution in this sample is approximately 75 percent as heavy iron-bearing minerals and 25 percent as oxide stain.

Near Aberdeen, large amounts of high-quality sand are produced from surficial deposits. These deposits occur in the principal upland areas and seldom exceed 15 feet in thickness. Since the sands are marketed without being washed, only the highest grade deposits are worked; however, in one large operation a very sandy phase of the subsurface formation is being mined and blended with the surficial sands. Although such blending is satisfactory for most general uses, it is doubtful that the underlying materials could be used for high-silica purposes. Tests on samples from the upper sands show that approximately 50 percent of the iron content is present as stain and the remaining 50 percent, as heavy minerals.

The surficial sands in the Sandhills area have been mined for years, and there are indications that sizable reserves remain, however no estimate of potential reserves can be made without considerable test drilling. The iron content of the sands is excessive, and beneficiation will be necessary to bring it within tolerances. Treatment must allow for both iron coating on the quartz and that occurring in individual mineral grains. A 1500-pound sample of typical surficial sand was submitted to the Minerals Research Laboratory in Asheville to determine its amenability to beneficiation.

Bay Sand District

Deposits of tan and white quartz sands occur sporadically throughout parts of Hoke, Cumberland, Robeson, Bladen, and Columbus Counties. Much of the surface in this area is covered by tan to brown Norfolk sands, which are quite thin in most areas and appear to vary considerably in purity. The largest concentrations of high-silica sands are in Bladen and Columbus

Counties. Here, they occur as low rims around parts of many of the shallow oval bays and as rather irregular deposits adjacent to some of the rivers and streams.

This sand, known as the St. Lucie, is quite limited in areal extent. Concentrations seldom exceed 10 feet in thickness, most being less than 5 feet. It is exceptionally white, medium grained, and relatively subrounded. Its color appears to have resulted from the removal of surficial iron stains by downward percolating ground water, since it becomes tan to brown in color at or near the local water table. Particle sizes range from 2 mm. to 0.125 mm., most of the grains being between 0.8 mm. and 0.115 mm. Impurities, chiefly dark minerals, constitute about 1 percent of the sand and are most prevalent in sizes below 0.25 mm.

The largest known deposit lies along the eastern edge of the Lumber River in Columbus County, approximately 9 miles northeast of Chadbourn and 4.5 miles north of Fair Bluff. It consists of a series of low ridges and mounds which cover areas as much as 500 feet wide and 2,500 feet long. The deposit occurs intermittently over a distance of about 3 miles. A series of auger holes showed the sand to range from 1 to about 10 feet deep and to average from 3 to 5 feet. The white sand grades into a light tan sand near the water table, and a considerable amount of organic material is concentrated at this level. The nature of the sand below the water table is unknown, but it is not expected to differ appreciably except to increase in iron content.

Chemical and screen analyses of the white sand are given below. Sample No. 1 is a composite from 5 locations in the deposit. Sample No. 2 represents the whitest material observed, and Sample No. 3 is organically stained sand from near the water table.

Chemical Analysis

Sample No.	SiO_2	Al_2O_3	Fe_2O_3	Ignition Loss
1	98.9	0.58	0.15	0.19
2	99.1	0.45	0.14	0.11
3	98.8	0.50	0.17	0.48

Screen Analysis

Sample No.	Percent Retained on Mesh							
	20	28	35	48	60	80	100	150
2	4.0	12.2	26.7	33.0	11.9	9.7	1.9	0.5
3	6.8	15.2	25.0	27.9	11.5	9.7	2.5	1.0

It is evident from chemical analyses that most of the iron contamination in the upper sand is in the form of dark minerals, since little or no surface stain is present. A heavy-mineral separation, using tetrabromoethane (sp. gr. 2.96), indicated that about 1 percent of the total sand is in the form of heavy minerals.

Another sizable occurrence of white sand is along the northeastern side of Singletary Lake in Bladen County, 8 miles southeast of Elizabethtown. This deposit is relatively thin, seldom being more than 5 feet deep. It extends for several thousand feet and ranges from less than 100 feet to more than 500 feet wide. A composite of 5 unwashed samples taken throughout the deposit analyzed 95.6 percent SiO_2, 1.2 percent Al_2O_3, 0.2 percent Fe_2O_3, and 2.6 percent ignition loss. Much of the alumina is present as clay and can be removed by washing. Ignition loss is due largely to small bits of charcoal and other similar organic materials.

