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COMMERCIAL FELDSPAR RESOURCES IN SOUTHEASTERN KANKAKEE COUNTY, ILLINOIS

Henry P. Ehrlinger III and John M. Masters

URBANA, ILLINOIS 61801

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ABSTRACT

This publication is the third in a series describing potentially commercial feldspar resources that occur in large deposits of unconsolidated surficial sand in five general areas of Illinois. All of the considerable tonnages of feldspar needed for industrial use in Illinois is at present imported from distant states. This report describes how at least a portion of this need could be produced within the state.

The large dune field of late Pleistocene age located in southeastern Kankakee County, part of the general area described in the first of this series, is one of the most promising areas for commercial production of feldspar. Several of the larger dunes were sampled and analyzed chemically and mineralogically in this study, and two representative samples were selected for extensive beneficiation tests. The tests were successful in producing high-quality feldspar concentrates and possible useful by-products. Significant progress was made toward reducing the residual iron oxide content of feldspar concentrates without reducing their alumina content.

During the study, a thick sand body was discovered underlying the dune ridges that considerably increases the previous estimates of the feldspar resource.

INTRODUCTION

The first of this series of investigations of potential feldspar sources in Illinois, described by Ehrlinger, ten Kate, and Jackman (1969), was exploratory in nature but generated commercial interest in the possibilities of developing the large dune field in southeastern Kankakee County as a source of feldspar. The beneficiation studies showed that a saleable grade

