GEOLOGIC STUDY of SAND DEPOSITS in the STATE of MICHIGAN

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INTRODUCTION

Industrial sand, also known as quartz or silica sand, has a variety of uses, the most important of which are as molds and cores for metal castings in foundries, and for making glass. A minor amount of industrial sand is used as traction sand (for railroad locomotives), as a propping agent in hydraulic fracturing of oil wells, as an abrasive, and in certain building materials. The requirements and specifications of the foundry and glass making industries vary depending on the exact usage but usually fairly rigid chemical and physical requirements must be met. Only certain select sands can meet these requirements.

Michigan is the nation's leading industrial sand producer. This is due partly to the large number of foundries related to the auto industry in the region. However, it is primarily because Michigan has large deposits of easily mined industrial sand, which meets, or can be relatively cheaply treated to meet, the specifications of the foundry industry, which is by far the largest user of industrial sand. There are a number of types and locations of industrial sand sources In Michigan, the most important being the coastal sand dunes, which occur along or near the shore of Lake Michigan. Because the dune sands are easily mined, and little treatment is necessary, production costs are low. Michigan dune sand is shipped to several other states in - the midwest as well as to Ontario.

Michigan sand producers furnish nearly 50% of the total U.S. consumption of foundry sand as well as a considerable amount of glass sand. In 1974, over 5,000,000 tons of industrial sand were produced In the state. The producers along the Lake Michigan shoreline (see Fig. 1) mine primarily coastal dune sands. The other production is from inland dune sands, glacial outwash sands, ancient beach sands and lake bottom sands (Saginaw Bay).

Because coastal sand dunes constitute a unique geographical and ecological environment, their preservation has recently become an important Issue. As a consequence, the Michigan Legislature passed the "Sand Dune Protection and Management Act, of 1976 to regulate and control coastal dune sand mining. Coastal dune sand, as defined by this act, includes all sands within 2 miles of the shoreline of any of the Great Lakes. This act also required that a study be made of potential sources of industrial sand, which might be developed, as an alternative to coastal dune sands.

The purposes of this study are: (1) to identify non - coastal dune sand deposits In Michigan by 'location, geologic type, and to a lesser extent, quantity and quality; (2) to assess the suitability of selected individual deposits for each of the major industrial uses of sand; (3) to determine on a limited basis the amenability of selected sands to beneficiation in order to meet specifications for various industrial uses; and (4) to formulate recommendations for the continuation of the study by the Geological Survey Division of the Michigan Department of Natural Resources of those areas not covered by the project.

The scope of Phase I of this study includes: (1) a literature search to acquire information relevant to the location, quantity, and quality of Michigan sand deposits, and (2) a broad scale reconnaissance and sampling of sands, other than coastal dune sands, of Michigan consisting of approximately 300 samples from inland dune areas, 200 samples from glacial outwash areas, and 50 samples from friable sandstone occurrences. Also included are pertinent laboratory tests on the sand samples, evaluation of all the acquired information, and recommendations for more selective and detailed work to be undertaken in Phase II of this study.

The literature review, field work, and laboratory work on which this report is based were carried out during the period from May through September, 1978.

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SUMMARY

A reconnaissance study was conducted as the first phase in an evaluation of the potential of inland sand deposits as substitutes for coastal dune sands of Michigan for industrial purposes. The study was conducted from May through September 1978.

A search was made for information relevant to industrial sand uses and to the location and geology of sand deposits in Michigan. Industry specifications were obtained from private and published sources and from a Michigan DNR Survey of dune sand producers and users.

Based largely on the geological and soil information obtained, a state - wide reconnaissance and sampling program was conducted. Over 590 surface samples of sand were collected representing inland dune, glacial outwash, lake bed and friable sandstone types. The samples were analyzed and evaluated as to their suitability for either foundry or glass sands. Relevant field information was recorded for each sample. Laboratory determinations were made of mineralogy, size distribution, AFS clay content, acid demand, and AFS Grain - Fineness Number to evaluate their suitability as foundry sands. Chemical analyses were made of selected sands to determine their potential for glassmaking.

The results indicated that the specifications of many samples fell within the rather broad range of satisfactory specifications as based on available industry sources. It is however, difficult to determine what physical or chemical parameters are really critical for what foundry uses, but considering that this is a search for substitutes for coastal dunes, it appears that inland dune sands •are generally too fine - grained to be satisfactory substitutes. Sandstone deposits, except for the already producing Sylvania formation, are too poorly exposed and too impure to be good glass sand sources. There do appear to be extensive areas in belts of glacial outwash which, based on preliminary data, contain sands which could be suitable substitutes for coastal dune sands.

The pinpointing of individual deposits cannot yet be reasonably done with available information, however, it is possible to select areas where a more detailed investigation is warranted. Nine such areas are identified in this report. The criteria for their selection were: (1) grain - fineness number approximating that of coastal dune sands; (2) acid demand values less than 5.0; (3) clay content less than 2.0; (4) apparent continuity in sand quality and (5) proximity to transportation and existing industrial sand production.

Selection of five areas for the Phase II study will be made by negotiations with the contracting officer.

GEOLOGY

General

During the Pleistocene epoch, continental glaciers repeatedly covered much of North America, reaching as far South as the Ohio and Missouri River valleys. There were at least 4 major glacial advances and retreats across Michigan.

As the ice moved over the surface, it picked up soil and rock particles and scoured and eroded the rock incorporating the debris within the ice. This material was ground up and reduced in size to varying degrees and was deposited at or near the margins of the glaciers as generally unsorted material ranging from clay size particles to boulders. Subsequent transport and sorting by water and/or wind formed various outwash, lake bed, beach, river, or dune deposits which occur on the land surface in Michigan.

The surface deposits and landscape of Michigan were largely formed during and shortly after the retreat of the last major Pleistocene glacial advance. As the last glacier retreated, the moraines and outwash features which we see today were deposited. As the front of the ice sheet retreated slowly northward, the ancestral Great Lakes formed, which at various stages stood at considerably higher, as well as lower levels than the present Great Lakes. At higher water levels, large portions of Michigan were under water resulting in the deposition of lake sediments, beach deposits and near shore wind blown deposits throughout these areas. In places, these deposits were formed many miles inland from the present coastline. The entire Eastern Upper Peninsula, for example, was under water at one time. Figures 1 and 2 show the distribution of lake bed sediments which indicate the parts of Michigan which were under water. The higher lake levels were fairly transitory, whereas the present level of the Great Lakes has remained relatively constant for a relatively much longer period of time.

Sand Deposits

The sand deposits which are believed to have reasonable potential under known current conditions as alternative sources for industrial sand are: (1) inland dunes which developed on ancestral lake sediments, particularly beach deposits; (2) lake sediment or old beach deposits; (3) portions of glacial outwash deposits and (4) near surface friable sandstone deposits which can be considered as partially indurated or cemented equivalents of the unconsolidated surface sands. Figures 1 and 2 show the areal distribution in Michigan of the important unconsolidated sand deposits. It can be seen that the areas of extensive inland dune deposits, most of which are related to old beaches, correspond to the areas which were covered by the ancestral Great Lakes (indicated by lake sediment deposits). Areas of outwash are very extensive, particularly in the northern part of the Lower Peninsula. In addition, sand also occurs within areas classified as moraines on the Surface Geology Map of Michigan (1955 and 1957). A very general map of the distribution of all types of sand in Michigan is shown in Figure 3 and shows just how extensive deposits of sand are in Michigan. It is believed that most glacial sand deposits which occur on moraines are probably too discontinuous and variable to be considered as good sources of industrial sand.

Sandstone outcrops in Michigan occupy a very small area and are not delineated on the map. However, sandstone sample locations indicate some of the places where there are surface exposures of sandstone. The only sandstone presently being utilized is the exceptionally pure friable Sylvania sandstone which outcrops in Wayne and Monroe Counties and is quarried near Rockwood for the manufacture of glass.

REQUIREMENTS AND SPECIFICATIONS

General

There are a number of requirements which sand deposits must meet to be considered potential sources for industrial sands, particularly as substitutes for coastal dune sands. They must meet the prescribed chemical and physical specifications for the particular use. They must be located close enough to the market and to transportation to be competitive with alternate sources. They must be able to be mined and processed economically. Reserves must be adequate to assure a supply which justifies developing the deposit.

Over 95% of the production of Michigan coastal dune sand is used by the foundry and glass manufacturing industries and the vast majority of this is used by foundries. Therefore, only the requirements and specifications of these two industries are considered in this study.

Foundry Sand Specifications [1]

"The heat - resistant nature of quartz (melting point = 1,700^{0}C (3,110^{0}F)) makes silica sand an excellent refractory substance for a number of industrial processes and products. In this capacity, the sand can be used directly as it is found (natural - bonded sand), in a beneficiated or treated state (synthetic - bonded sand) or for the manufacture of silica brick. The more common uses of refractory sand and their specifications are described below.

