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FELDSPAR IN ILLINOIS SANDS: A FURTHER STUDY

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ABSTRACT

The iron content of the feldspar and feldspathic grains in 21 samples of Pleistocene feldspar-bearing sands of Illinois was studied petrographically and by spectrographic analysis. The samples were washed and acid treated before study. Potash feldspar grains averaged lowest in iron content, soda-lime feldspar grains were intermediate, and feldspathic rock fragments averaged highest. The iron in the three kinds of grains occurs as small particles of iron-bearing minerals; in some potash feldspar grains, iron oxide also is associated with alteration products within the grains.

The finer grained sands generally contain a higher percent of feldspar and a lower percent of feldspathic rock fragments than the coarser grained sands. Sands of similar grain size from different parts of the state differ in their feldspar content. The ratio of potash to soda-lime feldspars also varies from place to place.

Various processes—including froth flotation, electrostatic separation, electromagnetic separation, and heavy liquids—may merit testing to determine their applicability to the separation of feldspar from Illinois sands.

INTRODUCTION

In 1942, the Illinois Geological Survey published Report of Investigations 79, "Feldspar in Illinois Sands," by H.B. Willman, which pointed out the presence of as much as 34 percent feldspar in some of the sands of Illinois and suggested that the feldspar might be commercially recoverable by flotation. The report aroused considerable interest, but no commercial development has occurred. A presumptive reason for this is the iron content of the feldspar. It appeared worthwhile, therefore, to obtain more detailed information regarding the occurrence and amount of iron in the feldspar in the Illinois sands with the hope of enhancing the commercial possibilities of the sands as sources of feldspar.

OCCURRENCE OF SANDS

A full discussion of the occurrence and general characteristics of the feldspar-bearing sands of Illinois is contained in the report by Willman (1942). Therefore, only a short summary is given here.

The sands studied are of Pleistocene age, and all were derived at least in part from glacial material. The sands are of three types: dune, river, and beach. The dune sands are found mainly in northern and central Illinois (fig. 1). The largest deposits of river sand occur in the Mississippi, Illinois, Wabash, and Ohio Rivers. The beach sands occur along Lake Michigan and in the area covered by Glacial Lake Chicago. The glacial outwash of Illinois also contains much sand, but this sand is generally rather coarse-grained and associated with gravel. Because coarse sand is generally less desirable as a source of feldspar than fine- or medium-grained sand due to its lower feldspar content, the glacial outwash sands were not included in the present study.

The dune sands are largely light brown in color because of an iron oxide coating on the grains. The sand in the lower parts of the dunes is less weathered and contains less iron oxide than that in the upper parts. Much of the dune sand is noncalcareous, but the lower parts of some dunes contain limestone and dolomite grains. The dominant size fraction varies from the 35- by 48-mesh fraction to the 65- by 100-mesh fraction in different dune sands (Willman, 1942, p. 16). Most of the dune sands contain less than 5 percent silt and clay.

The river sands are lighter gray in color than the dune sands. The sands of the Illinois and Wabash Rivers contain many limestone and dolomite grains. The sands of the Ohio and Mississippi Rivers contain lesser amounts of such grains, and some samples studied by Willman (1942, p. 20) contain no carbonate. With the exception of the Mississippi River sands south of Alton, few of the river sands sampled by Willman are as fine-grained as the fine-grained dune sands. In the Mississippi River south of Alton, large sand deposits occur in which the dominant size fraction is 65- by 100-mesh.

The beach sands are similar to the river sands in color and contain large amounts of limestone and dolomite grains. They range from pebbly sands to sands similar to the dune sands in grain size (Willman, 1942, p.23).

METHODS OF INVESTIGATION

Preparation of Samples

The samples studied included 14 of those reported on by Willman (1942) and 7 additional samples (table 1). The samples were washed to remove clay and treated with hydrochloric acid to remove carbonates and iron oxide stains. They were then sieved for 10 minutes on a rotap using Tyler sieves.

Petrographic Analyses

The mineralogic and petrographic compositions of the sands (tables 2 and 3) were determined by use of the petrographic microscope. The feldspars were identified petrographically rather than by the staining technique of Willman (1942) because it was thought that petrographic investigation would give more detailed data on the distribution of iron minerals in the grains and because it was desired to

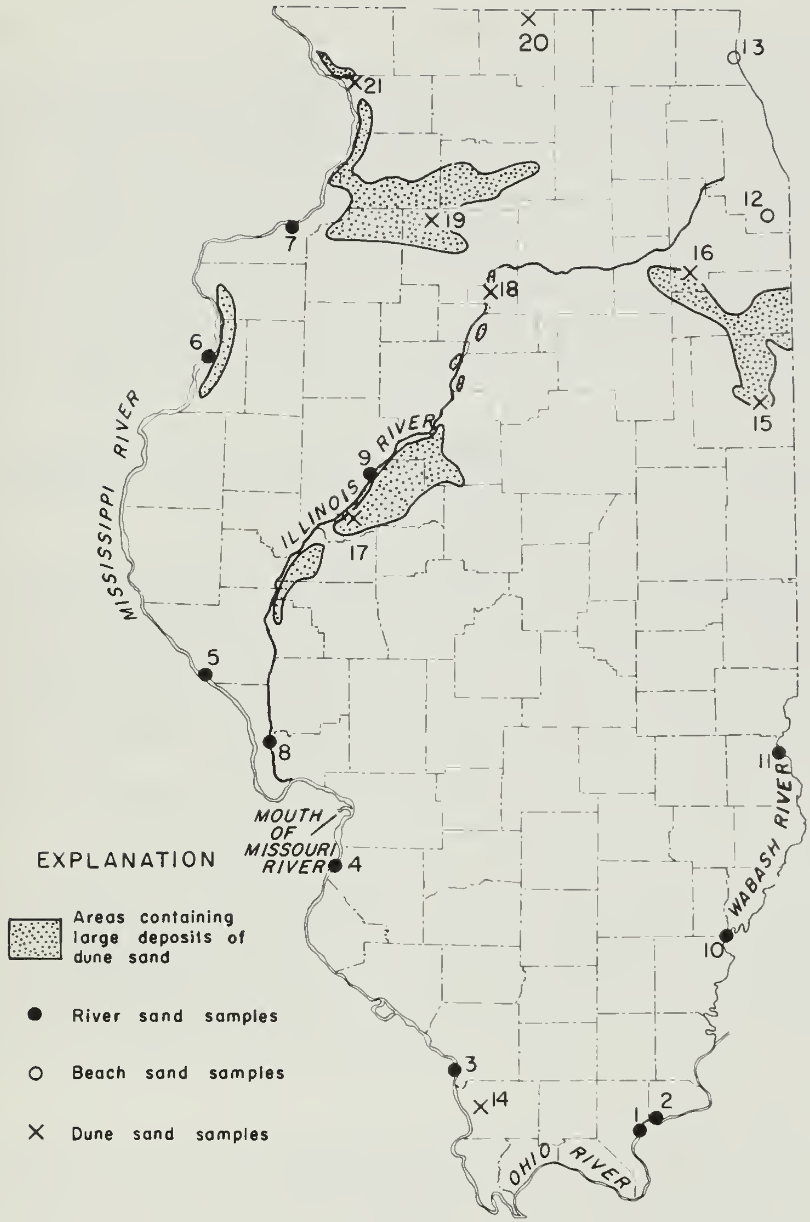

Figure 1 - Location of samples and main areas of occurrence of dune sand. Areas of occurrence are slightly modified from Willman (1942, p. 24).

separate identified grains for chemical analysis without the chemical alteration involved in staining.