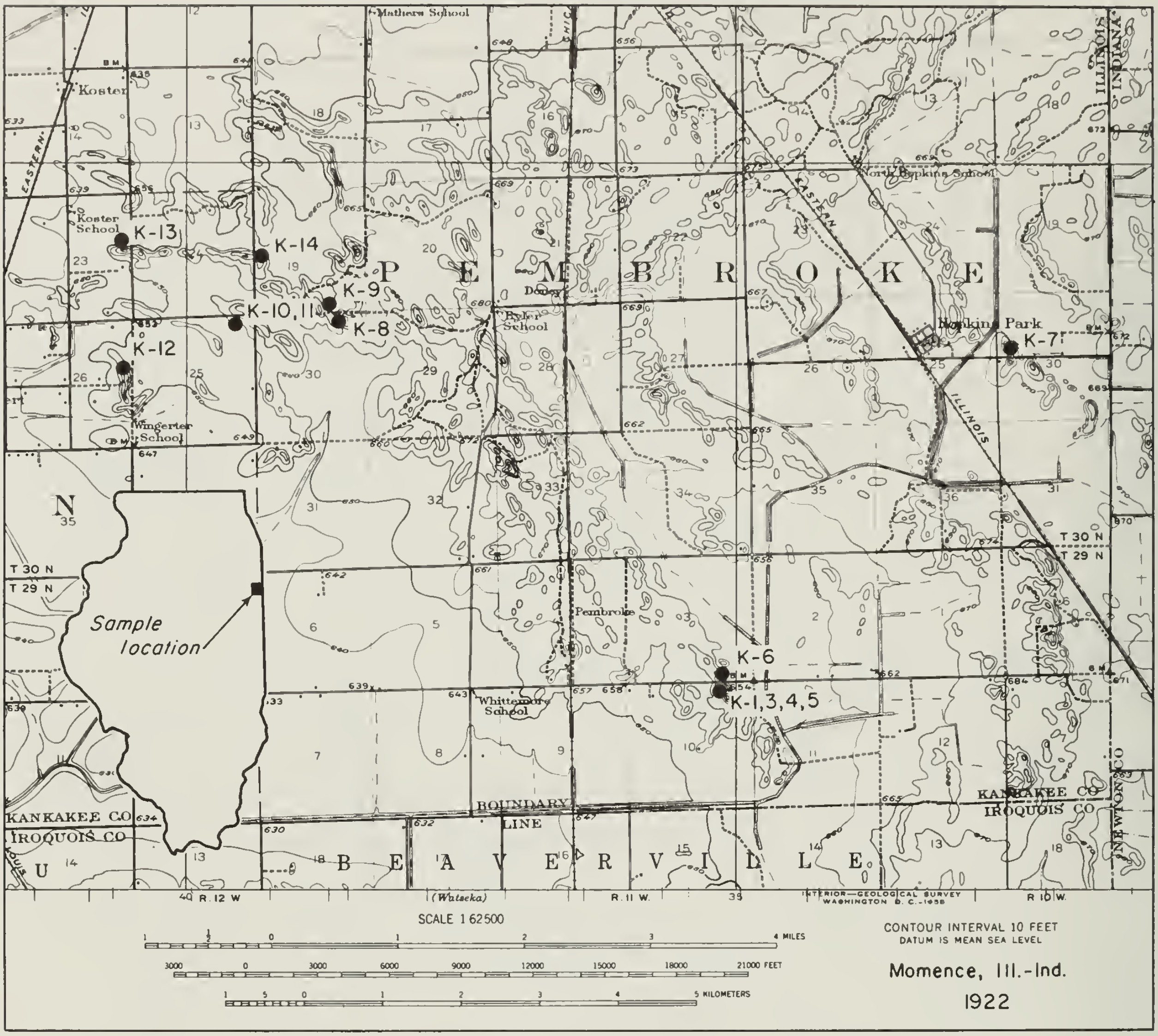


Fig. 1 - Locations from which samples were taken.

of feldspar concentrate could be made and that markets in Illinois could consume all the production of a reasonably large plant. Glass manufacturers, among others, would benefit by being able to obtain feldspar sands from Illinois rather than from traditional sources, such as South Dakota, North Carolina, and Ontario, Canada.

The present report continues the investigation and presents some new data on the thickness of sand that underlies the surficial dunes. Mineralogical and chemical data are given for 13 samples from surficial sites distributed over much of the dune field. New beneficiation studies have been made to determine the quality of feldspar concentrates and possible by-products that can be produced.

Acknowledgments

All chemical analyses were made by the Analytical Chemistry Section, Illinois State Geological Survey. The X-ray fluorescence tests were made by J. K. Kuhn and L. R. Henderson; the flame emission tests were made by L. R. Camp and D. B. Heck. Herbert D. Glass of the Stratigraphy and Areal Geology Section of the Survey supplied information on how to prepare, X-ray, and identify the clay minerals.

History of the Dune Field

The dune field is a prominent feature on the Momence, Illinois, 15-minute quadrangle, part of which is reproduced in figure 1 to show the sampling locations for this study. The dunes are concentrated in an area of about 50 square miles on the south side of the Kankakee Valley. The valley is bounded on the north and south by roughly parallel glacial ridges or moraines. The maximum difference in elevation in the area is only 100 feet. The highest dunes, about 700 feet above sea level, are as high as the segment of the St. Anne Moraine to the southwest. Most of the dunes are 15 to 25 feet high, although some reach 50 feet. The elevation of the well developed Valparaiso Morainic System, about 8 miles north of the dunes, is only slightly higher than the highest dunes. North of the dunes, the valley slopes gently downward for about 4 miles, from 650 feet to the 610-foot elevation of the Kankakee River. A more detailed physical description of the dune field was made by Willman (1942).

During the latter part of the Pleistocene Wisconsinan Stage, known as the Woodfordian Substage, the Kankakee Valley was part of the discharge system for the Kankakee Flood. The geologic events of this substage, summarized here, were treated more fully by Willman and Frye (1970, p. 34-36). During the Woodfordian Substage, the Lake Michigan Lobe of glacial ice was lying just north of the valley, building up the Valparaiso Morainic System and releasing an enormous volume of meltwater into the valley. When to this was added meltwater from the Saginaw Lobe and from the northwest side of the Erie Lobe, both draining westward from Indiana, the volume of water was too great for the then existing drainage through moraines to the south and west to carry away. The valley, therefore, filled with water during the time of greatest discharge. Lake conditions existed until the Illinois River, the major outlet for the floodwaters, had time to entrench its channel, improving drainage. As the ice lobes melted northward, their meltwaters abandoned the Kankakee Valley and established more efficient discharge channels. When the Kankakee Valley was finally drained, large areas of sand deposited by both lake and river waters were exposed to wind action in the Kankakee-Momence area, which resulted in the building of the present southeastern Kankakee County dune field. Most of the dunes were stabilized by vegetation cover soon after their formation; however, some large, recent blowouts are visible.