***Molding sand**. Large tonnages of silica sand are used in iron and steel foundries to make molds and cores for metal castings. Molten metal is poured into a shaped cavity in a block of sand where the metal cools and solidifies. The part of the cavity that forms the external surface of the castings is called the mold. Cores of molded sand may be placed in the mold to form the internal shape and dimensions of the casting. In each application the sand particles are held together by some material called a bond. From 4 to 5 tons of sand are prepared and handled per ton of metal poured.*

Two types of molding sands are distinguished on the basis of the bonding agent. Naturally bonded molding sands are those with a natural content of clay and silt sufficient to give plasticity and strength to the sand when tempered with water. The clay content generally limits the use of these sands to light iron, brass, or bronze castings.

Synthetically bonded sands are artificial mixtures of clean silica sand and a bonding agent such as fireclay or bentonite. Sand with little or no natural bond generally is more refractory than naturally bonded sands and is used in steel foundries, magnesium foundries, and in large grey-iron and malleable-iron foundries where extremely high temperatures are obtained.

The trend today is toward increasing use of synthetically bonded sand, for it can be controlled to offer molding properties that are dependably uniform. Uniformity becomes increasingly important as foundries become more and more mechanized.

***General requirements of molding sands**. The ideal molding sand has been described as "a sand consisting of uniform - sized rounded grains of silica (quartz), each grain evenly coated with the thinnest necessary layer of the most refractory and fattest clay" (Moldenke, 1930, p. 334). A foundry mold must have the ability to withstand the high temperature of molten metal without damage to the surfaces of contact between metal and sand. The required heat resistance varies with the type of metal being cast. For example, steel which melts at about 1510^{0}C (2750^{0}F) requires a much more refractory sand than aluminum alloys which melt at about 650^{0}C (1200^{0}F). Silica sand used for steel casting must consist entirely of quartz grains to be infusible. The coating of* *clay that binds the grains together must be sufficiently low in fluxing ingredients to resist softening or change of shape at least until the metal is fully set. Large castings require a more highly refractory sand than small castings, because of the longer cooling period and the sustained heat to which the sand is exposed.*

Another important requirement is that the finished mold be strong enough to withstand the pressure of the molten metal without yielding. The sand must be adhesive, containing sufficient clay bond to remain intact after being rammed into place about the pattern. On the other hand, the mold must be sufficiently permeable to allow the steam generated on contact of the molten metal with the damp mold surfaces to dissipate quickly. This steam should pass outward through the mold and not through the molten metal. Furthermore, any gases carried in the metal and liberated at the moment of set must be able to pass through the sand. To satisfy these conditions, a molding sand must have the proper grain size and shape relationship.

The mold should leave the casting with a smooth surface. The coarser the grains of silica, the rougher the surface of the casting; however, fine - grained sands do not provide the best venting qualities. A compromise must be made in the selection of a sand.

The quality of castings produced depends largely upon the properties of the sand utilized. To ensure good castings, the sand must satisfy specifications as to (1) refractoriness, (2) bond strength, (3) permeability, (4) grain fineness, and (5) moisture, as discussed below. The properties of typical molding sands used for various types of castings are given in Table 3.

(1) ***Refractoriness****. Quartz (SiO_2) the principal constituent of silica sand, is a highly refractory mineral, the fusion point of which is 1710^0C (3110^0F), well above the pouring temperature for either iron or steel castings. The alkali - bearing minerals are more readily fusible; feldspars, for example, melt at a temperature between 1200^0C (2190^0F) and 1300^0C (2370^0F). Thus, if metal is poured into a mold at a temperature higher than 1300^0C (2370^0F), any feldspar grains present may fuse and permit entry of metal into the mold. Fusion also is encouraged by the presence of micas and iron oxides; consequently, the content of these impurities must be carefully regulated. Lime, soda, and magnesia act as fluxes to reduce the refractoriness of the sand and should be present in three constituents combined being about 2 per cent. Chemical analyses of some foundry sands in common use are given in Table 1.*

The fine - grained silty or clayey bonding material of a molding sand is most susceptible to destruction from sustained heat, for it contains the least refractory and most active fluxing constituents. Thus, for steel casting synthetic sand is generally prepared by adding f ire - clay as a bond to grains of almost pure quartz (more than 98 per cent SiO_2). However, for metals such as aluminum or brass, naturally bonded sands containing feldspars or other low - melting constituents are satisfactory.

Refractoriness is also influenced by grain size, which determines the surface area of the quartz grains exposed to the action of heat and fluxing ingredients. The finer the quartz grains, the more readily are they attacked. For this reason much high temperature fine casting is now done using olivine ((Mg,Fe) SiO_4, zircon ($ZrSiO_4$), or chromite ((Mg,Fe)CO_2O_4) sands because of the superior refractoriness of these minerals over quartz.

(2) ***Bond Strength****. Bond strength of a molding sand depends primarily on the nature of the bonding clay. Kaolinite (such as china clay) gives low to medium bond strength, illite gives medium bond strength, and montmorillonite the highest bond strength. Sodium montmorillonite clays (such as some bentonites) will give nearly double the dry strength of calcium montmorillonite clays; on the other hand, the wet (green) strength of sand with calcium montmorillonite is higher. Although it is desirable to have fairly high green strength (and this is usually a test for the ability of a foundry sand to obtain good "lifts"), sands with very high green strength are hard to ram and may result in swollen castings (Parkes, 1950, p. 12). Bond strength generally is measured and expressed as "green shear strength" and "green compression" in pounds per square inch (Table 2).*

Grain shape also contributes to bond strength of a sand. As a rule, the finer and more angular the sand grains, the greater the bond strength of the sand because of the interlocking of grains. However, permeability is decreased, so that in most cases it is better to depend on the bonding material for cohesiveness.

(3) ***Permeability****. The best permeability is obtained with molding sand in which the grains are both rounded and uniform. Angular - grained sand tends to pack and makes permeability control difficult. Furthermore, if the grains are not of uniform size, small grains may pack between large ones whether they are angular or round, decreasing the porosity and thus impairing the permeability.*

The permeability of molding sands is expressed as an APS permeability number, which refers to the volume of air per minute, under a given pressure, passing through a unit volume of sand.

Finer sands have a lower permeability number because of their smaller and more complex pore systems. Air and gas will pass more easily through large pores, so that, generally, the coarser the sand the higher the permeability (Table 2). On the other hand, the surface finish of a casting is impaired by large pores. Therefore, the selection of a sand usually is a compromise between the desirable venting ability and the surface finish required.

Despite the fact that the highest permeability can be obtained by using a uniformly sized sand, in practice a range of five or six sieve sizes of sand is used to prevent all the grains from reaching the temperature of 573^OC [2] *at the same time during casting. At this temperature, silica undergoes a sudden change in volume, and if all the grains were to expand at the same time, serious "scabbing" may occur at the top of large mold cavities (Parkes, 1950, p. 9).*

Any excess of clay or other bonding material will tend to fill the voids and reduce permeability. The clay content should be sufficient to coat the sand grains but not much as to clog the pores.

*(4) **Grain Fineness**. Grain size or fineness has an important bearing on the physical properties of foundry sand as noted in the foregoing discussion and also in Table 3, which shows variation in properties with texture over a range of size grades of sand. Fineness also is important because of its relationship to the surface finish of castings. The finer the grains, the smoother the work produced, whereas coarse grains in the mold surface allow penetration of metal between grains, thus leaving a rough surface. The highest grade of art castings is made with the finest molding sand. Brass and bronze require fine sands. On heavy castings a fine - grained facing sand is used to give a smooth surface.*

On the other hand, the finer the sand, the poorer the venting, Therefore, the selection of a molding sand is for the finest grain size possible that still allows safe venting of the molds.

To the foundryman, the fineness of foundry sand is a prime indicator of quality and is expressed in terms of a grain fineness number (GFN), which represents approximately the sieve size (in meshes per inch) that would just pass a sand sample if all its grains were of equal size to the weighted average grain size. The GFN is determined in a standard AFS fineness test, which tells the foundryman not only the size of the sand grains and proportions of each size, but also the proportion of clay in the sand (expressed as AFS clay).

AFS clay by definition consists of mineral particles of less than 20 microns diameter, essentially a mixture of clay minerals and fine (quartz) silt. Its determination in the fineness test is by a standard method based on the settling velocities of different particle sizes in a suspension. The GFN is determined by removing AFS clay from a weighed amount of sand, subjecting the sand fraction to standard sieve analysis, and multiplying the percentage of sand retained on each sieve by a factor for that sieve size. The products of the multiplications are then added, and the total divided by the sum of the percentages retained on each sieve. The resulting number is the GFN.