Examination was restricted to the portions of the sands in the 35- to 200-mesh size range, as sand coarser than 35-mesh is in general less desirable as a source of feldspar because of its lower feldspar content and material finer than 200-mesh is present only in small amounts in the sands studied. Within this size range, the two, three, or four dominant sieve fractions of each sand were examined. The grains were placed in an immersion oil on a glass micrscope slide, and 200 grains in each analyzed size fraction were identified and tabulated as they were encountered during mechanical stage traverses. The percentages of the various constituents thereby determined were very nearly equivalent to the percentages by weight, for the constituents were approximately equal in density, with the exception of the "heavy minerals," which generally were present only in small amounts.

The components identified in this study were quartz, chert, nonfeldspathic rock fragments, feldspathic rock fragments, potash feldspar, soda-lime feldspar, and heavy minerals. These components are the same as those identified by Willman (1942) except for the rock fragments.

The nonfeldspathic rock fragments were defined as mineral aggregates estimated to contain less than 25 percent feldspar; these are in large part equivalent to Willman's (1942, p. 11) "shale" category. These rock fragments consist mainly of fine-grained quartz, mica, and chlorite in various proportions and are thought to be principally fine-grained sedimentary rocks, such as shale, and low-rank metamorphic rocks, such as argillaceous quartzite. The relatively few completely opaque rock fragments probably were mainly shale fragments and were grouped with the nonfeldspathic rock fragments.

The feldspathic rock fragments were defined as mineral aggregates estimated to contain more than 25 percent feldspar; these are equivalent in part to Willman's (1942, p. 11) category "other minerals." The feldspathic rock fragments consist mainly of feldspar and quartz, with small amounts of other minerals, and probably are mainly igneous and high-rank metamorphic rocks such as rhyolite, other volcanic rocks, and fine-grained granite and gneiss, although some highly feldspathic sedimentary rocks may be included. Some rock fragments containing fine-grained soda-lime feldspar but little potash feldspar may have been classified as nonfeldspathic because of the difficulty of recognizing the feldspar. Volcanic glass rarely was present and was included with the feldspathic rock fragments because of chemical similarity.

The percentages of feldspar found in this study are somewhat less for most samples, where a direct comparison is possible, than the percentages found by Willman (1942). This difference probably arises because mineral aggregates composed almost entirely of feldspar were counted as feldspar by Willman (1942, p. 11) but were counted as feldspathic rock fragments in this study. The sum of feldspar plus feldspathic rock fragments determined in this study is closely comparable, on the average, to the feldspar percentage determined by Willman. Willman's category "other minerals," which includes some feldspathic rock fragments, rarely comprises more than 3 percent in the size fractions studied in this report. The feldspathic rock fragments were counted separately from feldspar in this study because more information was desired on the iron content contributed by such grains.

Chemical Analyses

Samples of soda-lime feldspar and feldspathic rock fragments to be chemically analyzed consisted of hand-picked grains identified under the petrographic microscope. The desired grains were picked up from the oil in which they were immersed for identification purposes by a small-diameter glass tube with a rubber suction bulb on the upper end. The potash feldspars to be analyzed were first separated by a bromoform-acetone mixture, adjusted to a specific gravity of about 2.58, in which essentially all the potash feldspar floated and most other constituents sank. The grains of chert and rock fragments which also floated were removed then from the potash feldspar by hand picking under the petrographic microscope. Most of the analyzed samples weighed from 2 to 3 mg. An optical emission spectrographic method was used to analyze the samples.

OCCURRENCE OF IRON IN THE FELDSPARS AND ITS SIGNIFICANCE

Results of Chemical Analyses

Table 4 shows the spectrographic analyses for iron of feldspars and feldspathic rock fragments and the calculated percentages of Fe_2O_3 based on the assumption that the iron is in the ferric state. Fe_2O_3 contents of less than 0.10 percent are specified for the best grades of glass feldspar (Burgess, 1949, p.363), although the requirements would probably not be so stringent for amber glass and most other uses. Some of the potash feldspar samples have Fe_2O_3 percentages within or near this limit. The soda-lime feldspars tend to be higher in iron content, and the feldspathic rock fragments contain even more iron.

Iron in the Crystal Structure

Theoretically, iron may replace aluminum in the feldspar crystal structure, but most of the iron reported in analyses of common feldspar is probably in the form of mineral inclusions (Hewlett, 1959, p. 522-523). The feldspars in Illinois sands commonly contain inclusions, probably in sufficient abundance to account for essentially all the iron revealed by the analyses.

Iron in Surface Coatings

The dune sand samples were collected mainly from the oxidized zones of the weathering profiles and are colored various shades of brown by iron oxide. Thin sections of a dune sand sample show that nearly all the coloring is due to superficial coatings of iron oxide on the grains; rarely does iron oxide staining penetrate single-crystal grains along cracks. Iron oxide coatings are much less evident in the river and beach sands than they are in the dune sands, and many grains of river and beach sand have no visible iron-oxide coatings.

The iron-oxide surface coatings can be removed by digestion in acid, a treatment to which all the analyzed samples except the scrubbed samples were subjected. Willman (1942, p. 16) showed that the Fe_2O_3 content of a dune sand was lowered from 0.65 to 0.13 percent by acid digestion. Two sand samples were treated by scrubbing in an attrition mill in order to evaluate this possible commercial method of removing iron-oxide coatings. The effectiveness of the scrubbing proved to approach but not quite equal the effectiveness of the hydrochloric acid treatment in reducing iron content (table 4).

Possibly other variations of the scrubbing method might prove as effective as acid treatment in removing the surficial iron oxide, and a combination of acid treatment plus scrubbing might prove more effective than either one by itself. For example, Carter, Harris, and Strandberg (1964) showed that Oregon dune sands could be beneficiated to produce a glass sand having an Fe_2O_3 content of 0.07 to 0.09 percent by a combination of magnetic separation and attrition in an acidic leaching solution.