SAMPLING

The samples were collected in roadcuts through some of the larger dunes in southeastern Kankakee County. Thirteen samples were gathered from nine different sites (fig. 1). Channel samples were obtained from different intervals at

TABLE 1—SAMPLE LOCATIONS

Sample number*	Location	Sec.	T.	R.	Interval or length of channel sample (ft)	Remarks
K-1	± 1350' W of NE corner	10	29N	11W	25	South side of roadcut.
K-3	± 1350' W of NE corner	10	29N	11W	0-11	From road level upward.
K-4	± 1350' W of NE corner	10	29N	11W	11-19.5	Above road level.
K-5	± 1350' W of NE corner	10	29N	11W	19.5-25	Above road level. Several feet of sandy soil below surface of the dune not sampled.
K-6	± 1350' W of SE corner	3	29N	11W	5.5	North side of road on lee side of dune, from road level down toward base of dune.
K-7	2640' S, 500' E of NW corner	30	30N	10W	10.5	North side of roadcut.
K-8	975' W of NE corner	30	30N	11W	8	South side of roadcut.
K-9	1225' W of SE corner	19	30N	11W	8	North side of roadcut, 250 ft W of K-8.
K-10	200' W of NE corner	25	30N	12W	12-6.5	Above road level, south side of roadcut.
K-11	200' W of NE corner	25	30N	12W	6.5-0.5	Above road level, south side of roadcut.
K-12	1800' S, 300' W of NE corner	26	30N	12W	6-22	Interval above base of lee side of large dune.
K-13	1700' S of NE corner	23	30N	12W	3-10.5	Above road level, west side of roadcut.
K-14	2640' S of NW corner	19	30N	11W	3.5	East side of roadcut.

* Numbers refer to locations on figure 1.

the same site whenever possible to determine whether or not any significant differences could be expected at different depths in the dunes. Locations of the sampling sites appear in table 1. Sample K-2 was omitted from the series because it was a duplicate of K-1.

To determine the total thickness of sand in the area of the dune field, the drilling records for the area (on file at the Illinois State Geological Survey) were studied, and all available surficial sand samples taken during well drillings were inspected under a binocular microscope. Sand samples from 13 wells were studied, as were 108 well records.

A deposit of about 50 feet of clean sand was found in the center of the dune field, underlying the flat areas between the sand ridges. It thins toward the edges of the dune field, but has an average thickness of about 35 feet. Visual comparison indicates that this sand is quite similar in appearance to the K series samples taken for this study from the overlying dunes. Below the level of the thin, brownish black, sandy soil zone on the flat areas between the dunes, the sand is not leached or oxidized and has a low carbonate content. The presence of this thick, apparently continuous, sand body under the dune field increases the sand reserves of the area two to five times over previous estimates, which were based on the dunes alone.

TREATMENT OF SAMPLES

Chemical and mineralogical analyses were made on the dune sand samples as untreated sand, as sieved sand fractions, and as beneficiated sand fractions. Representative analyses are reported here to show the quality of the sand as a feldspar resource. The chemical analyses were made by standard laboratory procedures. Mineralogical methods of analyses, which are not as uniformly established between laboratories, are described in the following paragraphs.