Many foundries use GFN and the percentage AFS clay as the basis for specifying the sand required from producers to maintain uniform properties of sand in the foundry. The GFN by itself does not give much information on the size distribution of grains in the sand, but it is a convenient means of expressing the average grain size. Sieve analyses and corresponding GFN's are given in Table 4 for a variety of foundry sands in common use.

*(5) **Moisture**. The ideal amount of moisture in a molding sand is that just sufficient to yield the necessary plasticity and adhesiveness in order that molding operations can be performed properly without excessive remolding or defective molds. Excess moisture results in the formation of large volumes of steam, which cannot be vented adequately through the sand. Entrapped steam thus produces cavities in the casting.*

Core Sand. Core sand has similar properties to molding sand but is coarser grained and always requires a bond that will bake at the temperature of pouring but will break down easily. Bonding material may consist of linseed oil, cereal flour, resin or some other material that "sets" when it is baked.

The sand should be high in silica and low in. alumina. Well - rounded grains provide the best venting power, but with oil sand cores in which a very small amount of binder is used, angular grains provide better bonding power.

Core sands of three of four sieve sizes in the AFS grain fineness range of 45 - 55 are marketed for iron and steel work. Generally, the most satisfactory particle size distribution is from 30 to 140 mesh with 90 per cent or more lying between 40 and 100 mesh. Table 5 gives grain size analyses of some widely used core sands.

[1] The following discussion of specifications, shown as indented text, is taken from McLaws, 1971, pp. 20 - 26.

[2] The critical temperature for a crystallographic transformation In the mineral quartz, from low temperature α-quartz to high temperature β-quartz .

As part of the "Economic Study of Coastal Sand Dune Mining in Michigan" (1978), the Michigan Department of Natural Resources sent out questionnaires to 4,211 potential users of Michigan dune sand. Some 2,139 responses to the questionnaire were received, of which 135 indicated the use of Michigan dune sand. Of these, 123 indicated foundry use and four indicated glassmaking use. Among the information requested on these questionnaires were the users specifications of industrial sand in regard to the following items: (1) The grain shape; angular, sub-angular, rounded, or no specifications. (2) The grain size distribution, as a percentage of sand retained on U.S. sieve numbers 30, 40, 50, 70, 100, 140, 200, and pan, or no specifications. (3) Critical control limits on impurities as a percent maximum limit of Al_2O_3, CaO, Cr_2O_3, MgO, MnO_2, K_2O, TiO_2, Fe_2O_3, or no impurity specifications.

Compilation of the answers to the above 3 questions are shown in Figures 4, 5, and 6. These results represent a compilation of all foundry users without regard to the specific use of the sand which was not known,and it must be remembered that as a rule, sand for each use must meet more specific chemical and physical requirements than are indicated, some of which are quite rigid. Exact specifications for foundries vary depending on the metal being cast, the size of the casting, the required surface finish and other factors. For example, most steel castings in automobile foundries require a highly refractory sand and very few impurities can be tolerated. For these foundries, coastal dune sands are Ideally suited because of their relatively high quartz content, and coarse grain size as compared with other natural sands. It can be seen from Figure 4 that there appears to be no definite uniform requirement regarding grain shape among the users of Michigan dune sands, This is in conflict with the generally accepted idea that rounded or sub - angular grains are preferable primarily because they allow greater permeability In the casting process. It is believed that the general lack of consensus shown in the user response is probably due to a lack of knowledge of the grain shape on the part of many users. The responses in the "No Specification" category particularly reflect this. Specifications would probably become specific regarding shape if the users began receiving sands which were not rounded enough to work properly.

Grain Shape	No. of Foundries Responding
Round	19
Sub - angular	49
Angular	23
No specifications	41

Figure 4. Results of Michigan DNR Dune Sand User Survey of Grain Shape Specification

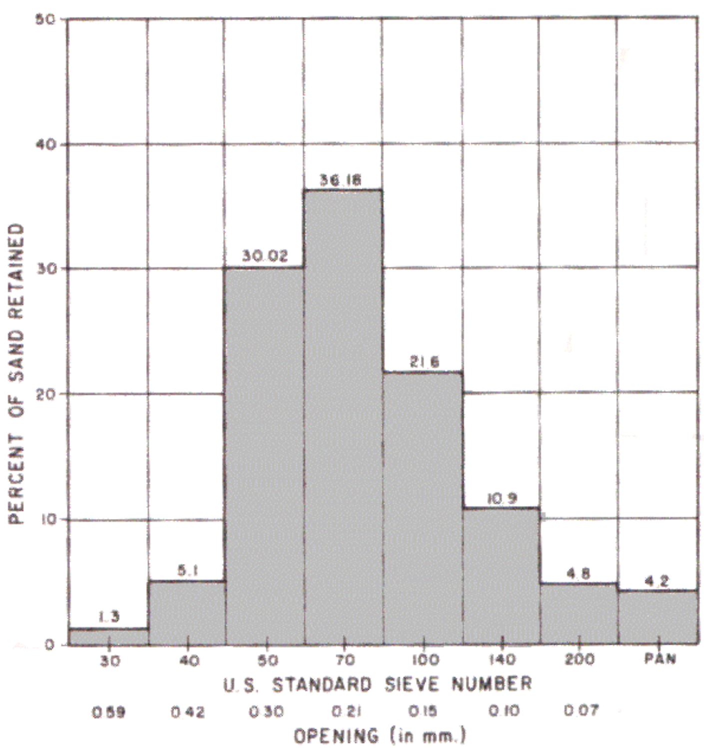


Figure 5 Grain size specifications (see also RI 20 - Economic Study of Michigan's coastal Dunes, 1978)

Glass Sand [3]

"Silica sand is the major raw material for almost all common commercial glasses, comprising 70 to 75 per cent by weight of the furnace batch. Because it forms such a large percentage of the raw materials entering the batch, its chemical quality is of paramount importance. The quality of sand demanded by glass manufacturers depends largely on the type of glass made, e.g., optical, sheet, container, fiberglass, etc. For the better grades of glass the sand must have an extremely high silica content (99 per cent or more) and be essentially free of inclusions, coatings, stains, or accessory detrital heavy minerals. The quality must be guaranteed by the supplier, and uniformity must be maintained.

The most important types of glass in terms of volume and value are the soda - lime - silica glasses. These constitute approximately 95 per cent of the manufactured tonnage. Table I (not in this report) lists the raw materials used to make a typical soda - lime - silica glass, the major constituents supplied by these materials, and the resulting chemical composition of the glass.

The criteria for evaluating a sand deposit as a source of glass sand are chemical composition and grain size, which must meet the chemical and physical specifications discussed below.

Chemical Specifications.

Silica *(SiO_2). Glass sand requires a high silica content, 1 to 100 per cent SiO_2. Any departure from near absolute purity causes trouble and expense to the glassmaker.*

Iron Oxide *(Fe_2O_3). Very small amounts of certain impurities in the sand will lead to tinted or opaque glass. Iron oxide, in the ferric state of oxidation is the most common and most troublesome impurity of this kind, and the glass industry incurs great expense to obtain silica sand sufficiently low in Fe_2O_3. The permissible total iron content, commonly reported as Fe_2O_3 is lowest for optical glass.*

As the need for crystal quality diminishes, as in bottles, plate glass, window glass, and finally in amber and green bottles and colored ware, successively larger amounts of total iron (up to 0.20 per cent) are allowed. Sands for making optical glasses generally have less than 0.008 per cent; colorless containers, e.g., milk bottles, less than 0.04 per cent; and window glass, less than 0.15 per cent.

Although various reagents may be used to neutralize color [4] due to iron oxides, manufacturers of high grade glass prefer, if possible, to start with sand of low iron content, because iron is picked up in other ways during the process (e.g. from other raw materials, crucible walls, ladles, etc.); Moreover, the use of neutralizers causes problems in the manufacturing process; for example, in the making of flint glass, if the Fe_2O_3 content *exceeds 0.02 to 0.25 per cent, decolorizers must be employed which tend to dull the luster of the product.*

Alumina *(AlO). Alumina formerly was considered an objectionable impurity in glass sand, but it is now intentionally added to some glass batches. It gives greater chemical durability, lower coefficient of expansion, and greater freedom from devitrification (crystallization of glass). Too much alumina, however, increases the viscosity of the glass, making it difficult to melt and work, and also decreases the transparency of the glass. For the best grade of flint glass, the alumina should not exceed 0.1 per cent, but for some types of amber glass up to 4 per cent may be tolerated.*

If alumina is present in the sand, its content should be uniform. The form in which it is present also is of great importance; if the alumina is in the form of clay, it is not readily soluble; if in the form of feldspar, however, it is more easily dissolved. Several glass plants in the United States have adjusted glass batches to accommodate feldspathic sands.