Iron-Bearing Inclusions

Potash Feldspar

The most common type of inclusion in the potash feldspar is a very fine-grained material that appears opaque in transmitted light, giving the crystals a cloudy brownish appearance (fig. 2). In reflected light the color is generally whitish, but in some grains the color is brownish or reddish, evidently due to the presence of iron oxide. A small proportion of the grains in all samples are so pervasively penetrated by this fine-grained material and accompanying iron oxide as to be nearly opaque (fig. 2D), but over 90 percent of the grains are essentially free of iron oxide (fig. 2A). The fine-grained material is uniformly distributed throughout some grains, but more commonly it is concentrated in irregular, poorly defined patches (fig. 2, C and D) or in diffuse zones along cleavage planes (fig. 2, A and D). Its distribution generally bears no apparent relation to grain edges. The nature of this very fine-grained material is uncertain, but it is assumed to be a clay mineral alteration product.

Whether the alteration is due to weathering or took place while the feldspar was enclosed in its source rock is uncertain. Ledent, Patterson, and Tilton (1964, p. 116) state that even potash feldspar in igneous rocks is commonly cloudy. Willman (1942, p. 18) states that there is no readily apparent difference in the extent of alteration of the feldspar in the calcareous dune sands and in the noncalcareous sands overlying them. The wide range in degree of alteration from grain to grain within a single sample also suggests that most of the fine-grained material is not a product of present weathering.

Apart from this very fine-grained material, iron-rich mineral inclusions are rare in the potash feldspars; they occur in less than 1 percent of the grains. The most common are magnetite and biotite, occurring as discrete particles generally less than 0.01 mm. in diameter (fig. 2B). The iron content of the potash feldspar is probably associated mainly with the very fine-grained alteration product, although the small amounts of magnetite and biotite inclusions also contribute to the iron content. Reduction of this iron content could probably be accomplished by removal of the small percentage of grains containing unusually large amounts of the iron-bearing impurities. Such removal might be accomplished by electromagnetic separation, especially after roasting the feldspar to convert hydrous iron oxide to a more magnetic form (Stone, 1964, p. 1289).

Soda-lime Feldspar

The soda-lime feldspars commonly contain abundant mineral inclusions scattered through the grains (fig. 3, A and B), and few grains are essentially free of these inclusions. The most common are mica, chlorite, epidote, clinozoisite, and actinolite. Of these, chlorite, epidote, and actinolite contain appreciable amounts of iron, and iron impurities probably are associated with the fine-grained mica also. In some grains, the inclusions are altered to iron oxide. The inclusions are generally less than 0.01 mm. in diameter. They occur uniformly distributed through the grains or in irregular, poorly defined patches. Due to the abundant iron-bearing inclusions, the soda-lime feldspars contain considerably more iron than the potash feldspars in the same sands (table 4).

Most of the minerals found as inclusions in the soda-lime feldspars are characteristic of a deep-seated origin. Therefore, the soda-lime feldspars probably acquired these inclusion while they were enclosed within the source rocks rather than during weathering at or near the earth's surface.

Reduction of the iron content of the soda-lime feldspar would probably require the removal of the grains containing abundant inclusions.

Iron in Feldspathic Rock Fragments

The feldspathic rock fragments in the Illinois sands are largely acidic igneous and metamorphic rocks (fig. 3, C and D), although some highly feldspathic sedimentary rocks may be included. Such rocks have Fe_2O_3 contents ranging from about 1 to about 3 percent, the iron being contained mainly in iron-bearing minerals present as minor constituents of these rocks. The Fe_2O_3 contents of the analyzed feldspathic rock fragment samples range from 0.28 to 1.50 percent (table 4); the iron contents are somewhat less than they are in igneous rocks, probably because some of the rock fragments consist of only two or three crystals of feldspar and quartz with no accompanying iron-rich minerals. With the exception of one sample, the iron contents of the feldspathic rock fragments are much higher than the iron contents of the single-crystal potash and soda-lime feldspars (table 4). Thus, it is essential that the rock fragments be separated from the single-crystal feldspar grains if a feldspar concentrate is to meet the highest commercial specifications of iron content.

DISTRIBUTION OF FELDSPAR AND FELDSPATHIC ROCK FRAGMENTS

Because the iron contents of potash feldspar, soda-lime feldspar, and feldspathic rock fragments differ, sands having various proportions of these constituents will differ in their value as a possible source of feldspar, even though their total feldspar content may be the same. Potash feldspar is more desirable than soda-lime feldspar from the standpoint of iron content, and feldspathic rock fragments are the least desirable source of feldspar in the sands. The proportions of these constituents in the sands of Illinois have been found to vary in different sand deposits and in different grain-size classes of a given sand deposit.

Variation with Grain Size

Willman (1942) showed that the percent of potash and soda-lime feldspar generally increases with decreasing grain size to at least 200-mesh and that mineral aggregates are more common in the coarser size fractions. The analyses in table 2 show similar trends. In order to reduce random variation and to reveal