Light Minerals

A 2- to 3-gram split of each sample was taken and acidized in a hot solution containing 20 percent hydrochloric acid (HCl) and 5 percent stannous chloride ($SnCl_2$), which dissolves iron hydroxide grain coatings, carbonate grains, and some heavy minerals. The samples were then further split with a miniature Jones-type riffle splitter to a size convenient for mounting on a 1- by 3-inch glass microscope slide. After they were mounted, the grains were etched and stained for identification purposes. The percentage of each mineral present was determined from about 400 point counts per slide, an operation facilitated by the Swift Automatic Point Counter. The observations were made with a binocular microscope with oblique illumination.

The basic procedure used to mount and stain the samples is outlined below. The use of a liquid tar mounting medium was suggested by Gross and Moran (1970). The feldspar staining technique used is more fully described by Reid (1969), who also gives variations of reagents, techniques, and basic literature references.

Reagents

Four reagents were used to prepare the samples:

1. Concentrated hydrofluoric acid (Technical, 52 to 55 percent).

2. Sodium cobaltinitrite; 120 grams dissolved in 200 milliliters of deionized water.

3. Rhodizonic acid dipotassium salt; 0.5 grams dissolved in 200 milliliters of deionized water.

4. Amyl acetate and liquid tar; about 10 drops of each mixed in a dropper bottle. Amyl acetate is added if mixture was not dilute enough to spread very smoothly and thinly over a glass slide.

Mounting

The sample number was engraved with a diamond scriber at one end of the 1- by 3-inch glass slide. One large drop of the tar mixture was applied to a slide and spread evenly, leaving one-half to three-fourths of an inch of the slide uncovered at each end. The tar was allowed to dry for half an hour, after which a representative sand sample was carefully sprinkled over the entire tarred surface to achieve a dense but even distribution. The tar was allowed to dry another half hour.

Staining

The grains on the tarred surface were etched with hydrofluoric (HF) fumes for 1¼ minutes, as described by Reid (1969), in batches of six slides. After they were etched, the slides were air dried, placed in a holder, and rapidly subjected to the following procedures: (1) submersion for 1 minute in the sodium cobaltinitrite solution; (2) gentle rinsing in two beakers of tap water; (3) dipping in the 5 percent barium chloride ($BaCl_2$) solution; (4) gentle rinsing in two beakers of tap water; (5) gentle rinsing in a beaker of deionized water; (6) submersion in the potassium rhodizonate solution just long enough for the red stain to develop—never more than 15 seconds; (7) gentle rinsing in two beakers of tap water; (8) quick but gentle drying with compressed air.

After the slides were stained, the major constituents were identified as: (1) quartz—colorless and transparent; (2) potassium feldspar—grains covered with a yellow stain; (3) sodium-calcium feldspar—grains covered with a red stain; (5) composite feldspar—grains with separate areas of yellow and red stains; (6) feldspathic rock fragments—grains with a stain; not pure feldspar; (7) chert—chalky-textured grains; and (8) heavy minerals (removed from some samples)—usually black or translucent grains.

TABLE 2—CHEMICAL ANALYSES OF THE DUNE SAND SAMPLES

Sample number	Analyses (%)						
	K_2O	Na_2O	CaO	Al_2O_3	SiO_2	Fe_2O_3	TiO_2
K-1	1.41	0.99	1.58	5.10	83.4	1.29	0.29
K-3	1.50	1.02	1.15	4.92	86.0	1.13	0.15
K-4	1.95	1.17	0.28	5.81	86.4	1.73	0.29
K-5	1.35	0.93	0.66	5.57	82.2	1.65	0.21
K-6	1.50	1.00	1.14	4.62	85.9	1.08	0.19
K-7	1.34	0.76	0.49	5.19	85.0	1.51	0.17
K-8	1.52	0.88	0.45	4.74	85.9	0.75	0.10
K-9	1.53	0.74	0.34	4.90	82.5	0.98	0.09
K-10	1.32	0.78	0.55	5.04	84.8	1.08	0.20
K-11	1.45	0.81	0.42	5.13	82.1	1.27	0.14
K-12	1.24	0.72	0.49	4.43	87.4	0.77	0.09
K-13	1.34	0.79	0.67	5.09	89.8	1.40	0.24
K-14	1.38	0.93	0.65	4.88	84.6	1.41	0.20

* All chemical analyses were made by the Analytical Chemistry Section, Illinois State Geological Survey. The X-ray fluorescence tests were made by J. K. Kuhn and L. R. Henderson; flame emission tests were done by L. R. Camp and D. B. Heck.