These bay sands are of considerable geologic interest. Their volume, however, is so restricted that large-scale commercial development does not appear feasible in most instances. The best possibility appears to be the

Lumber River occurrence, but the depth to which this sand extends below the present water table must be determined before it can be appraised accurately.

Wilmington District

In New Hanover County there are two principal localities in which large volumes of sand occur. One lies between the Cape Fear River and U.S. Highway 421, south of Wilmington, and the other is located between the Cape Fear and Northeast Cape Fear Rivers, northwest of Wilmington. Sands in both locations constitute old dune deposits and are quite similar in physical and chemical properties.

The area south of Wilmington extends southeastward from near the city limits to Carolina Beach. Most of the deposits lie west of U.S. Highway 421 and are well exposed along the river road from the Wilmington Shipyards southward to the Inland Coastal Waterway. Although this zone is intersected by several streams and tidal marsh basins, sizable volumes of sands are present along interstream divides. Deposits consist of low rounded hills and ridges from 10 to 30 feet high. The sand is medium- to coarse-grained and is subangular to subrounded. It is very white near the surface but grades rapidly to a light tan at shallow depths. Little or no clay minerals are present. A washed sample of typical sand from this locality analyzed 97.25 percent SiO_2, 1.31 percent Al_2O_3, 0.10 percent Fe_2O_3, and 0.26 percent ignition loss. It is estimated that approximately 50 percent of the iron impurities are in the form of dark minerals.

Large deposits of dune sand occur approximately 3 miles northwest of Wilmington. They lie between the Cape Fear and Northeast Cape Fear Rivers and extend northwestward from Swift and Company's fertilizer plant for about 6 miles. The area ranges from one-half mile to 1.5 miles wide and is crossed by U.S. Highway 421 and the Atlantic Coast Line Railroad.

Deposits consist of old dunes ranging from 5 to 25 feet high. Recent borings for foundations indicate that the sand extends approximately 20 feet below the general land surface. The quality of this sand is yet to be proved. There are indications that these underlying sands may represent older geologic formations and be of a lower quality than that in the surficial deposits. The dunes in this area are covered by light growths of pine, scrub oak, and wire grass. Overburden is estimated at about 2 feet and consists principally of organic matter.

Except for a thin white layer near the surface, the sand is light tan and contains little visible clay. After being washed with water, a sample of typical sand analyzed 98.6 percent SiO_2, 0.79 percent Al_2O_3, 0.18 percent Fe_2O_3, 0.07 percent TiO_2, and 0.40 percent ignition loss. Most of the impurities occur as small mineral grains and include ilmenite, zircon, tourmaline, anatase(?), and magnetite. It is estimated that between 40 percent and 50 percent of the total iron content is concentrated in these minerals, the remainder occurring as oxide stainings on the quartz.

The sands are generally medium-grained, approximately 95 percent of the particles being between 0.8 mm. and 0.175 mm. in diameter. Small concentrations of coarser quartz occur locally, but in most instances the sand is relatively uniform in size. Individual grains are frosted very lightly and are more angular than those in samples of sands from other areas to the northwest. The general distribution of particle sizes is shown in the following screen analysis of a composite sample which was taken throughout the area.

Screen Analysis of Sand from Area North of Wilmington

Percent Retained on Mesh							
20	28	35	48	60	80	100	150
44	12.6	21.3	33.5	11.5	10.9	4.2	1.2

In the area north of Wilmington, it is estimated that there are more than 20 million tons of sand within easy access to rail and highway transportation facilities. If this sand is to meet high-silica specifications, the iron-bearing minerals must be removed. A 1000-pound sample of typical sand was sent to the Minerals Research Laboratory in Asheville for iron-removal treatment. Results of this testwork are presented in the section of this report on beneficiation.

Other Areas

In addition to those occurring in the three principal districts, deposits of silica sand are widespread in the Coastal Plain region. Most of them, however, are too small or are located unfavorably for large-scale development.