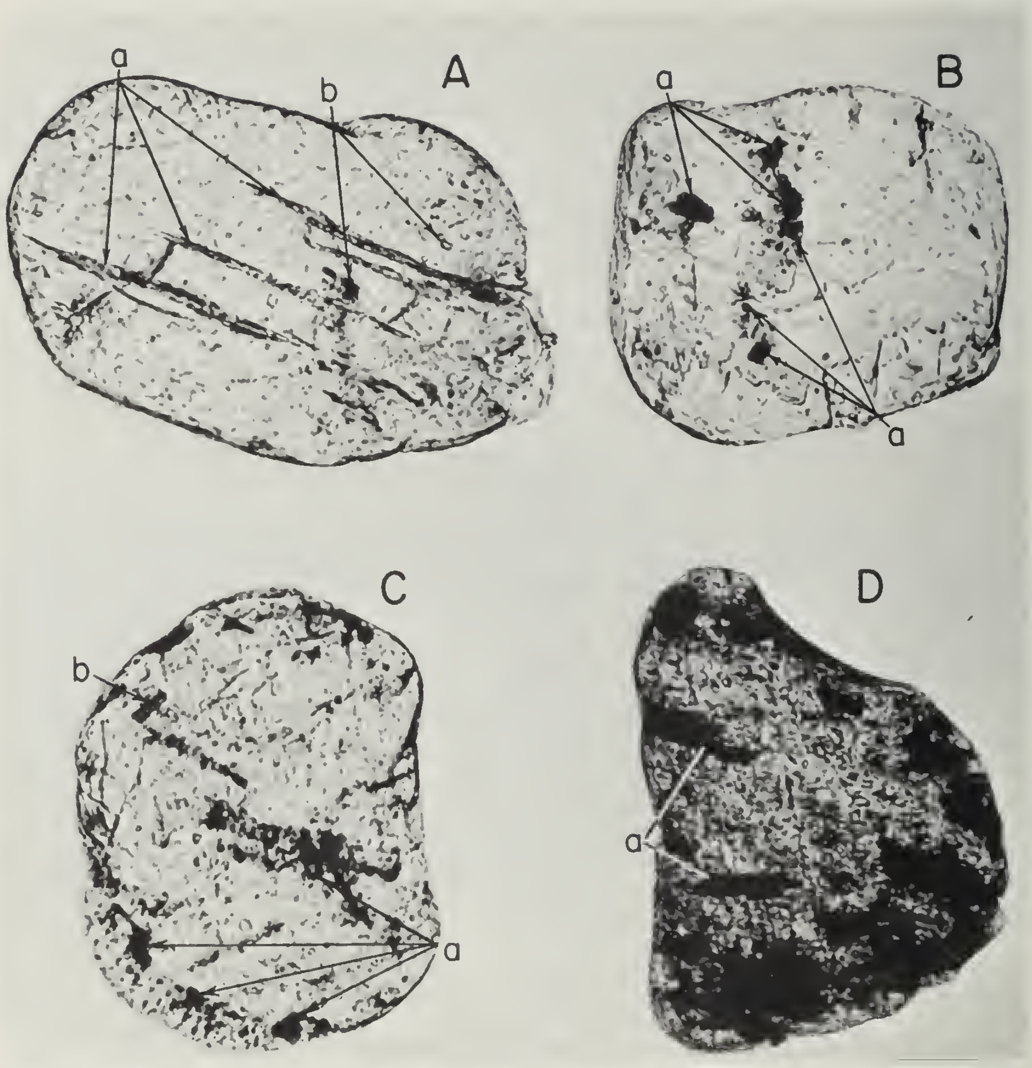

Figure 2 – Photomicrographs of thin sections of potash feldspar grains. The grains have been acid-treated. Magnification 270X. [A] Potash feldspar grain with no visible iron oxide and free of fine-grained alteration products except for small amounts along cleavage cracks (a). A few very small inclusions, which are probably not iron-rich minerals, occur within the grain as at (b). Grains of similar purity make up the bulk of the potash feldspar in most Illinois sands. [B] Potash feldspar grain with a few small inclusions (a) of a brown mineral that is probably biotite, an iron-rich mineral, partially oxidized to iron oxide. Less than one percent of the potash feldspar grains have inclusions of iron-rich minerals such as biotite or magnetite. [C] Potash feldspar grain containing irregular patches (a) of fine-grained alteration products accompanied by reddish brown iron oxide, which appears black in the photograph. A small inclusion of tourmaline (b), which may contain small amounts of iron, also occurs within the grain. Less than 10 percent of the potash feldspar grains contains visible iron oxide accompanying fine-grained alteration products. [D] Potash feldspar grain containing many black-appearing patches (a) composed of reddish brown iron oxide and fine-grained alteration products. Some of the iron oxide patches are aligned roughly parallel to cleavage. The mottled gray areas are feldspar with finely disseminated alteration products, in part accompanied by iron oxide. Potash feldspar grains with such large amounts of iron oxide are rare in Illinois sands.

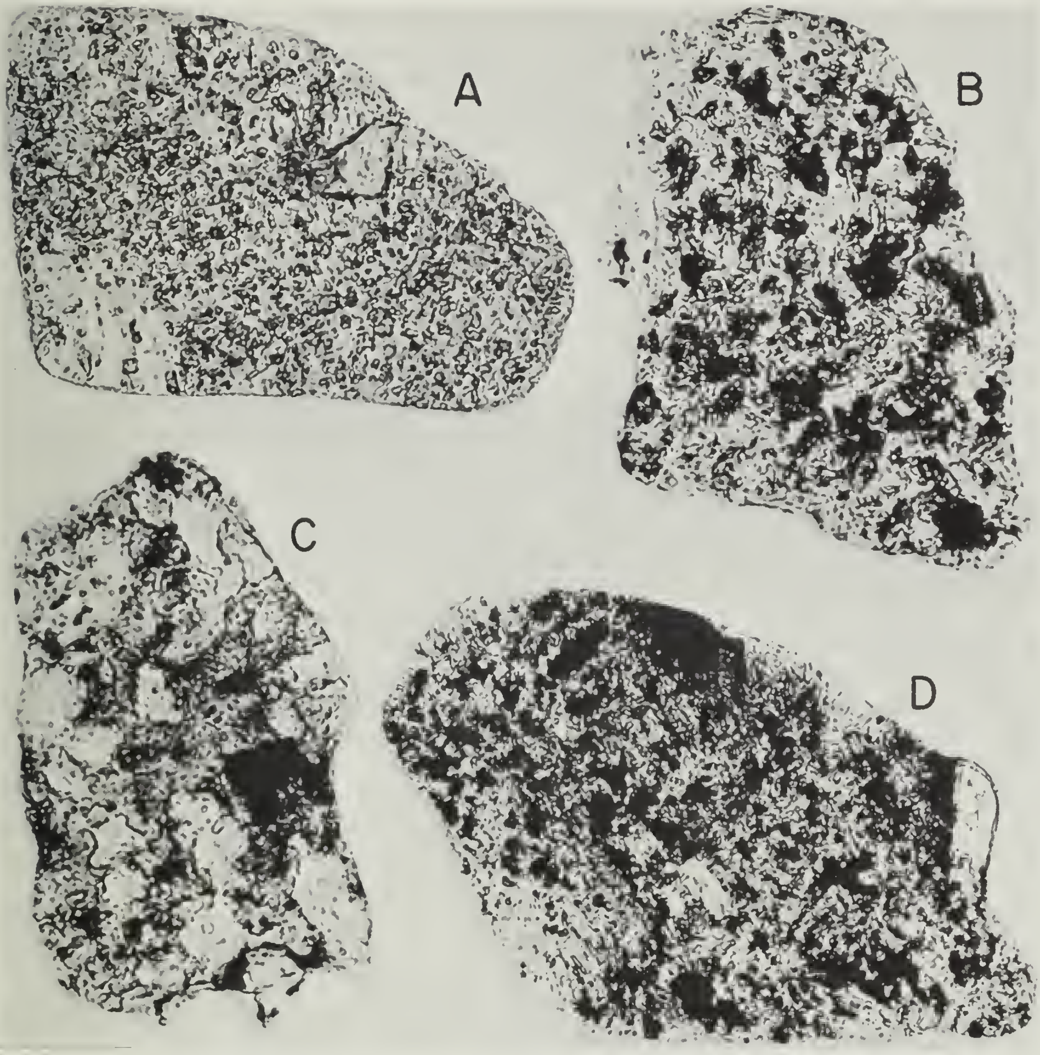

Figure 3 – Photomicrographs of thin sections of soda-lime feldspar grains and feldspathic rock fragments. The grains have been acid-treated. Magnification 270X. [A] Soda-lime feldspar grain containing abundant small mineral inclusions. The inclusions are largely a pale green mica and are probably not iron-rich, but they probably add to the iron content of the feldspar. Many of the soda-lime feldspar grains in Illinois sands contain similar amounts of inclusions. [B] Soda-lime feldspar grain that is part of a single crystal and contains abundant small inclusions of pale green mica and a mineral with high relief, appearing dark in the photograph, that is probably epidote, and iron-bearing mineral. Many of the soda-lime feldspar grains contain inclusions of iron-bearing minerals such as epidote, chlorite, and actinolite. [C] Relatively coarse-textured feldspathic rock fragment, consisting principally of potash feldspar (gray in photograph), quartz (white in photograph), and iron-rich minerals that are partially oxidized to iron oxide (black in photograph). The rock is probably a microgranite. Its content of iron-bearing minerals is fairly typical of the relatively coarse-textured feldspathic rock fragments in Illinois sands. [D] Fine-textured feldspathic rock fragment consisting largely of fine-grained soda-lime feldspar and very fine-grained material with high relief, appearing dark in the photograph, most of which is probably chlorite. The rock is probably a metamorphosed extrusive igneous rock. Its content of iron-bearing minerals is fairly typical of the fine-textured feldspathic rock fragments in Illinois sands.