Lime *(CaO). Sands containing lime in the form of calcite $CaCO_3$, and dolomite ($CaMq(CO_3)_2$) are to be avoided, for although lime is an important ingredient in many commercial glasses, the calcareous material that is present naturally in sand is generally erratic in its distribution. It is preferable to use lime - free sand and add raw limestone to the batch as required rather than rely on daily analyses for lime content. Lime provides durability of glasses against attack by water and also depresses the melting temperature.*

Magnesia *(MgO). Magnesia is generally present in sands in such small quantities that it causes little trouble in glassmaking. An excessive amount (1 per cent or higher) raises the fusion point of the batch, necessitating extra fuel requirements. MgO is added to some glass batches to improve resistance to devitrification.*

Titanium Dioxide *(TiO_2). TiO_2 content in glass sand generally should be below 0.03 per cent, for it colors glass and Is more difficult to neutralize than iron. However, special glasses high in titanium dioxide are used as glass beads in highway reflective paint because of their high refractive index.*

Minor Contaminants.

Most detrital "Heavy' minerals [5] in sands are undesirable and must be removed or at least reduced to extremely low levels if the sand is to qualify for glassmaking. Minerals such as magnetite (Fe_3O_4) and ilmenite ($FeTiO_3$) are objectionable because of their iron oxide content. Highly refractory minerals such as the alumina silicates (andalusite, sillimanite, kyanite) and the spinel group (spinel, magnetite, chromite) are detrimental because they survive in the melt, giving rise to unsightly "stones" in the product. The sand should be free of mica, which causes spots and holes in the glass.

Secondary mineral coatings and stains on the sand grains also are objectionable; for example, manganese oxide often is associated with trace amounts of cobalt, a powerful blue colorant. As little as 0.0002 per cent cobalt produces a distinct tint in the glass.

One glass manufacturer states in its specifications for glass sand that the weight of heavy minerals of specific gravity greater than 3.0 is not to exceed 0.001 per cent, and also that the weight of coloring oxides other than Fe_2O_3 (e.g., oxides of chromium, manganese, nickel, cobalt, copper) is not to exceed 0.0001 per cent.

Chemical analyses of some typical glass sands used in North America and Europe are given in Table 6. The desired chemical specifications for glass sands of major glass manufacturing firms in Canada are given in Table 7.

Physical Specifications.

Silica sand to be used for glass - making generally should pass a 20 - mesh sieve (0.83 mm) and 95 per cent or more should be retained on a 100 - mesh sieve (0.15 rim). Some manufacturers extend the lower limits to 200 - mesh (0.07 rim). In the midwest and eastern United States, glass producers use silica sand passing a 30 - mesh sieve (0.59 rim) with a maximum of 2 per cent passing a 140 - mesh sieve (0.1 rim) (36). West coast glassmakers have adapted to the finer - grained sand native to that region and have extended their tolerance limit of fines to 2 per cent passing a 200 - mesh sieve.

Excessive fines in the sand are undesirable because they tend to carry impurities, cause dusting, can be partly lost with the flue gases, and are believed to cause foaming in the tanks. Fines also can contribute to small but persistent seeds or blisters in the glass. On the other hand, excessively coarse grains often survive in the melt and cause the formation of harmful batch scum and otherwise lower the quality of the glass. Coarse sand also is more difficult to fuse and tends to decrease the daily throughput of each furnace."

[3] The indented section from Mctaws 1971, pp. 3-12.

[4] In the bottle industry considerable sums of money are spent on decolorizing the glass. The process involves adding arsenous oxide and sodium nitrate to the batch to oxidize the iron, thus minimizing the absorption caused by iron itself, and then adding small amounts of selenium and traces of cobalt to provide a neutral color. Typical additives for decolorizing 1000 pounds of sand are: 5 - 8 grams selenium, 0.5 - 0.8 grams cobalt oxide, 0.5 - 1 pound arsenic (Douglas, 1969, p. 350). These quantities are interdependent and also depend on the amount of iron and organic material in the sand and on the melting conditions. For example, if the concentration of organic material in the sand is high, extra nitrate is added.

[5] Heavy minerals are the minor accessory minerals in sands and sandstones that are marked by a relatively high specific gravity (more than 3.0). Common examples are magnetite, ilmenite, zircon, hornblende, garnet, tourmaline, kyanite and rutile.

The glass sand chemical specifications obtained from the Michigan DNR Sand Consumers Questionnaire are summarized in Figure 7. Physical properties of sand did not appear to be particularly important to the glass manufacturers who responded to the survey, as no particular grain shape or size distributions were specified. It is believed, however, that grain sizes on the extreme ends of the U.S. Standard Sieve Number scale are generally avoided.

The only source of high quality glass sand in Michigan able to meet the specifications is the Sylvania sandstone which is being quarried south of Detroit. However, some fiberglass and amber or green - colored glass can be made from the generally less pure dune sands and some dune sand is used for this purpose.

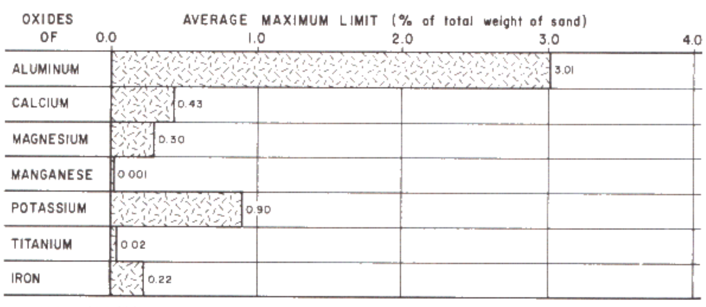


Figure 7 Glass chemical impurities limits

SAMPLING PROGRAM

Site Selection

Sample sites were selected to evaluate 3 general types or categories of potential sand deposits. Approximately 280 samples were selected on inland dune deposits, about the same number from glacial outwash deposits, and 20 samples from friable sandstone deposits. Since Phase I of this study was primarily a reconnaissance study, the most important criteria used in selecting the sampling locations were those which would indicate sand deposits of suitable size and physical and chemical quality rather than geographic, market, ownership or other criteria which will be important in making a more definitive evaluation of industrial sand deposits in Michigan as called for in Phase II.

1. **Inland Dunes**. Extensive sampling of the known areas of sand dunes located more than 2 miles inland from the Great Lakes shorelines was an important objective of this study. This was done because it was believed that these old dune sands resembled the coastal dune sands, and therefore, should be a good potential alternative industrial sand source. The general locations and distribution of inland dunes in Michigan were obtained from the map “Sand Dunes of Michigan”, (Kelly, 1962) and are shown on Figures 1 and 2 of this report. Kelly’s map was compiled largely from information obtained from the United States Department of Agriculture county soil survey maps and from county land use maps. For counties where soil surveys were not available, inland dune areas were located using incomplete geologic maps and manuscripts, air photos, and topographic maps. All of the above information was also used in selecting sample sites for this study, the county soil survey maps being particularly useful.

As a first step in site selection, areas which had extensive concentrations of inland dunes were chosen. Specific sites within these general areas were picked utilizing the county soil maps or land use maps. Dunes or other wind blown sand deposits are recognizable on these maps as represented by a specific soil type which often occurs as a specific “dune - shaped” deposit shown on the maps. Sample sites were picked for representativeness and ease of access for sampling. Because of the short time available for the field program, most sample sites were picked along a road where they could easily be reached by vehicle. In the scope of work section of the contract for this project, eight regions of inland dune occurrences are mentioned. These regions were picked arbitrarily and serve only to provide a breakdown of the data for purposes of evaluation and comparison. In this study, three of these regions in the northern lower peninsula have been combined into two to make a new total of seven regions in the state. The counties which comprise these seven regions are listed in Table 8 and shown on Fig. 3 located in the pocket of the report.

2. **Glacial Outwash**. The selection of outwash sample areas in general, and specific sites in particular were more difficult than the dune sites primarily because of the fact that glacial outwash deposits cover extensive areas in Michigan. In addition, there are other areas which have sand deposits such as glacial lake beds and even glacial moraines which are also potential sources of industrial sands and, for the purposes of this study, are considered and sampled under this category. Figures 1 and 2 show that a large portion of the state is covered by glacial outwash and lake bed deposits. Available criteria used in selecting sample sites in these sand areas were not nearly as definitive as those for picking the dune sample sites. In general, the greatest concentrations of sandy glacial outwash deposits are located in the northern 1/3 to 1/2 of the lower peninsula. This area also contains the greatest concentration of sandy type soils shown on the ‘toil Map of Michigan”(Veatch, 1953) which show a fairly close correspondence to the outwash belts. For this reason, it was decided to concentrate the outwash sampling in this general area. Although there are some large areas of outwash in the western Upper Peninsula, the fact that they are less extensive as well as much farther from the markets for industrial sand was a prime factor in not doing much sampling there. Some outwash samples were taken outside the general area of the northern lower peninsula area to ensure an evaluation of unforeseen possibilities. The location of sample sites relative to outwash and lake beds areas can be seen in Figures 1 and 2.