Sands on the Outer Banks: Some of the more important occurrences of sand are as dunes along the Outer Banks. These deposits constitute sizable reserves of silica sand but are not well located with respect to market areas. Samples were taken from the large dunes at Nags Head in Dare County and from near Fort Macon in Carteret County. Chemical and screen analyses of the samples collected are, as follows:

Chemical Analysis

Location	SiO_2	Al_2O_3	Fe_2O_3	Ignition Loss
Nags Head	94.5	2.3	0.60	0.24
Fort Macon	94.6	2.3	0.70	0.85

Screen Analysis

Location	Percent Retained on Mesh				
	35	48	80	100	200
Nags Head	17.44	14.26	46.38	15.38	6.37
Fort Macon	2.75	24.50	56.89	11.56	4.25

Impurities include small amounts of sea shell fragments, sericite, ilmenite, rutile, zircon, titanite, tourmaline, garnet, and epidote. Most of the sand is stained by iron oxides.

Deposits near Goldsboro, Wayne County: Approximately 3 miles south of Goldsboro, deposits of light tan sand have been worked for many years and sold for general construction purposes. These sands, although comparing favorably with other sands in iron content, are quite high in alumina. In addition to iron stain, impurities include feldspar, tourmaline, zircon, epidote, titanite, ilmenite, and magnetite. Chemical and screen analyses of the samples collected are, as follows:

Chemical Analysis

Location	SiO_2	Al_2O_3	Fe_2O_3	CaO+MgO	Ignition Loss
3 miles south of Goldsboro	95.1	3.4	0.35	0.09	0.49
5 miles south of Goldsboro	96.0	3.2	0.25	0.08	0.36

Screen Analysis

Location	Percent Retained on Mesh				
	35	48	80	100	200
3 mi. south of Goldsboro	56.5	29.6	10.7	1.6	0.7
5 mi. south of Goldsboro	78.7	12.8	6.2	1.4	0.6

Fayetteville Area: Approximately 8 miles southeast of Fayetteville, large amounts of a brown sand and gravel are produced from deposits adjacent to the Cape Fear River. Deposits vary in quantity and quality. A picked sample of sand analyzed 97 percent SiO_2, 1.5 percent Al_2O_3, 0.29 percent Fe_2O_3, 0.1 percent CaO+MgO, and 0.32 percent ignition loss. The screen analysis is:

Percent Retained on Mesh				
35	48	80	100	200
68.3	23.2	7.2	0.8	0.3

Spruce Pine District: A potential source of high-silica sands is in the Spruce Pine district of Mitchell and Yancey Counties. Within this area feldspar flotation and kaolin recovery plants produce several thousand tons of crystalline quartz sands each month as tailings. Some of the sand is upgraded and sold to pottery and other industries in nearby states. Much of it, however, is not sold and is discarded along with garnet, biotite, and other impurities associated with the feldspar and kaolin. Most of the sand is ground to pass 20 mesh (0.8 mm.). It is of excellent quality and is quite free from surface stain. A sample of quartz tailings from one of the feldspar flotation plants analyzed 96.4 percent SiO_2, 2.4 percent Al_2O_3, and 0.06 percent Fe_2O_3. Batch flotation tests on samples averaging about 95 percent SiO_2 and 0.06 percent Fe_2O_3 produced a sand containing 99 percent SiO_2 and 0.015 percent Fe_2O_3 which represented approximately 80 percent of the original feed. Although the volume and availability of the sand depend upon feldspar and kaolin production, the outlook for a continuous steady supply appears favorable.

General Appraisal

Few sands in North Carolina are of sufficient purity to be considered as potential glass sands without first being subjected to some type or treatment. The degree to which a sand can be treated profitably depends not only upon the amenability of the sand to beneficiation but also upon its location with respect to market areas, transportation, cheap fuel supplies, and other competitive sands in the area.

The byproduct sands of the Spruce Pine district are potentially important high-silica materials if suitable markets can be developed within economic hauling distances. Although some of the bay sands approach specifications, their geographic location and lack of volume are determining factors in considering them for large-scale commercial development. The largest reserves of silica sands are in the Sandhills and Wilmington districts, and their development as high-silica materials will depend upon the economic removal of impurities and accessibility of deposits to markets. Sands along the Outer Banks will require considerable processing, and their location is unfavorable to inland markets.