the size effect more clearly, the average composition by size class was calculated for a group of relatively uniform samples (fig. 4). This group was made up of the 17 samples of sand derived largely or entirely from the glacial material of Illinois and the upper Mississippi, Wabash, and Lake Michigan drainage basins. This includes all the sands studied except those from the Ohio River and the Mississippi River below the mouth of the Missouri, which were excluded because they contain significant amounts of material from nonglacial or distant glacial sources. The trends shown in figure 4 indicate that the finer-grained sands are generally more promising as sources of feldspar than the coarser sands because they have a lower content of feldspathic rock fragments and a higher feldspar content.

Variation in Different Deposits

The sand deposits of Illinois differ widely in their percent of potash feldspar, soda-lime feldspar, and feldspathic rock fragments (table 3). In general, the sands shown to be high in feldspar by Willman (1942) were also found to be high in feldspar in this study. The number of samples in this study is not sufficient to characterize the sand deposits as fully as in Willman's study. Some features bearing on the possible value of Illinois sands as sources of low-iron feldspar are shown in table 5.

Among the river sands, the samples from the Ohio and Illinois Rivers have relatively small amounts of feldspar, the samples from the Wabash River have medium feldspar contents, the samples from the Mississippi River above the mouth of the Missouri vary from medium to high in feldspar content, and the Mississippi River sands below the mouth of the Missouri have consistently large amounts of feldspar. This order of feldspar abundance is similar to that shown by Willman (1942, p. 13). However, the Mississippi River sands below the mouth of the Missouri have a very high percent of feldspathic rock fragments. The sample from the Mississippi River above the mouth of the Missouri that has a high feldspar content (sample 6), on the other hand, has a low percentage of feldspathic rock fragments. It also has a fairly high ratio of potash to soda-lime feldspar and a fairly low carbonate content. The high feldspar content and low content of feldspathic rock fragments of sample 6 are due in part to its fine grain size. It is uncertain whether sands similar in composition to sample 6 are common in the Mississippi River above the mouth of the Missouri.

The samples of beach sand from Lake Michigan and Glacial Lake Chicago have a medium to fairly large percent of feldspar but also contain large proportions of feldspathic rock fragments. These sands are also calcareous.

Among the dune sands, the samples from the Kankakee area (samples 15 and 16) have the best combination of high feldspar content and high ratio of

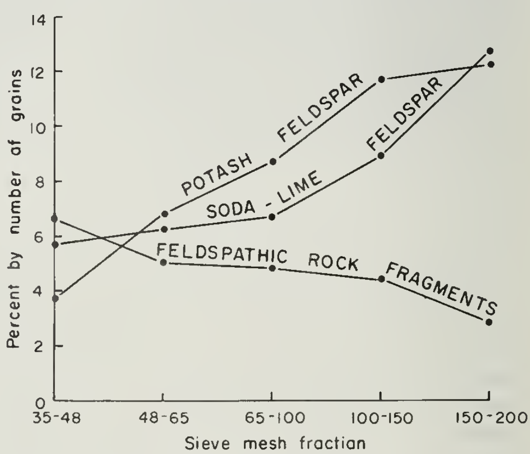

Figure 4 - Average percent of potash feldspar, soda-lime feldspar, and feldspathic rock fragments in different size fractions of 17 sands of glacial source. Included are the dune sands, beach sands, and sands of the Illinois River, the Wabash River, and the Mississippi River above the mouth of the Missouri River.

feldspar to feldspathic rock fragments (table 5). This is due in part to the relatively fine grain size of these sands, as the compositions of the finer size fractions of dune sand samples from the Havana area (sample 17), Lacon area (sample 18), and Prophetstown area (sample 19) are similar to the composition of the Kankakee area dune sands. The Kankakee area dune sands also have a high ratio of potash to soda-lime feldspar.

The dune sand from the vicinity of Anna (sample 14) has a high feldspar content but also has a high content of feldspathic rock fragments.

The dune sand from the Savanna area (sample 21) has a large feldspar content and a fairly low content of feldspathic rock fragments, even though the sand is relatively coarse grained. However, it has a low ratio of potash to soda-lime feldspar; in fact, it contains more soda-lime feldspar than any other sample in this study. This sample probably is similar in composition to the other dune sands and the noncalcareous glacial outwash sands of the Savanna and Oquawka areas along the upper Mississippi River, for the analysis of this sample by Willman (1942) is similar to his analyses of the other sands of the Savanna and Oquawka areas.

The fine-grained dune sands from the Kankakee area (samples 15 and 16) and the fine-grained sand from the upper Mississippi River (sample 6) appear to be the most promising of the samples studied as sources of feldspar of low iron content. However, these were among the finer grained of the sands studied, and sands of equally fine grain size from other parts of the state may be equally promising as sources of feldspar. Willman (1942) showed that dune sands of equally fine grained size and similar feldspar content do occur in other areas, especially the Chicago and Havana areas. Willman's size analyses include no river sands as fine grained as sample 6 except in the Mississippi River below the mouth of the Missouri, and the present study shows that these sands have a very large percentage of feldspathic rock fragments despite their fine grain size.

POSSIBLE PROCESSES FOR RECOVERING FELDSPAR

The testing of commercial processes that might be used to separate feldspars from Illinois sands was beyond the scope of this investigation, but several processes are mentioned below that are in use or have been tried experimentally for separating feldspar from sand or crushed pegmatite rock.

Froth Flotation

One of the factors leading to the study of Illinois feldspars by Willman (1942) was the description by O'Meara, Norman, and Hammond (1939) of a froth flotation process for separating feldspar from quartz and other constituents of pegmatites. The flotation method is now in use in the feldspar industry.

Preliminary flotation experiments reported by Willman (1942, p. 8) resulted in feldspar concentrates of encouragingly low iron content, but a definite conclusion on the quality of the feldspar could not be reached with the data then available. An experimental study of the separation of feldspar from river sands of Kansas by the flotation method also showed that feldspar concentrates that met all commercial specifications except possibly iron content could be produced (Bowdish and Runnels, 1952); the least percentage of Fe_2O_3 reported was 0.25 percent, and other feldspar concentrates ranged up to 0.5 percent Fe_2O_3.