TABLE 3—MINERALOGICAL ANALYSES OF THE DUNE SAND SAMPLES

	Analyses (%)									
							Feldspar			
Sample number	Weight loss*	Quartz	Quartz and feldspar	Feldspathic rock fragments	Chert	Remaining heavy minerals	K	Na-Ca	Composite	Total
K-1	3.2	69.4	3.3	1.3	1.7	1.5	9.3	8.4	1.9	19.6
K-3	4.9	64.6	7.9	0.8	1.2	1.5	11.0	6.3	1.8	19.1
K-4	2.5	68.0	3.6	1.8	0.4	1.0	12.1	9.8	0.8	22.7
K-5	2.6	68.1	5.2	1.6	0.8	3.0	10.4	6.9	1.4	18.7
K-6	2.0	72.2	3.7	2.6	1.0	1.3	9.9	4.7	2.6	17.2
K-7	4.1	78.1	1.7	2.5	0.3	2.0	6.8	4.0	0.5	11.3
K-8	1.9	68.6	4.8	2.3	2.1	0.9	11.7	6.6	1.1	19.4
K-9	2.8	69.6	11.4	1.9	0.6	0.4	8.8	3.9	0.6	13.3
K-10	2.6	67.2	8.0	1.5	2.2	1.2	9.6	6.5	1.2	17.3
K-11	2.5	68.5	8.0	0.6	0.3	2.2	11.1	5.6	1.2	17.9
K-12	1.4	75.0	5.5	0.5	0.3	0.5	8.9	7.1	0.8	16.8
K-13	2.3	67.9	8.8	0.3	0.6	0.6	9.7	8.6	1.2	19.5
K-14	1.7	71.3	6.7	2.3	0.3	1.1	11.0	4.8	0.8	16.6

* After acidizing and washing, which removes carbonates, some heavy minerals, iron hydroxide, clay, and organic material.

Heavy Minerals

Heavy mineral separations and identifications were made on each whole sample of dune sand and on gravity and magnetic fractions from selected beneficiation series. A 60- to 80-gram split was taken from each whole sand sample, which was weighed and then soaked overnight in 200 milliliters of deionized water. Each sample was treated for 3 minutes with an ultrasonic probe to disaggregate small particles. About 100 milliliters of water containing very fine silt and clay-size particles was decanted for clay mineral analysis. The remaining very fine silt and clay-size particles were washed out of the sample, which was then dried and reweighed. At this point, heavy minerals were separated from each sample with bromoform by standard procedures (Krumbein and Pettijohn, 1938, p. 343).

Magnetite was then separated from the heavy mineral fractions with a strong hand magnet and weighed. The remaining heavy minerals were acidized to clarify the grains, and the loss in weight was recorded. Representative splits of each heavy mineral fraction were then taken and mounted on 1- by 3-inch glass slides in Canada balsam. Then about 400 point counts of each heavy mineral suite were made using a Swift Automatic Point Counter and a petrographic microscope.