In order to appraise a sand and to evolve the proper beneficiation process, it is necessary to determine the nature of the sand, distribution of iron, and mineralogical classification of all impurities. For general commercial considerations, the sands of the southern Coastal Plain are quite similar physically. Most of them contain only small amounts of clay, which can be removed readily by washing. The distribution of grain sizes is within the range preferred for glass sands. Iron, however, is excessive, and its removal constitutes a major economic problem.

Preliminary tests show the iron to be present as oxide stains, as heavy minerals in individual grains, and as heavy minerals included in particles of quartz. In most instances surface stains can be removed by washing and scrubbing, but heavy-mineral separation requires special treatment. In the Sandhills and Wilmington sands, iron stain accounts for from 30 percent to 50 percent of the total iron, and heavy minerals, from 50 percent to 70 percent. Locked grains (heavy minerals included in quartz grains) are not excessive but appear more prevalent in the dune sands. Small amounts of zircon, kyanite, and other refractory minerals are present and must be removed.

To determine the amenability of the Coastal Plain quartz sands to beneficiation, two large samples were taken from deposits representing sizable reserves. Sample A was collected from a deposit in New Hanover County, 3 miles north of Wilmington. The sample was taken from road cuts along U.S. Highway 421 over a distance of approximately 2 miles and is representative of material to a depth of 15 feet. Sample B is typical Sandhills sand from Moore and Hoke Counties and is a composite sample from two commercial sand pits, one near Aberdeen and the other near Eagle Springs. This sample is representative of the upper sands in the Sandhills area and was taken to depths of about 12 feet. Both samples were submitted to the Minerals Research Laboratory in Asheville for evaluation.

BENEFICIATION TESTS ON COASTAL PLAIN SANDS

This work was under the supervision of Mason K. Banks, chief engineer of the Minerals Research Laboratory in Asheville, and was performed by Walter G. Wells and Philip N. Sales, members of the laboratory staff employed by the North Carolina Department of Conservation and Development.

Evaluation Procedure

Two large samples of sand were delivered to the Minerals Research Laboratory by the Assistant State Geologist. Sample A was from near Wilmington, New Hanover County, and Sample B was a composite sample from localities in

Moore and Hoke Counties. A small representative portion was cut from each of the large samples for use during preliminary investigations. After being thoroughly dried at 100° C., the representative samples were cut into smaller fractions for chemical analysis, screen analysis, and batch testwork. The chemical and screen analyses of the sands as obtained from the field are:

Chemical Analysis

Sample	SiO_2	Al_2O_3	Fe_2O_3	CaO+MgO	TiO_2	Ignition Loss
A	98.6	0.79	0.18	Nil	0.07	0.04
B	96.5	2.30	0.35	Nil	0.26	0.66

Screen Analysis

	Sample A			Sample B		
Size	Wt.	Cum. Wt.	Fe_2O_3	Wt.	Cum. Wt.	Fe_2O_3
+20	4.4	4.4	0.37	9.4	9.4	0.17
-20+28	12.6	17.0	0.18	15.6	25.0	0.21
-28+35	21.3	38.3	0.15	22.4	47.4	0.25
-35+48	33.5	71.8	0.11	20.5	67.9	0.25
-48+60	11.5	83.3	0.16	7.5	75.4	0.29
-60+80	10.9	94.2	0.19	10.1	85.5	0.31
-80+100	4.2	98.4	0.44	7.5	93.0	0.47
-100+150	1.2	99.6	0.86	1.6	94.6	0.62
-150	0.5	100.1	1.20	5.3	99.9	1.10
	100.1			99.9		

Since the iron and alumina contents of these sands restrict their possible use to the lower grades of glass, beneficiation efforts were directed toward removal of these impurities. Examination of the sands under the binocular microscope showed that most of the individual quartz grains were covered by very thin coatings of iron oxide and clay and that numerous grains of dark minerals were present. The dark fraction consisted of ilmenite, magnetite, tourmaline, garnet, kyanite, rutile, anatase, epidote, and minor amounts of other minerals.