Experiments on Oregon coastal dune sands by Carter, Harris, and Strandberg (1964, p. 15-16) showed that feldspar concentrates could be produced by a combination of flotation and high-intensity magnetic separation, but they report that reagent costs probably were excessive and that the feldspar concentrate contained 0.23 percent Fe_2O_3. Feldspar concentrates are produced commercially from coastal dune sands of California by the flotation process, and the feldspar concentrate has an iron content of only 0.10 percent (Messner, 1954). However, the sand used is unusual in that it consists of 53.0 percent quartz, 46.5 percent feldspar, only 0.5 percent heavy minerals, and no recognized rock fragments; the raw sand contains only 0.12 to 0.18 percent Fe_2O_3 (Messner, 1964).

From the published evidence, it is uncertain whether feldspar concentrates produced by flotation from Illinois sands would be sufficiently low in iron content to meet commercial specifications. The major difficulty may be that the flotation process probably does not distinguish feldspar of low iron content from feldspar of high iron content and from feldspathic rock fragments. In combination with some other process to reduce iron content, however, the process might be of use. As feldspar flotation requires an acidic reagent, the noncalcareous sands such as dune sands and some Mississippi and Ohio River sands are probably more favorable for this process than the calcareous sands (Willman, 1942, p. 12).

Electrostatic Separation

Electrostatic separators are used in some commercial operations to recover feldspar from pegmatite deposits. Because quartz has a negative charge, albite a weakly negative charge, and microcline is inert in the electrostatic separator, the three minerals theoretically may be separated (Diamond, 1957). Experimental separation of artificial mixtures of quartz and potash feldspar, quartz and soda-lime feldspar, and potash feldspar and soda-lime feldspar showed that separates of 85 to 100 percent mineralogical purity could be produced by this method (Druzhinin, 1960). Northcott and LeBaron (1958) have shown that the ratio of potash to soda in feldspar from pegmatite can be increased by electrostatic separation.

The effectiveness of this method in producing feldspar concentrates of low iron content from sands of complex mineralogy, such as those of Illinois, is uncertain. The process was not found effective in producing glass sand of low iron content from the Oregon dune sands (Carter, Harris, and Strandberg, 1964, p. 14).

Electromagnetic Separation

High-intensity magnetic separators are used in some commercial feldspar operations to remove the iron-rich minerals present in small amounts in pegmatite deposits. Wet magnetic separators recently have come into use in the feldspar industry (Stone, 1964). A laboratory electromagnetic separator has been used to separate soda-lime feldspar with few impurities from that with more impurities (Gates and Clabaugh, 1953, p. 6-10). A laboratory electromagnetic separator also has been used in combination with heavy liquids to separate potash feldspar with few impurities from river and beach sands (Ledent, Patterson, and Tilton, 1964, p. 114). In experiments on the beneficiation of Oregon coastal dune sands for use as glass sand (Carter, Harris, and Strandberg, 1964), it was found that high-intensity magnetic separation plus acid leaching in an attrition scrubbing cell gave better results than electrostatic separation or flotation. The method was successful in removing the black minerals and rock fragments from the sand, and the iron content after acid leaching was 0.07 to 0.09 percent Fe_2O_3. However, the feldspar was not separated from the quartz by this method.

Electromagnetic separation appears from the published information to be effective in removing most iron-bearing grains but probably is not capable of separating quartz from feldspar.

Heavy Liquids

Heavy liquids were used in this study to separate potash feldspar from the other components of the sands. The concentrates produced by this method contained from 50 to 97 percent potash feldspar, and essentially all the potash feldspar in the sands was contained in these concentrates. The impurities consisted largely of chert and feldspathic rock fragments, which probably could be removed by high-intensity magnetic separation as shown by Ledent, Patterson, and Tilton (1964, p. 114). Heavy liquids proved promising in laboratory and pilot plant experiments for the commercial extraction of feldspar from pegmatite deposits (Baniel et al., 1963).

CONCLUSIONS

The following conclusions are drawn regarding the feldspar-bearing sands of Illinois:

The Fe_2O_3 content of the potash feldspar in the sands is lower than that of the soda-lime feldspar and feldspathic rock fragments; analyses of acid-treated potash feldspar show Fe_2O_3 contents ranging from 0.10 to 0.31 percent. Potash feldspar is, therefore, the preferable material in the sands from the standpoint of probable commercial usefulness. The iron within the potash feldspar grains occurs as iron oxide accompanying fine-grained alteration products within the grains and as small particles of iron-bearing minerals within the grains.

The Fe_2O_3 content of acid-treated soda-lime feldspar ranges from 0.16 to 0.56 percent. The iron occurs mainly as small particles of iron-bearing minerals within the grains.

The Fe_2O_3 content of the feldspathic rock fragments varies from 0.40 to 1.17 percent. The iron occurs in iron-bearing minerals within the grains.

Surface coatings of iron oxide in feldspar grains can be removed by acid treatment or probably by abrasive scouring. The iron compounds within the grains cannot be removed in this way.

The percentages of potash and soda-lime feldspars generally increase with decreasing grain size down to at least 200-mesh. The percentage of feldspathic rock fragments generally decreases with decreasing grain size. The finer-grained sands are, therefore, generally more promising than coarser-grained sands as possible sources of feldspar of low iron content.

The ratio of potash to soda-lime feldspar in the sands shows relatively little relation to grain size but varies in different deposits.

The fine-grained dune sands in general contain the greatest percentage of potash feldspar. They usually are not calcareous, but the sand grains commonly are coated by a film of iron oxide.

The Mississippi River sands below the mouth of the Missouri River have relatively high percentages of potash feldspars, are only slightly calcareous, and are relatively free of iron oxide grain coatings. However, they have very large percentages of feldspathic rock fragments.

Some of the Mississippi River sands above the mouth of the Missouri River contain comparatively large percentages of potash feldspar, are relatively free of iron oxide grain coatings, and contain comparatively small percentages of feldspathic rock fragments.

Various processes, including froth flotation and electrostatic, electromagnetic, and heavy liquid separation, have been used with varying degrees of success in separating feldspar from crushed pegmatite rock and natural sands.