Clay Minerals

Samples K-3 through K-11, K-13, and K-14 were examined to determine the presence of clay minerals. The very fine silt and clay-size material was centrifuged out of the 100 milliliters of water retained from the heavy mineral

TABLE 4—GRAIN SIZE FRACTIONS OF THE DUNE SAND SAMPLES

Sample number	Size fractions, Tyler Screen Series (%)*								Average particle size (µm)
	> 35	35 - 48	48 - 65	65 - 100	100 - 150	150 - 200	200 - 325	< 325	
K-1	0.08	9.16	32.31	34.22	14.35	8.38	1.21	0.29	167
K-3	0.11	14.05	36.86	30.21	11.91	5.87	0.78	0.21	180
K-4	0.03	4.84	26.53	32.71	23.56	10.58	1.50	0.25	151
K-5	0.01	5.92	26.39	33.58	21.39	10.86	1.51	0.34	153
K-6	0.08	12.71	40.50	31.39	10.84	4.08	0.32	0.08	183
K-7	2.11	39.26	30.60	16.46	6.05	3.79	1.03	0.70	222
K-8	0.18	5.83	33.30	41.79	12.46	5.53	0.62	0.29	166
K-9	0.16	7.55	31.18	43.15	12.48	4.00	0.58	0.90	168
K-10	0.09	12.59	43.77	29.94	8.05	4.20	0.54	0.82	184
K-11	0.04	8.28	36.47	35.96	12.11	5.52	0.71	0.91	171
K-12	0.08	23.95	47.31	20.49	5.97	1.93	0.15	0.12	207
K-13	0.01	8.14	43.32	29.93	11.44	5.57	0.86	0.73	175
K-14	0.01	5.19	37.64	36.76	14.33	5.33	0.39	0.35	167

* Tyler Screen Series

Meshes per inch		Opening in µm		Wentworth grain size classes†
35	=	417		Medium sand
48	=	295		
			250 µm	
65	=	208		Fine sand
100	=	147		
			125 µm	
150	=	104		Very fine sand
200	=	74		
			63 µm	
325	=	43		Silt

† Krumbein & Pettijohn, 1938, p. 80.

separations. These solids were then resuspended in 30 milliliters of water. After the sediment had settled, fractions containing suspended clay-size material were drawn off with an eyedropper and spread on glass slides. The clay mineral content was so low that several applications were necessary to build up enough oriented clay-size material on the slides to obtain adequate X-ray patterns. Diffraction patterns of each sample were run on a Norelco X-ray unit after glycolation and again after the sample had been heated at 300° C for 1 hour.