Scrubbing Tests

The iron-bearing, clay-like surface coating is removed most commonly by attrition scrubbing and washing. A representative fraction from each sample was scrubbed for 5 minutes at 70 percent solids with 1 pound of caustic (Sample A) and 5 pounds of caustic (Sample B) per ton of sand. After scrubbing, the samples were washed several times in clear water and dried. Chemical analysis of the two scrubbed samples follows:

Sample	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	Ignition Loss
A	98.60	0.80	0.13	0.07	0.15
B	97.90	1.40	0.17	-	-

As shown by the above analysis, scrubbing tests alone were not completely successful in lowering the iron and alumina contents of either sample. However, by removing the clay-like surface coating, scrubbing did lower the iron and alumina by nearly 50 percent in the Sandhills sand, Sample B, and by 25 percent in the Wilmington sand, Sample A. A microscopic inspection of the scrubbed sands revealed that the dark heavy minerals were present in sufficient quantity to affect vitally the iron content.

Heavy-mineral Determinations

To determine the extent of contamination by these heavy minerals, portions of each scrubbed sample were placed in tetrabromoethane (sp. gr. 2.96), and quartz sand that floated was washed, dried, and analyzed for iron. The iron analysis of the scrubbed sand with and without the heavy minerals was:

Sample	Percent Fe_2O_3 With Heavies	Percent Fe_2O_3 Without Heavies
A	0.13	0.05
B	0.17	0.06

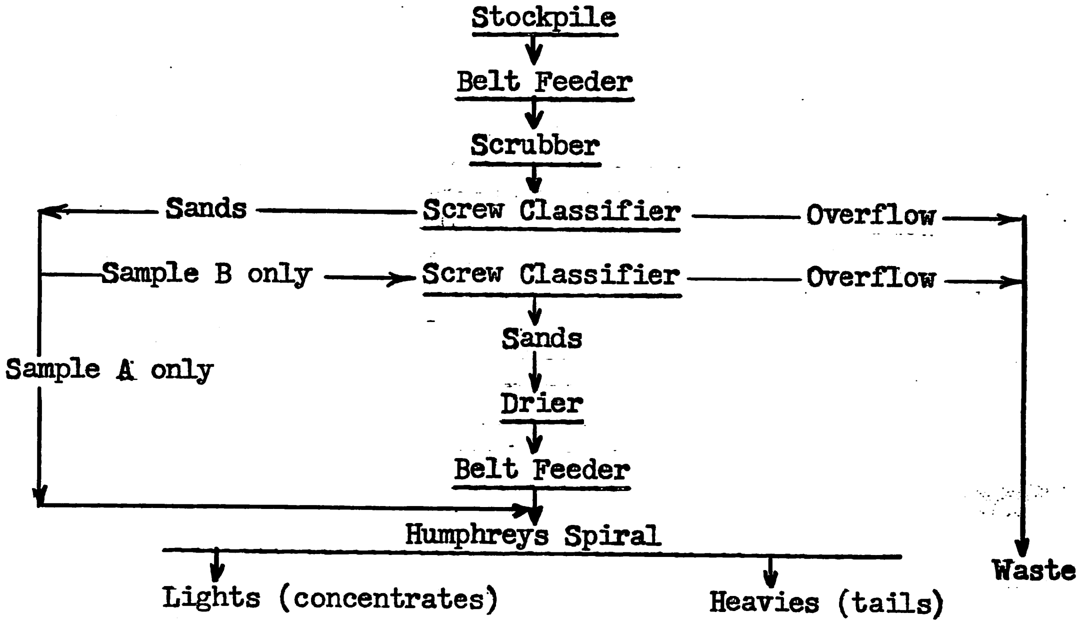
These results indicate that the heavy minerals account for at least 62 percent of the iron in the scrubbed portion of Sample A and 65 percent in scrubbed Sample B. The calculated percentage distribution of the total iron content of the original unscrubbed samples is, as follows:

	Sample A	Sample B
Iron Coatings or Stain	28	51
Heavy Minerals	44	32
Locked Grains (Estimated)	28	17
	100	100

After proper scrubbing and removal of the heavy minerals, the iron content in Sample A was reduced from 0.18 percent to 0.05 percent and in Sample B, from 0.35 percent to 0.06 percent. The remaining iron can probably be traced to locked grains and incomplete removal of surface stain.