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TABLE 1. LOCATION AND DESCRIPTION OF SAMPLES

Sample number	Location: Town near	County	Section ¼	¼	¼	sec.	Township	Range	Thickness sampled ft.	Sample number (Willman, 1942)
					OHIO RIVER SANDS					
1	Golconda	Pope	NE	NE	NW	20	13 S	7 E	—	
2	Rosiclare	Hardin	SE	SW	SW	5	13 S	8 E	—	99
					MISSISSIPPI RIVER SANDS BELOW MOUTH OF MISSOURI RIVER					
3	Grand Tower	Jackson	NW	NE	NE	25	10 S	4 W	2	
4	East Carondelet	St. Clair					1 N	10 W	—	90
					MISSISSIPPI RIVER SANDS ABOVE MOUTH OF MISSOURI RIVER					
5	Louisiana	Pike	SW	SE	NW	13	7 S	6 W	—	86
6	Gladstone	Henderson					10 N	5 W	—	
7	Hampton	Rock Island					18 N	1 E	—	
					ILLINOIS RIVER SANDS					
8	Hardin	Greene	SW	SE	SW	1	8 N	14 W	—	82
9	Havana	Fulton	SW	NE	SE	29	4 N	4 E	—	80
					WABASH RIVER SANDS					
10	Grayville	Wabash	SW	NE	NE	21	3 S	14 W	—	97
11	Hutsonville	Crawford		NE	SE	29	8 N	11 W	—	96
					BEACH SANDS AROUND LAKE MICHIGAN					
12	Homewood	Cook	NW	NW	NE	4	35 N	14 E	3	
13	Lake Bluff	Lake	SE	SW	SE	9	44 N	12 E	—	
					DUNE SANDS					
14	Jonesboro	Union	SE	SW	SW	20	12 S	2 W	8	79
15	Watseka	Iroquois	NE	NE	NW	20	26 N	12 W	3	14
16	Wilmington	Will	SE	SE	NW	34	33 N	9 E	11	
17	Bath	Mason	SE	NE	SE	18	20 N	9 W	6	44
18	Hennepin	Putnam	SW	SW	SE	35	32 N	2 W	7	29
19	Normandy	Bureau	SW	SW	NW	11	18 N	7 E	10	56
20	Rockton	Winnebago	SW	NW	NW	12	46 N	1 E	5	48
21	Savanna	Carroll	NW	NE	SW	17	25 N	3 E	5	64

TABLE 2. PETROGRAPHIC COMPOSITION OF INDIVIDUAL SIZE FRACTIONS OF SAND SAMPLES

Sample number	Sieve fraction, mesh	Percent by weight in whole sample	Acid soluble (percent by weight in whole sample)	Percent by number of grains						
				Potash feldspar	Soda–lime feldspar	Feldspathic rock fragments	Nonfeldspathic rock fragments	Chert	Quartz	Heavy minerals
				OHIO RIVER SANDS						
1	35–48	23.9		4.0	4.5	2.0	10.5	1.5	77.0	0.5
	48–65	13.5	1	7.0	5.5	1.0	7.5	1.0	75.0	3.0
	65–100	2.3		3.0	6.0	2.5	8.5	0.5	72.0	7.5
2	35–48	20.4		4.0	6.5	5.0	8.0	0.5	75.5	0.5
	48–65	39.9	3	2.5	2.5	3.0	7.5	0.5	84.0	0.0
	65–100	31.4		3.0	6.0	2.0	7.0	1.5	78.5	2.0
				MISSISSIPPI RIVER SANDS BELOW MOUTH OF MISSOURI RIVER						
3	65–100	25.2		9.0	9.0	12.5	15.0	6.0	47.5	1.0
	100–150	35.4	9	7.5	9.0	12.0	12.0	3.0	54.0	2.5
	150–200	19.9		9.5	8.0	11.0	10.5	1.0	54.5	5.5
4	48–65	26.6		7.0	6.5	15.0	5.0	3.5	61.5	1.5
	65–100	55.1	3	11.0	13.5	12.5	7.5	2.5	52.5	0.5
	100–150	12.4		8.5	9.5	11.5	8.0	1.0	59.5	2.0
				MISSISSIPPI RIVER SANDS ABOVE MOUTH OF MISSOURI RIVER						
5	35–48	48.5		2.5	6.0	7.5	0.5	0.0	82.0	1.5
	48–65	33.0	0	6.0	6.5	6.5	2.0	0.0	77.5	1.5
	65–100	12.0		7.5	7.5	7.5	1.5	0.5	72.5	3.0
6	48–65	6.9		12.0	10.0	3.5	3.5	1.0	68.0	2.0
	65–100	26.7	7	11.5	10.0	2.5	5.0	1.0	67.0	3.0
	100–150	33.0		10.0	10.0	2.5	1.5	0.0	70.0	6.0
	150–200	19.7		10.5	14.0	2.0	2.5	0.0	64.5	6.5
7	35–48	33.4	1	4.5	5.0	2.0	2.5	2.0	84.0	0.0
	48–65	16.1		8.5	4.5	3.0	3.0	1.0	79.0	1.0
				ILLINOIS RIVER SANDS						
8	35–48	31.5		2.5	4.5	3.5	1.5	2.0	86.0	0.0
	48–65	17.6	10	4.5	6.0	5.5	1.5	2.0	79.5	1.0
	65–100	7.3		6.5	4.0	5.0	5.0	1.5	74.0	4.0
9	35–48	36.1		2.0	3.0	6.0	4.0	0.5	82.5	2.0
	48–65	12.6	5	7.0	8.5	5.0	2.0	0.5	74.5	2.5
	65–100	5.1		10.0	8.0	7.5	2.0	1.5	65.5	5.5
				WABASH RIVER SANDS						
10	35–48	35.0		4.5	9.5	6.5	4.5	2.0	71.0	2.0
	48–65	20.3	9	6.0	10.0	2.5	3.0	2.0	73.5	3.0
	65–100	7.7		10.5	7.5	2.0	3.5	0.5	70.5	5.5
11	35–48	13.1	23	5.5	5.5	9.5	12.0	1.5	64.5	1.5
	48–65	4.9		5.0	8.0	7.0	7.5	2.5	68.5	1.5
				BEACH SANDS AROUND LAKE MICHIGAN						
12	35–48	20.5		4.5	7.0	22.0	11.0	3.0	52.5	0.0
	48–65	14.6	6	10.0	5.0	9.5	8.5	3.0	64.0	0.0
	65–100	15.6		12.0	4.5	9.5	6.0	1.0	67.0	0.0
	100–150	8.0		18.5	9.0	7.0	9.0	0.5	54.5	1.5
13	35–48	16.9		1.5	7.0	8.5	3.5	2.0	70.5	7.0
	48–65	48.0	14	5.5	4.5	4.5	1.5	2.5	74.5	7.0
	65–100	30.2		5.5	6.5	6.5	3.0	1.5	57.0	20.0
				DUNE SANDS						
14	48–65	29.3		11.5	8.5	12.0	1.5	1.0	65.5	0.0
	65–100	39.9	0	13.0	8.0	9.5	2.5	1.5	64.5	1.0
	100–150	10.4		12.0	8.0	9.0	2.5	0.5	64.0	4.0
15	65–100	32.2		10.5	5.5	4.0	1.0	2.0	76.5	0.5
	100–150	20.8	0	10.5	6.5	2.0	2.0	1.0	74.0	4.0
	150–200	24.2		13.0	9.5	5.0	1.5	0.0	62.5	8.5
16	48–65	19.6		6.0	5.0	4.0	1.5	2.0	81.5	0.0
	65–100	39.4	4	9.5	5.5	3.0	2.0	1.0	78.5	0.5
	100–150	22.7		12.0	9.0	3.0	2.5	1.0	71.0	1.5
	150–200	8.5		13.0	14.5	1.5	2.5	0.5	62.5	5.5
17	35–48	20.3		3.5	4.5	3.0	3.0	2.0	84.0	0.0
	48–65	32.4	0	6.0	5.5	4.5	1.5	0.5	81.0	1.0
	65–100	34.2		9.0	6.0	3.5	2.0	1.5	75.0	3.0
18	35–48	24.6		5.5	3.5	3.0	3.5	1.0	82.5	1.0
	48–65	23.9	0	5.5	5.5	1.5	2.0	1.0	84.0	0.5
	65–100	24.0		10.0	6.0	2.5	3.0	2.0	74.0	2.5
19	35–48	32.4		1.0	3.5	2.0	2.5	2.5	87.5	1.0
	48–65	25.6	7	4.5	2.5	3.0	1.0	1.0	87.5	0.5
	65–100	20.6		6.0	5.5	2.0	2.5	0.5	81.0	2.5
	100–150	4.8		7.5	11.0	3.0	1.0	2.5	67.5	7.5
20	35–48	35.8		2.0	1.5	2.5	1.0	2.0	90.5	0.5
	48–65	29.0	0	3.0	1.5	1.5	1.5	1.0	90.5	1.0
	65–100	17.6		3.5	1.5	0.5	1.0	0.0	92.0	1.5
21	35–48	20.8		8.0	13.0	9.0	2.0	1.5	66.5	0.0
	48–65	44.0	0	7.5	10.5	5.5	5.0	0.5	70.5	0.5
	65–100	27.0		5.0	13.0	5.0	4.5	1.0	66.5	5.0