In the scope of work for this project, it was stated that there was to be reconnaissance done on two glacial outwash regions. After studying the distribution of outwash, it was determined that any breakdown into two regions at this stage would be arbitrary and not meaningful. For comparative and discussion purposes in evaluating the sands later in this report, the data was broken down into the same 7 regions as the inland dunes. For outwash samples, Region 7 was expanded to include the entire Upper Peninsula.

Specific sample sites were selected primarily by trying to spread out the sample distribution somewhat evenly throughout the outwash areas. Where possible, specific sites were chosen with reference to soil types which were known or believed to have developed over sandy parent material. This is not always reliable because often a soil normally considered representative of a “good” sandy sub - soil or parent material can also develop over sub - soils which are gravely or otherwise unsuitable as industrial sands. Also the degree of accuracy, nomenclature, and classification of soils shown on the county soil maps has changed over the years and it was often not possible to correlate soil types among counties. In general, sample sites were chosen in areas which appeared to have the largest areal extent of a favorable soil type within an outwash area. Other criteria, which were used to a very minor extent, included factors such as distance to existing transportation facilities, existing land use in area, and ease of sample access.

Region 1	Region 4	Region 7
Berrien	Cheyboygan	Luce
Van Buren	Presque Isle	Chippewa
Cass	Otsego	Mackinac
Kalamazoo	Montmorency	School craft
Region 2	Crawford	Alger
Ottawa	Alpena	Delta
Muskegon	Oscoda	Menominee
Newaygo	Alcona	Marquette
Oceana	Roscommon	Baraga
Lake	Ogemaw	Houghton
Mason	Iosco	
Osceola	**Region 5**	
Clare	Arenac	
Region 3	Gladwin	
Manistee	Midland	
Wexford	Bay	
Missaukee	Saginaw	
Benzie	Tuscola	
Grand Traverse	Huron	
Kalkaska	**Region 6**	
Leelanau	St. Clair	
Antrim	Macomb	
Charlevoix		
Emmet		

Table 8 Sampling Regions (Counties)

3. **Friable Sandstones**. Surface exposures of sandstone are very limited in Michigan due to the extensive glacial cover, and most of the sandstones which are exposed have not been considered suitable for industrial sand uses. The known exception is the Sylvania sandstone which outcrops in Wayne and Monroe counties and is quarried near Rockwood in Wayne County. This is very pure friable sandstone and is used only in the manufacture of glass.

Sandstone sample locations were selected primarily on the basis of published information as well as the personal knowledge of members of the Michigan DNR, Geological Survey Division who furnished many of the samples. Samples were taken from most of the sandstone formations which crop out in the state and the most important criteria used as a guide was that the rock be exposed at, or very near the surface, be relatively friable, and appear to be composed, at least in places, of material which might have some potential for use as a glass sand.

Sample sites were chosen in Jackson, Eaton, Ionia, Huron, and Wayne Counties in the Lower Peninsula, and Alger and Houghton Counties in the Upper Peninsula. The geological formations represented include the Grand River, Marshall, Coldwater, Jacobsville, Freda, Trempealeau, Munising, and Sylvania. These formations are believed to represent all the exposed sandstones in Michigan which can be considered to have possible potential as glass sands.

Sampling Methods

The final choice of the sample sites was made by the sample collector in the field and was a matter of judgement. Wherever possible the sample was taken just off the roadway, preferably at a road cut. Samples from road cuts were preferred because much or most of the soil layer had been removed there and the sample was more likely to be representative of the underlying parent material.

Most of the samples of unconsolidated sands were taken from between 2 - 5 feet below the ground surface. Many of the samples from road cuts were, therefore, from a considerably greater depth below the original ground surface. To obtain the sample, a hole was dug using a spade and/or a post - hold digger. Approximately 3 - 5 pounds of sample were taken from the bottom of the hole and placed in a polyethylene bag along with a numbered tag. At the time the sample was taken, other observations relevant to the evaluation of the sample were made and recorded on a field information sheet, an example of which is shown in Figure 8. Most of the information recorded on the field sheet was easily obtainable and is believed to be reasonably accurate. However, the depth to water table data was not readily obtainable with any degree of accuracy and the figures recorded were, therefore, only rough estimates.

Sampling methods used to obtain the sandstone samples varied, depending largely on the nature of the outcrop. Sampling techniques included taking chip samples along a quarry or cliff face, spot or grab samples from an outcrop, and grab samples from rubble piles at the base of steep quarry faces. Where obvious variations in the quality of the sandstone were observed, representative samples of the “best” appearing material were collected.

Sample No. ____________________ Date ____________________

Sample Type: __________________ Sampler: ________________

Location: Fr.___Sec.___T.___R.____ Co. ________________

Elevation: ____

Depth of Sample: ______________________________________

Depth to Water Table: _________________________________

Vegetative Cover: (1) Trees, (2) Grasses, (3) Crops, (4) Brush.
(5) Other - ________________

Degree of Drainage: (1) Poor, (2) Moderate, (3) Good

Existing Land Use: (1) Agricultural, (2) Suburban,
(3) No intensive use (4) Other __________________

Available Transportation: RR____(mi) Road_____(mi)

General Topography: (1) Flat - dry, (2) Flat - wet,
(3) Gently Rolling, (4) Rolling, (5) Steep Slopes

Surface Geology: (1) Glacial Outwash, (2) Moraine, (3) Lake Beds, (4) Beaches, (5) Dunes, (6) Till Plain, (7) Bedrock

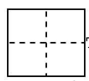
Soil Type: ____

Ownership: (1) State, (2) Federal, (3) Private

Miscellaneous: ____

Notes:

R



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Section

Figure 8. Sample Field Information Sheet

The information shown on the field sheets is largely self - explanatory but a few items may need clarification and are defined as follows: (1) Sam le t e - refers to the 3 major categories of samples; inland glacial outwash and friable sandstone; (2) Elevation - refers to vertical distance above sea level and was taken off the topographic maps; (3) Available transportation - distance from a road; in almost all cases was 0 miles (on road), but the quality and type of road varied; (4) Surface geology - refers to the geology at the site as indicated on the "Maps of the Surface Formation of Michigan"; (5) ~it~ - refers to soil type at the site as shown on the county soil map. Where detailed soil maps were not available, the general soil grouping from the "General Soil Map of Michigan" was used, and (6) Notes - refers to any special information which appeared to be relevant regarding the sample or location.

Results of Field Sampling

The results of the field observations - are shown in Table 9 in the Appendix B.

Discussion of Field Observations

Inland dunes. An examination of Figures 1 and 2 shows the heaviest concentrations of inland dune deposits in 3 very general areas: (1) western lower Michigan, particularly around the Muskegon area (Region 2); (2) the Saginaw Bay area (Region 5); and (3) eastern upper Michigan (Region 7). Although inland dune sands were sampled at other locations, these 3 areas were considered to be the most promising, because of the greater concentration and quantity of sand and sampling was concentrated In these areas.

The inland dune areas are all characterized by having little relief, being moderately to poorly drained, and occurring generally at low elevations. The above features are also consistent with the fact that these same areas were covered after the retreat of the last glacier by the ancestral Great Lakes. The dunes developed along the beaches and lake deposits which formed throughout these areas during the various stages of fluctuating lake levels. None of the inland dunes are as large as the present coastal dunes mainly because the present lake levels have been relatively constant for a much longer period of time than any of the older higher levels. They also appear to form deposits which are not very thick.

Glacial outwash. Only a few conclusions can be drawn from the field observations noted in the glacial outwash areas. Elevations varied considerably and the topography ranged from flat to rolling. In general, the relief in the outwash areas was greater than in the areas of lake and dune deposits, but less than in areas of moraine deposits. The soil types varied depending largely on topography conditions as well as varying accuracies of the soil surveys. As was expected, the observed properties of the samples in the out - wash areas were much more varied than the inland dune samples and ranged from clean fine sand, to sand clay, to "dirty" gravel.

In a number of places, particularly notable in the exposed walls of gravel pits, it was observed that there were considerable horizontal and vertical variations in the grain size and sorting characteristics of the outwash over relatively short distances. Irregular clean sand layers alternated with unsorted gravel in the same pit face. Occasionally a sample hole encountered both gravel and sand layers. It is also very difficult to estimate the extent of the area and thickness represented by individual samples. The above observations suggest that outwash samples taken in a reconnaissance survey such as this may not accurately represent the character of the material in an area. This of course, as well as other factors such as great topographic variations, makes any estimate of the size of potential outwash deposits subject to considerable uncertainty. Generally, the field observations confirmed the enormous overall extent of glacial outwash as indicated on the glacial and soil maps.

Friable sandstones. Most sandstone samples, except for the ones from the Jacobsville and Freda formations were relatively friable. Because of processing costs, the non-friable sandstones can not be considered as suitable for foundry or glass sands and are ruled out on this basis alone.