Gravity Separation Tests

Since a separation of 72 percent of the iron in Sample A and 83 percent in Sample B was effected by a combination of scrubbing and heavy-liquid treatment in batch tests, a pilot plant was set up to determine whether or not such a separation could be duplicated in a continuous process utilizing scrubbing and gravity units. Included were scrubbers, classifiers, and Humphreys spirals, as shown in the following flowsheet:



As noted in the flowsheet, the sands from Sample A were washed in only one screw classifier before being sent to the spiral. When running Sample B, the flowsheet was cut into two parts. The sand was scrubbed and washed in two classifiers and then dried before feeding to the spiral with a belt feeder. This was necessary because the desired feed rate to the spiral was three times the maximum feed rate to the scrubbers.

The following procedure was followed when running Sample A through the pilot plant. Sand was fed to the scrubbers at the rate of 500 pounds per hour, and caustic was added at the rate of 5 pounds per ton of sand. Scrubbing time was 10 minutes at 70 percent solids. The scrubbed sand was washed one time with clear water and passed over a spiral at 30 percent solids. When running Sample B through the pilot plant, the feed rate to the scrubbers was lowered to 350 pounds per hour. The material was scrubbed 10 minutes at 70 percent solids, and 5 pounds of caustic per ton of sand were added, washed 2 times, and dried. After drying, the belt feeder was used to convey the scrubbed sand to the spiral at a rate of 1,750 pounds per hour at 30 percent solids. The spiral products were dewatered and stored. During the run, small control samples were taken for evaluation. The chemical analysis and distribution of the products are given below:

Chemical Analysis of Pilot Plant Scrubbed Sand

Sample	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	Ignition Loss
A	98.6	0.80	0.14	0.07	0.15
B	97.9	1.40	0.17	0.20	0.23

Distribution of Products

Product	Sample A			Sample B		
	Rate #/hr	% Wt.	% Fe_2O_3	Rate #/hr	% Wt.	% Fe_2O_3
1st Class Overflow	70.0	14.0	-	13.9	4.0	-
1st Class Sand	430.0	86.0	0.13	-	-	0.16
2d Class Overflow	-	-	-	-	-	-
2d Class Sand	-	-	-	-	-	0.16
Spiral Heavies	90.0	21.0	0.12	360.0	21.5	0.30
Spiral Lights	340.0	79.0	0.15	13.20	78.5	0.07

Results of the pilot-plant scrubbing, as shown above, are as good as those obtained when batch scrubbing. This is an important factor, in that it indicates that comparable results can be obtained when working on a large scale.

The failure of the spiral to improve the iron situation on Sample A can be attributed to two factors: First, the feed rate of 500 pounds per hour to the spiral was not sufficient and resulted in a narrow band of material on the spiral that was hard to control; and, second, the fluctuations in the feed rate affected adversely the separation. This, of course, resulted in a variation in the width of the band of material being taken off at each port. Since the heavy iron-bearing minerals were supposed to be taken off at the ports, a fluctuating feed rate caused some of the heavies to be missed part of the time; at other times, the heavies were accompanied by considerable iron-free sand. The sporadic operating conditions and poor results of this test on Sample A prompted changes in the pilot plant for Sample B. After making the changes, the improvement in operating technique gave better results on Sample B. As shown in the tabulated results, the spiral removed approximately 60 percent of the iron left in the sample after scrubbing. This is a fairly close check on results obtained by heavy-liquid determinations on Sample B, in which it was indicated that 65 percent of the iron in the scrubbed sample was due to heavy minerals.

Flotation Tests

Since the iron removal by gravity methods was only partially successful, batch flotation tests were made on the scrubbed portions of Samples A and B. Encouraging results were obtained. In order to eliminate as much error as possible, three tests were made on each sample and results were cross-checked by two operators.

Three 500-gram portions of Sample A were scrubbed 10 minutes at 70 percent solids with 5 pounds per ton caustic, washed two times, and decanted. The scrubbed feed was conditioned 6 minutes at 70 percent solids with 1 pound per ton H_2SO_4, 1 pound per ton ODL (Reagents 801 and 825), and 0.2 of a pound per ton MIBC. The iron minerals were removed as the froth product. Cell tailings were decanted, drained, and dried as the finished sand product. The flotation tests on Sample B were performed under conditions similar to those run on Sample A, except the H_2SO_4 was raised to 2 pounds per ton of feed. Results presented, as follows, are the averages of three tests on each sample:

Sample A

Product	Weight	Al_2O_3	Fe_2O_3	SiO_2	Ignition Loss
Iron Minerals	0.8				
Silica Sand	96.8	0.7	0.037	98.9	0.22
Loss	2.4				
	100.0				
		Sample B			
Iron Minerals	1.6				
Silica Sand	96.7	0.4	0.017	99.3	0.22
Loss	1.7				
	100.0				

Results of these tests indicate that both samples can be brought up to high-grade glass sand specifications by a combination of attrition scrubbing and froth flotation. This method achieved results far superior to the scrubbing and spiralling system. This superiority may be due to the fact that flotation is able to remove some of the locked particles, whereas gravity separation apparently does not. It is also of interest to note that flotation substantially improved the alumina content at the same time it removed the iron. This is due to the fact that the flotation collector used is an excellent collector for the kyanite-sillimanite group as well as for iron minerals.

Evaluation of Testwork

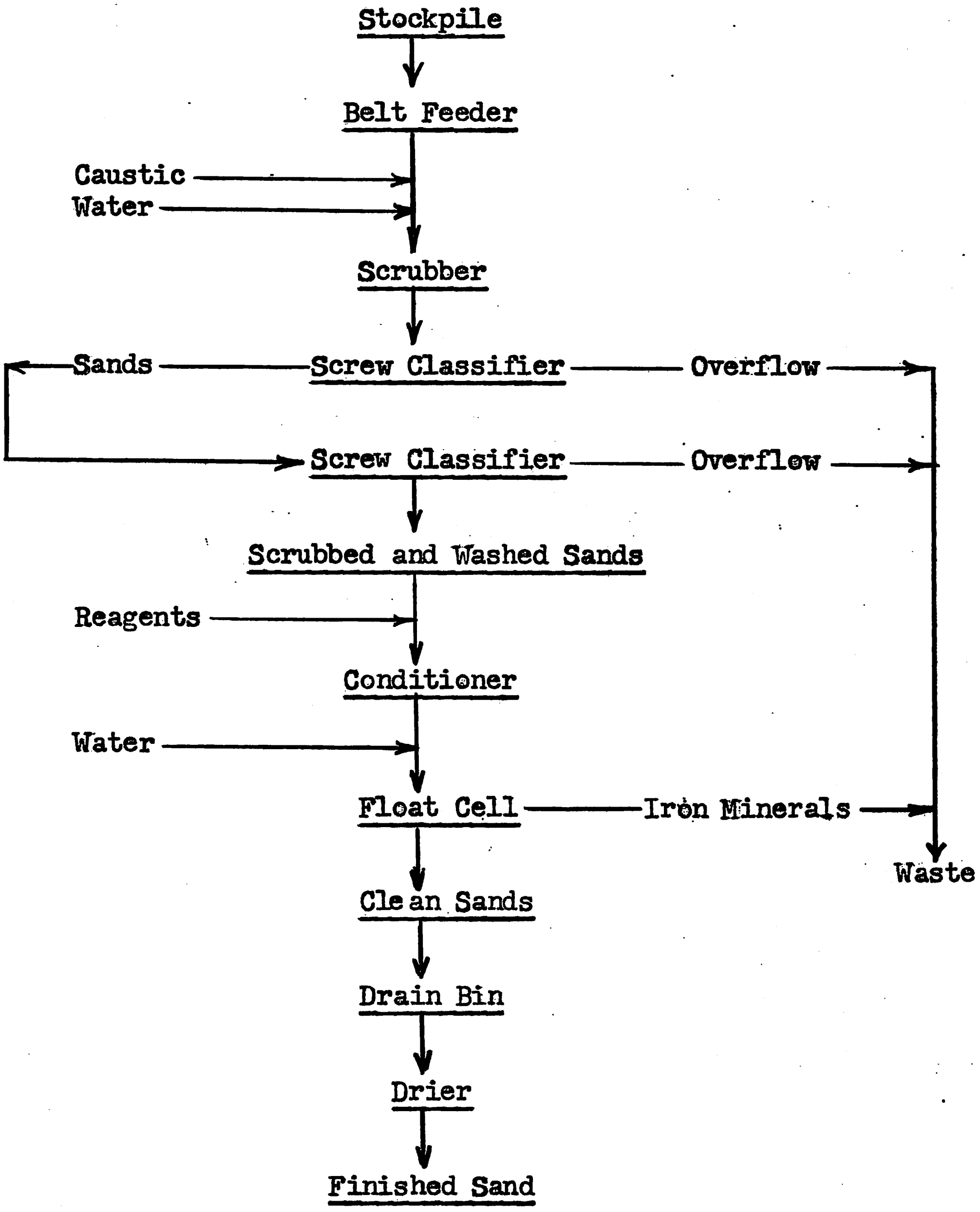
For the purpose of evaluation, the foregoing beneficiation tests are summarized in the following paragraphs:

A substantial part, 30 to 50 percent, of the iron and alumina in the crude sands was present as light coatings of ferruginous clay. The bulk of this coating was successfully removed by attrition scrubbing in the presence of a dispersant followed by decantation washing. This technique was demonstrated in a continuous operation using a feed rate of 300 pounds per hour of crude sand. Duplication of the operation on a commercial scale should present no serious problems. The other major portion, 33 to 45 percent, of the iron and alumina in the crude sands was present in the form of heavy minerals. Attrition scrubbing followed by spiralling for removal of heavy minerals resulted in a recovery of approximately 80 percent of the crude sand with analysis of approximately 0.07 percent Fe_2O_3. While this was a considerable improvement over the original sample, the product obtained could be used only for fifth and sixth grades of glass.

Turning from partially successful gravity methods to froth flotation, it was indicated by batch tests that attrition scrubbing followed by froth flotation for removal of heavy minerals resulted in a recovery of approximately 95 percent of the crude sand with analyses of 0.037

percent Fe_2O_3 for Sample A and 0.017 percent Fe_2O_3 for Sample B. The product obtained will meet second- and third-grade glass specifications. Sample B met first-grade specifications from the standpoint of iron content but had too much alumina to meet fully first-quality requirements.

It is suggested that batch scrubbing and flotation tests be confirmed by a continuous pilot-plant operation. A flowsheet which would place the procedure used on a continuous basis follows:



The following is an estimate of the cost per ton of mining and processing glass sand. These figures are predicated upon the assumption that large-scale production methods would be used with a production rate of 300 to 500 tons of sand per day:

Mining Cost		$0.20
Storage and Feeding		.05
Scrubbing:		
NaOH	$0.20	
Power	.15	.35
Washing		.10
Flotation:		
Reagents	0.20	
Power	.10	.30
Dewatering		.05
Drying		.75
Storage and Loading		.10
Maintenance and Repairs		.20
		$2.10

Recovery represents 95 percent of original feed; therefore, the final operating cost per ton of sand concentrate is estimated at $2.20.

CONCLUSION

The physical, mineralogical, and chemical characteristics of the silica sands in North Carolina compare favorably with and certainly equal those of such sands in other coastal regions of Eastern United States. Their potential use as glass sands lies in the development of suitable markets within North Carolina and adjacent states in order to keep mining, transporting, and processing costs within the limits imposed by profitable economic operation.

Tests conducted prove conclusively that the sands can be beneficiated to meet specifications for high-grade glass by the froth flotation process outlined in the foregoing sections. These sands can be made suitable for the manufacture of a wide variety of glass products at an estimated cost of $2 per ton. The somewhat lower cost gravity process, although not as effective as the flotation process, removed a large portion of the impurities and should not be excluded from consideration if the manufacture of low-grade glass products is contemplated. If local markets can be developed, the saving thus effected in transportation cost can be applied to the processing cost.

The utilization of the silica sands in North Carolina as glass sands is controlled by economic factors beyond the scope of this report. As a raw material, the sands are well within the size distributions desired for making glass and can be beneficiated to meet chemical requirements for high-grade glass sands.

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REFERENCES

1. Broadhurst, Sam D., A general survey of some high silica materials in North Carolina, N. C. Dept. Cons. and Devel. Info. Circular 7, 1948.

2. Burchard, E. F., Glass sand, other sand, and gravel: Mineral Resources of the United States for 1911, pt. 2, pp. 594-5.

3. Shreve, R. N., The Chemical Process Industries, McGraw-Hill Book Co., p. 219, 1945.

4. Industrial Rocks and Minerals, Am. Inst. Min. and Met. Engrs., 2d ed., p. 973, 1949.

5. Mining Engineering, p. 386, March 1950.