TABLE 3. PERCENT BY WEIGHT OF POTASH FELDSPAR, SODA-LIME FELDSPAR, AND FELDSPATHIC ROCK FRAGMENTS IN 35 BY 200 MESH FRACTIONS OF SAND SAMPLES. (The percentages were calculated from data in Table 2.)

	Acid-treated			Natural		
Sample number	Potash feldspar	Soda-lime feldspar	Feldspathic rock fragments	Potash feldspar	Soda-lime feldspar	Feldspathic rock fragments
			OHIO RIVER SANDS			
1	5.0	5.0	1.5	5.0	5.0	1.5
2	3.0	4.5	3.0	3.0	4.5	3.0
			MISSISSIPPI RIVER SANDS BELOW MOUTH OF MISSOURI RIVER			
3	8.5	9.0	12.0	7.5	8.0	11.0
4	9.5	11.0	13.0	9.0	10.5	12.5
			MISSISSIPPI RIVER SANDS ABOVE MOUTH OF MISSOURI RIVER			
5	4.5	6.5	7.0	4.5	6.5	7.0
6	10.5	11.0	2.5	10.0	10.0	2.5
7	6.0	5.0	2.5	6.0	5.0	2.5
			ILLINOIS RIVER SANDS			
8	3.5	5.0	4.5	3.0	4.5	4.0
9	4.0	5.0	6.0	4.0	4.5	5.5
			WABASH RIVER SANDS			
10	5.5	9.5	4.5	5.0	8.5	4.0
11	5.5	6.0	9.0	4.5	5.0	7.5
			BEACH SANDS AROUND LAKE MICHIGAN			
12	10.0	6.0	13.5	9.5	5.5	12.5
13	5.0	5.5	6.0	4.5	4.5	5.0
			DUNE SANDS			
14	12.5	8.0	10.5	12.5	8.0	10.5
15	11.5	7.0	4.0	11.5	7.0	4.0
16	9.5	7.0	3.0	9.0	6.5	3.0
17	6.5	5.5	4.0	6.5	5.5	4.0
18	7.0	5.0	2.5	7.0	5.0	2.5
19	3.5	4.0	2.5	3.5	3.5	2.5
20	2.5	1.5	1.5	2.5	1.5	1.5
21	7.0	12.0	6.0	7.0	12.0	6.0

TABLE 4. SPECTROGRAPHIC ANALYSES OF IRON CONTENTS OF SELECTED FELDSPAR AND FELDSPATHIC ROCK FRAGMENT SAMPLES FROM ILLINOIS SANDS.
(Analyses by Miss Juanita Witters)

Sample number	Component	Type of treatment	Percent Fe	Percent Fe_2O_3 (calculated)
3	Potash feldspar	Acid	0.22	0.31
3	Potash feldspar	Scrubbing	0.26	0.37
3	Soda-lime feldspar	Acid	0.30	0.43
3	Soda-lime feldspar	Scrubbing	0.47	0.67
3	Feldspathic rock fragments	Acid	0.82	1.17
6	Potash feldspar	Acid	0.12	0.17
12	Potash feldspar	Acid	0.07	0.10
12	Soda-lime feldspar	Acid	0.11	0.16
12	Feldspathic rock fragments	Acid	0.28	0.40
16	Potash feldspar	Acid	0.14	0.20
16	Potash feldspar	Scrubbing	0.14	0.20
16	Soda-lime feldspar	Acid	0.15	0.21
16	Soda-lime feldspar	Scrubbing	0.23	0.33
16	Feldspathic rock fragments	Acid	0.77	1.10
18	Potash feldspar	Acid	0.09	0.13
18	Soda-lime feldspar	Acid	0.39	0.56
18	Feldspathic rock fragments	Acid	0.64	0.92
21	Soda-lime feldspar	Acid	0.26	0.37
21	Feldspathic rock fragments	Acid	1.05	1.50

TABLE 5. CHARACTERISTICS OF ILLINOIS SANDS BEARING ON THEIR POSSIBLE VALUE AS SOURCES OF LOW-IRON FELDSPAR

Sand deposit	Sample numbers	Amount of feldspar			Ratio of feldspar to feldspathic rock fragments			Ratio of potash to soda-lime feldspar			Carbonate content	Amount of iron oxide grain coatings
		Small	Medium	Large	Low	Medium	High	Low	Medium	High		
Ohio River sands	1,2	X	X			X	X	X	X		Small	Small
Mississippi River sands below Missouri River	3,4			X	X				X		Small	Small
Mississippi River sands above Missouri River	5,6,7		X	X	X	X	X	X	X		Small or none	Small
Illinois River sands	8,9	X			X			X			Large	Small
Wabash River sands	10,11		X		X	X		X	X		Large	Small
Beach sands	12,13		X		X				X	X	Large	Small
Anna dune sand	14			X	X					X	None	Moderate
Kankakee area fine-grained dune sand	15,16			X			X			X	Small or none	Moderate
Havana and Lacon areas medium-grained dune sand	17,18		X			X	X		X	X	Small or none	Moderate
Rockford and eastern Prophetstown areas dune sand	19,20	X				X			X	X	Small or none	Moderate
Savanna area dune sand	21			X		X		X			None	Moderate

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