In all cases the very limited exposures of the friable sandstones would most likely require considerable overburden stripping prior to quarrying which would probably be prohibitively expensive.

If the sandstones were of the right purity, perhaps the premium prices paid for high quality glass sand could cover mining costs in some cases.

LABORATORY STUDIES

General Statement of Treatment

The samples collected in the field were processed using the general treatment flowsheet as shown in Figure 9.

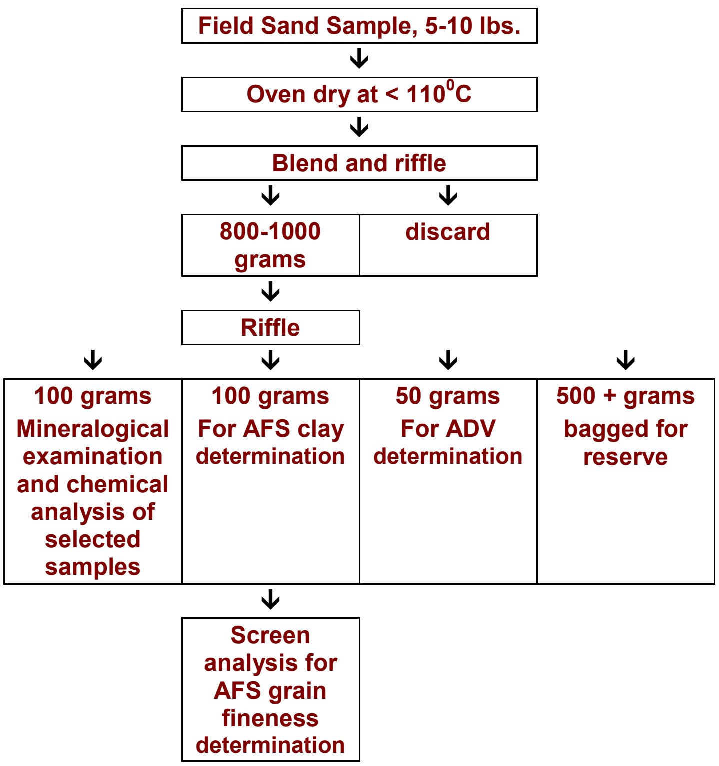

Figure 9 General laboratory treatment flowsheet

Mineralogical Examination

A 100 gram sample was split approximately 5 times or until a desirable sample size was obtained (roughly 3-5 grams). Half of this sample was then used to determine shape, texture and some mineralogy. The remaining two quarters were used to determine calcite arid dolomite content. The following determinations were made:

a. The shape of the sand grains expressed as roundness and sphericity were determined by visual comparison of the sample under a binocular microscope with photographs of Powers' roundness scale (Powers, 1953). This scale has six divisions; very angular, angular, sub-angular, sub-rounded, rounded and well-rounded. Sphericity is shown on Powers' scale as either high or low. An attempt was made in this analysis to choose the shape that best describes the majority of the grains in each sample.

b. Surface texture was classified as dull, polished or coated, and further distinction was made as to whether the grains are smooth, frosted or pitted.

c. Mineralogy was determined insofar as the mineral grains could be easily identified under the binocular microscope. Calcite and dolomite content in each sample were determined by staining methods described in Procedures in Sedimentary Petrology (Carver, 1971). The calcite stain consists of .1 gram Alizarine red S. dissolved in 100 ml of .2% hydrochloric acid. The stain and sample are placed on a watch glass, and calcite is stained bright red within one to two minutes.

The dolomite stain is made by dissolving .2 gram of Alizarine red S. in 25 ml of methanol, then adding 15 ml of 30% NaOH solution. Each sand sample was placed in a small beaker, covered with stain, and boiled for 7 to 10 minutes. The sample was then rinsed until the water became clear, taking care not to pour out the finer-grained material. The dolomite grains stained purple.

Percentage of calcite and dolomite were estimated by comparing the stained sample under a binocular microscope with Shvetsov's diagram for visual estimation of percentages of minerals in rock sections (Shvetsov, 1955).

Lithic fragments, feldspars, biotite, garnet and hornblende were noted only as 'present' if they occurred in a sample. No attempt was made to determine the percentage of each, as all were very minor constituents, could not easily be identified, and often occurred only sporadically.

Magnetite grains were listed as present if they could be removed from the sand sample with a hand magnet.

Figure 10 is an example of the Mineralogical Examination Sheet completed for each sand sample.

Results. The results of the mineralogical studies were tabulated by computer and are shown in Table 10, Appendix B.

Sieve and Clay Analyses

AFS Clay Determination. "AFS Clay is defined as that portion of a foundry sand which, when suspended in water, fails to settle at a rate of one in./min. The AFS clay material is determined by the AFS standard clay test. The AFS clay material consists of clay and material of less than 20 microns (0.02 mm or 0.0008 in.) in diameter. In other words, it is a mixture of true clay and fine silt. The proportions of these can vary in naturally bonded molding sands."

AFS clay determinations were made on each of the crude sand samples collected. Procedures for this determination are described at length in the Mold & Core Test Handbook (2) but are described briefly as follows:

a. An approximate 100 gram representative sample was riffled from the dried parent sample and placed in a 1000 ml Berzelius beaker. To the sample, 475 ml of room temperature, distilled water and 25 ml of a 1.5% solution of tetra sodium pyrophosphate (Na4P207IOHZO) was added.

b. The sand-fluid mixture was then stirred with an electric stirrer for 5 minutes at 1750 rpm.

c. The agitator (stirrer) was then removed from the beaker and the beaker filled to a 900 ml mark with additional distilled water.

d. The material was stirred with a glass rod until most of the solids were in suspension and then allowed to settle for 10 minutes after which the top 5 inches of water and suspended solids were siphoned off.

Sample #	Date
Mineralogist	
SHAPE	
1. Roundness	2. Sphericity
1. Sub-angular 2. Sub-rounded 3. Rounded	1. high 2. low
SURFACE TEXTURE	
3. Appearance	4. Texture
1. dull 2. polished 3. coated	1. smooth 2. frosted 3. pitted
MINERALOGY (non-quartz minerals)	
5. Calcite	6. Dolomite
1. less than 1% 2. 1% 3. 2% 4. 3% 5. greater than 3%	1. less than 1% 2. 1% 3. 2% 4. 3% 5. greater than 3%
7. Lithic fragments	8. Other minerals present
1. present 2. absent	1. magnetite 2. biotite 3. garnet
9. Feldspar	4. hornblende
1. present 2. absent	5. 6.

Figure 10. Sample Mineralogical Examination Sheet

e. The beaker containing sand was then refilled to the 900 ml mark, restirred and allowed to settle for an additional 10 minutes after which the suspended solids were again siphoned off as before.

f. The procedure of filling, stirring with a glass rod and allowing to settle, but for only 5 minutes each time hereafter, was repeated until the water became relatively clear after the 5 minute settling period.

g. The excess water was then poured off, being careful not to lose sand grains and the beaker and contents oven dried between 1040C and 1100C until dry.

h . The dried sand was then weighed and the percent AFS Clay calculated as follows:

AFS Clay Content, ~ = dry starting wt. - dry washed wt. x 100 dry starting wt.

Size of Sample:	100.3 grains
AFS clay content:	0.31 grams or 0.3%
Sand grains	99.99 grams or 99.7%

USA Sieve Series No.	Grams*	Percent*	Multiplier	Product
6	- -	- -	3	- -
12	- -	- -	5	- -
20	0.27	0.27	10	2.7
30	1 .62	1 .62	20	32.4
40	8.96	8.96	30	267.9
50	32.64	32.64	40	1302.0
70.	38.85	38.85	50	1937.0
100	14.83	14.83	70	1035.3
140	2.39	2.39	100	238.0
200	0.37	0.37	140	51.8
270	0.04	0.04	200	8.0
pan	0.02	0.02	300	6.0
total	99.99			4881 .1

* Amount of near 100 gram Sample Retained on Sieve

$$\text{AFS Grain Fineness No.} = \frac{\text{total product}}{\text{total percentage of retained grain}}$$

$$\text{AFS Grain Fineness No.} = \frac{4881\ 1}{99{:}7} = 49.0$$

Figure 11.Typical Results of Screen Analysis and Calculation of AFS Grain Fineness Number

h . The dried sand was then weighed and the percent AFS Clay calculated as follows:

$$\text{AFS Clay Content, \%} = \frac{\text{dry starting wt - dry washed wt.}}{\text{dry starting wt.}} \times 100$$

AFS Grain Fineness No. (GFN). “Grain fineness number is a rapid method for expressing the average grain size of a given sand and is also of value in comparing grades of sand from a given deposit or from deposits having similar grain distribution, or in aiding control of heap or system sand in a foundry. It is also useful in calculating other data relative to foundry sand practice.” (American Foundrymens Society, 1978). It should be emphasized, however, that this number does not give much information regarding the size distribution of the sand grains.

The AFS grain fineness number was determined on each of the sand samples collected by performing a screen analysis on the washed and dried sand residue from the AFS clay wash on each sample.

Procedures for determining the AFS grain fineness numbers for the respective sands are described as follows:

a. The weight of the grains of the various sizes as determined by the screen analysis was expressed as percentages of the original sample.

b. Each of the percentages were then multiplied by a factor, illustrated in a typical calculation presented in Figure 11

c. The products of the multiplications were totaled and this total product divided by the sum of the grain percentages obtained. The result is the AFS grain fineness number. Figure N illustrates data relative to, and a typical calculation of, an AFS grain fineness number.

Acid Demand Value (ADV). When acidic activators used in synthetic bonding materials are added to molding sands containing alkaline substances such as calcium carbonate, a portion of the catalyst or activator is no longer available for complete satisfaction of the programmed resin-catalyst reaction. Therefore it is important that the presence of these alkaline reacting materials be measured so that uniformity and formulation control may be achieved. The acid demand value and assigned number has been recommended not as a direct value, but as an indicator (Mold & Core Test Handbook, 1978).

The procedure for determining the acid demand value of the sands tested was as follows:

a. Fifty (50.0) grams of sand were placed into a 400 ml beaker.
b. Fifty (50.0) ml of distilled water were added to the sand.
c. Fifty (50.0) ml of N/10 HCl were added to the sand.
d. The above mixture of sand, water, and acid was stirred continuously for fifteen (15) minutes.

e. After stirring, the water-acid mixture was decanted and filtered with the sand being washed with five l0-ml portions of distilled water, This wash water was added to the filtrate.

f. The filtrate was titrated with standard N/l0~sodium hydroxide to a phenolphthalein endpoint.

g. Acid demand of the sand was calculated as follows:

Let X equal ml of 0.1 N HCl
Y equal ml of 0.1 N NaOH
Acid Demand = X - V

Results. The laboratory tests described above were performed on approximately 590 samples collected during the field sampling program. The results of the tests were tabulated by computer and are shown on Table 11, Appendix B.

Chemical Analysis (Glass Sands)

Eighteen samples, thirteen of which were sandstones, were selected for quantitative chemical analyses to determine their potential as glass sands. Since the costs of mining bedrock sandstones is almost certainly prohibitively high for foundry sands, they can only be realistically considered for the higher price, high quality glass sands. Of the sandstone formations sampled, only the Freda in Houghton County was not analyzed because it was not friable and visual examination indicated that it had no potential value as a glass sand. Five of the samples analyzed represented inland dune samples which looked to represent a fairly clean uniform sand and thus have some potential as a glass sand, at least for colored glass.

In preparation for the chemical analysis, all glassware and crucibles were cleaned with hot nitric acid in preparation for the analyses.

Samples of 1.0 gram were weighed, then digested in a mixture of nitric and hydrochloric acids. After digestion the samples were then filtered into 250 ml volumetric flasks. The residues were placed in platinum crucibles and ignited in an electric muffle. The ignited residue were then treated with a few drops of HCl and about 20 ml of hydrofluoric acid. The portions remaining after treatment with HF was dissolved in HCl and added to the original filtrates in the 250 ml flasks. Total volumes were made to 250 ml. Samples were then analyzed for Ca, Mg, Al, Ma, Cr, Co. Fe, Na, and K by atomic absorption spectrometer.

Samples for TiO_2 were weighed, digested with HCL and HNO_3. They were then filtered and the residues were ignited in platinum crucibles. The ignited residues were treated with a few drops of H_2SO_4 and about 20 ml HF. The residues remaining after evaporation of the HF were dissolved with HCL and added to the original filtrates. The pH of the solution was adjusted to just slightly acid and the iron was removed by reducing It to the ferrous state with sodium thiosulfate and acetic acid. The titanium and elemental sulfur were filtered (hot) off and ignited in Vycor crucibles. These residues were then fused with Potassium pyrosulfate, dissolved in 5% H_2S0_4 and 5% H_2O_2. The volumes were made to 100 ml and TiO_2 was determined photometrically.

Results. Table 12 (on page 20) summarizes the results of the chemical analyses of the sands selected for glassmaking potential. It should be noted that the values reported for Cr_2O_3, and most of the values for Co_3O_4 and MnO_2 approach or are at the limits of detectability of the analytical method and may not actually be present in the amount indicated.

DISCUSSION AND EVALUATION OF RESULTS

General Observations

The field and laboratory data were tabulated by computer and were organized by county. Within each county the samples were ranked in order of increasing Grain Fineness Number, the most important single criteria of selection for foundry use.

For each county in which samples were taken, the mean, and standard deviation of the Grain Fineness Number, Acid Demand Values, and the AFS clay contents were calculated. The same statistics were calculated for each of the seven regions discussed earlier and described in Table 8. These statistical results are shown in Tables 13 and 14.

Field Data

Although the field data was not directly utilized in the computer calculation, the data was used as an aid in evaluating the samples. Samples which represent material at a considerable distance from rail transportation were given less consideration than those close to a railroad, other factors being equal. Sands from areas which were not intensively used were considered better prospects than those in or very near urban areas. Although the importance has not been evaluated, the land ownership may also be of importance.

Mineralogy

The mineralogical data was primarily qualitative but served to modify or reinforce the more quantitative laboratory data in evaluating the samples. Some of the data such as determinations of roundness and presence of accessory minerals is difficult to evaluate because of the lack of established industry specifications regarding them.

Other Laboratory Data

The quantitative information obtained including the AFS Grain Fineness Number, the Acid Demand Value, and the AFS Clay Content constituted the primary data used to evaluate the suitability of the sands for foundry uses. The importance of these values is somewhat difficult to judge because of the uncertainty and the range of apparently acceptable specifications for foundry sands.

The Grain Fineness Number is probably the most important parameter determined. It is widely recognized. and foundries commonly have specifications regarding the Grain Fineness Number of the sands which they can use. The GFN of the samples was compared with that of typical coastal dune samples as a means of evaluating them. In the effort to select areas for additional exploration, groupings or clusters of samples with relatively low Grain Fineness Numbers were sought. It is considered significant that, in general, the outwash samples, with an average GFN of 55, are considerably coarser grained than the inland dune samples, with an average GFN of 67. The Inland Dune samples in the northern lower peninsula are coarser grained than those of the Muskegon region which in turn are coarser than those in the general area around Saginaw Bay. Most of the inland dune samples are considerably finer grained than the coastal dune sands although there are a few minor exceptions.

The Acid Demand Values of most of the samples were quite low indicating there would be very little consumption of acid if an acid-activated binding agent were used in the molding process. It should be pointed out, however, that all the samples were taken at, or very near, the ground surface where maximum opportunity for leaching of soluble acid consuming carbonates has occurred. Therefore, the samples may not be representative of a mineable sand deposit. Deeper sampling Is necessary to determine a representative ADV. Outwash samples had an overall average ADV of 3.8 as compared with an ADV of 2.9 for inland dune samples.

The importance of the AFS clay value is difficult to evaluate because of the absence of published specifications. However, in modern foundry practice, clay is clearly undesirable and so the lower the clay content the better the sand. Clay can be removed by screening or washing but this adds to the cost of processing. Other things being equal, the lower the clay content, the better. Overall the clay content was higher in the outwash sands than in the inland dunes but the difference was not appreciable.

Glass Sands

Of the 18 samples which were chemically analyzed to determine their suitability as glass sands, none met the overall specifications for a good quality glass sand. Two of the samples were from the Sylvania formation which is a present source of glass sand. There is some question whether the samples analyzed (Nos. 3-253 and 3-254) are truly representative of the material being shipped from the operation. A problem in evaluating the samples for glass sand potential is that they represent untreated material and it is not known whether they would meet the necessary specifications if they were beneficiated. It is possible that some of the inland dune or outwash sands could, if they were treated, be used for making lower quality colored glass as some coastal dune sands are now being used.

CONCLUSIONS AND RECOMMENDATIONS

The known industry specifications for foundry sands cover a wide range of values, and a large number of the samples collected during this study have Grain Fineness Numbers, size distributions, and Acid Demand Values which fall within this range and would appear to be suitable for foundry sands as far as the preliminary data is concerned. However, the primary purpose of this study is to determine if there are inland sources of sand which could be specifically utilized as alternatives to coastal dune sands. Based on the specifications of coastal dune sands, many samples taken in this survey including almost all the inland dune sands are believed to be too fine grained to be considered as substitutes for coastal dune sands. Many do, however, fall within the higher portions of the known range of acceptable GFN's and may be able to substitute in part for coastal dune sands.

None of the sandstone samples meet the specifications for high quality glass sands and mining costs are too high to justify an operation of this type for lower quality and lower priced sands used in making colored glass. It is possible that, if beneficiated, some of the sandstones such as the Munising formation in Alger County or the Grand River formations in Jackson County may meet specifications, but it is considered unlikely. The very limited exposures of most of these deposits make them difficult to evaluate.

A large number of the outwash samples have a GFN and size distribution which is similar to those of the coastal dune sands. The ADV, although possibly not representative of the material at depth of most of the outwash samples, appears to be satisfactory, and the clay content of almost all samples is satisfactorily low. It Is believed that virtually all samples with a low ADV, low AFS clay content, and a GFN <50 can probably be considered as potential substitutes for coastal dune sands. An examination of the data sheets in the appendix of the report suggests that many of the outwash samples, particularly from throughout most of the northern 1/2 to 1/3 of the lower peninsula, as well as parts of the eastern Upper Peninsula meet these criteria. This represents an enormous area with apparently good foundry sand potential. As discussed previously, it is not certain just how representative the samples are, as admixed gravel encountered in the sampling and observed in pits may constitute a significant amount of waste material which will affect the suitability of the outwash sands.

In making the recommendations below regarding further work on the outwash areas, it was necessary to utilize all available information including economic and marketing factors as an aid in selecting Phase II target areas. In selecting the specific area, groupings or clusters of good samples which occurred within apparently extensive sand belts were chosen. Areas near to present markets and producers were favored over other areas.

The recommendations for further study include the following:

(1) If Phase II exploration is to be continued on sands which have a potential as substitutes for coastal dune sands, then further work on inland dune sands is not recommended. However, if they are not too fine-grained to be utilized, or if it is considered desirable to do more detailed exploration on this sand type for other reasons, one of the following sites is recommended for additional work:

a. The area of dune complexes in southeastern Ottawa County in which sample numbers 1-229, 1-230, 1-231, and 2-232 occur.

b. An area of dune complexes in southeastern Muskegon County in the general vicinity of sample number 1-140.

c. One of several dune complexes in the northern or east-central part of Cheboygan County.

d. An area of dunes in the vicinity of Trout Lake in Chippewa County.

It is suggested that the decision involving the continued work on inland dune sands be a matter of discussion and negotiation with the Michigan Geological Survey Division of the Department of Natural Resources.

(2) It is recommended that the bulk of Phase II work be directed at further evaluation of glacial outwash sands because of their apparent suitability as substitutes for coastal dune sands. The selection of areas recommended, from which a maximum of & are to be examined, was made with difficulty as the sampling indicated that much of the extensive outwash belts contained material which may be as good. The following areas have been selected for more detailed exploration:

a. An area within the general boundaries of the mapped belt of glacial outwash in northwestern Wexford County and the southwestern corner of Grand Traverse County.

b. An area of outwash located in east-central Grand Traverse County and extending across the northwest part of Kalkaska County.

c. An area of outwash which covers much of southwestern Lake County and extends into the southeastern part of Mason County.

d. An area of outwash which covers most of the north half of losco County.

e. An area classified as lake bed sands which occurs in south west-central Tuscola County.

f. An irregular belt of outwash which extends throughout Oscoda County.

If additional information is obtained prior to the start of the Phase II field work which indicates other choices of areas may be more preferable, it is recommended that changes be discussed with the Michigan Geological Survey and the Corps of Engineers.

(3). Because they do not meet the published specifications for quality glass sands and are certainly not economic deposits for lower quality glass sands, the sandstone deposits are not recommended for additional work. If further work on sandstone deposits is desirable for some reason, deposits in Jackson or Alger Counties might be examined as discussed earlier.

(4). Further attempts should be made to obtain the important or critical specifications of the major users of coastal dune sands which may further narrow, eliminate or change the present choices for Phase II work.

(5). If it is determined that the accessory mineral content or grain shape of sands is of critical importance to the foundries, more detailed mineralogical evaluation should be done on the Phase II samples.

(6). If the laboratory tests and mineralogical examinations do not appear to be able to provide information which is definitive enough to make a clear evaluation in Phase II of the substitutability of the inland sands for coastal dune sands, it Is recommended that moldability tests be undertaken, subject to negotiation with the Contracting Officer.

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Alpena	Series 1924 Number 28
Antrim	Series 1923 Number 29
Barry	Series 1924 Number 14
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St. Joseph	Advanced Sheet Issued 1923
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Washtenaw	Series 1930 Number 21
Wexford	Advanced Sheet Issued 1909

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Emmet	Issued Dec. 1973
Genesee	Issued Apr., 1972
Gladwin	Issued March, 1972
Ionia	Issued Dec., 1967
Lapeer	Issued Jan., 1972
Leelanau	Issued 1973
Lenawee	Series 1947 Number 10
Livingston	Issued Nov., 1974
Macomb	Issued Sept., 1977
Montcalm	Series 1949 Number 11
Muskegon	Issued Oct., 1968
Osceola	Issued June, 1969
Ottawa	Issued Dec., 1972
St. Clair	Issued May, 1974
Sanilac	Series 1953 Number 10
Shiawassee	Issued June, 1974
Wayne	Issued Nov., 1977
Washtenaw	Issued June, 1977

Agricultural Experiment Station, Michigan State University Natural Land Type Maps

Alcona	Issued 1941
Baraga	Issued 1941
Houghton (North Part)	Issued 1942- 1943
Houghton (South Part)	Issued 1942- 1943
Iosco	Issued 1942
Mackinac (East Half)	Issued 1952
Mackinac (West Half)	Issued 1952
Marquette (Northwest)	Issued 1939
Marquette (Southeast)	Issued 1939
Marquette (Southwest)	Issued 1940
Presque Isle	Issued 1954

Michigan Dept. of Natural Resources County Maps: Scale Approx. 1:169,000 For The Following Counties:

Alcona	Emmet	Monroe
Alger	Gladwin	Montmorency
Alpena	Grand Traverse	Muskegon
Antrim	Houghton	Newaygo
Arenac	Iosco	Ogemaw
Baraga	Kalamazoo	Oscoda
Bay	Kalkaska	Osceola
Benzie	Kent	Ottawa
Berrien	Lake	Presque Isle
Cass	Leelanau	Roscommon
Calhoun	Luce	Saginaw
Charlevoix	Mackinac	St. Clair
Cheboygan	Macomb	School craft
Chippewa	Manistee	Tuscola
Clare	Marquette	Van Buren
Crawford	Menominee	Wayne
Delta	Midland	Wexford
Eaton	Missaukee	

U.S. Geol. Survey 15’ and 7½’ Topographic Maps for the State of Michigan

Sample Number	Type	Location County	Percent									
			CaO	MgO	Al_2O_3	MnO2	Fe_2O_3	Cr_2O_3	Cr_3O_4	K_2O	Na_2O	TiO_2
6-101	SS	Alger	.27	.32	4.14	.017	.91	.006	.005	3.97	.30	.25
6-111	SS	Alger	.04	.04	.34	.006	.58	.007	<.001	.19	.04	.05
6-135	Sand	Houghton	.03	.02	.52	.014	.53	.007	<.001	.26	.02	.09
4-278	Sand	Schoolcraft	.18	.06	2.75	.005	.54	.004	.002	1.69	.05	.06
4-285	SS	Alger	.04	.09	2.72	.005	.52	.006	.002	2.20	.10	.12
3-147	Sand	Saginaw	.29	.15	1.92	.010	.84	.006	.002	1.13	.72	.06
3-253	SS	Wayne	.03	.22	.05	.002	.36	.005	<.001	.01	.01	.03
3-254	SS	Wayne	.40	.28	.04	.002	.35	.006	.001	.01	.02	.03
3-255	SS	Eaton	.04	.06	1.32	.005	1.26	.007	.001	.51	.04	.13
1-137	Sand	Muskegon	.21	.10	2.52	.009	.80	.006	.001	1.31	.47	.07
1-182	Sand	Chippewa	.18	.07	2.36	.007	.65	.006	.002	1.72	.56	.05
6-142	SS	Jackson	.02	.06	1.40	.006	.81	.006	.001	.56	.05	.09
6-143	SS	Jackson	.02	.22	2.27	.010	.27	.006	.001	.83	.07	.19
6-144	SS	Jackson	.15	.60	6.90	.023	3.67	.008	.004	2.23	.40	.33
6-145	SS	Jackson	.01	.04	.48	.002	.53	.007	.001	.08	.02	.07
6-146	SS	Huron	.49	1.06	6.85	.122	7.36	.007	.005	1.95	.24	.44
6-147	SS	Ionia	.09	.08	1.32	.035	2.25	.012	.001	.30	.04	.23
6-148	SS	Eaton	.05	.04	1.35	.004	1.17	.005	<.001	.51	.05	.13

Type: -- SS = sandstone or Sand = sand

Table 12. Chemical Analyses of Selected Sandstone and Sand Samples