SAND SAMPLES

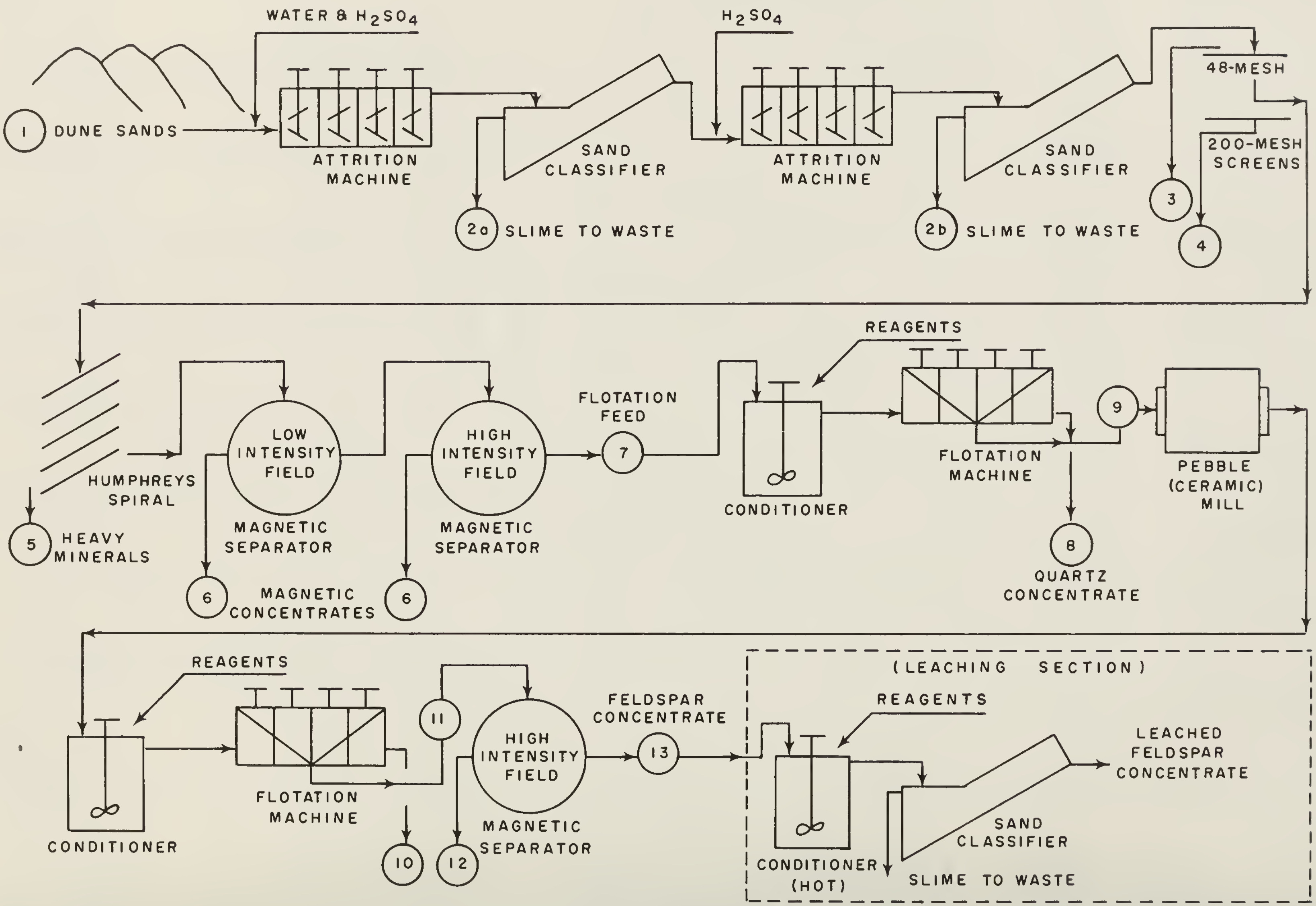
Chemical analyses of each sample are shown in table 2. The mineralogical analyses of each sample are shown in table 3. These tables show that the alumina content varies from 4.43 to 5.81 percent, while the total feldspar in the samples varies from 11.3 to 22.7 percent. Of the total feldspar, the potassium feldspars average 10.0 percent, the sodium-calcium feldspars average 6.4 percent, and the composite feldspar grains average 1.2 percent. The alumina content of the samples is predominantly in the feldspar, but it is also present in the much less abundant feldspathic rock fragments, some heavy minerals, and the clay minerals. The silica in the samples is predominantly in the quartz, but it is also present to a much lesser extent in the rest of the mineral fractions. The average quartz content is 69.9 percent, ranging from 64.6 to 78.1 percent. These chemical and mineralogical analyses agree very closely with those of samples from the same area reported by Willman (1942) and by Ehrlinger, ten Kate, and Jackman (1969).

A separate study was made on the heavy mineral fraction of each dune sample. This fraction averaged 2.4 percent of the total weight of each sample. Individual minerals do vary slightly in percentage between samples, but the suite of minerals present is nearly identical in all samples.

The clay minerals, determined by X-ray diffraction in 11 samples out of the total 13, make up less than 0.5 percent of each sample. The most abundant clay minerals are chlorite-vermiculite and illite. They form three clay mineral assemblages, two samples in which illite is dominant and chlorite-vermiculite in minor amounts, four samples with approximately equal amounts of illite and chlorite-vermiculite, and five samples in which chlorite-vermiculite is dominant and illite is a minor constituent. Distribution of these assemblages in the dune field forms no regular pattern. However, as the deepest samples from a dune were dominantly illite and an overlying sample fell into the equal illite and chlorite-vermiculite group, it is possible that there is some vertical zonation of the clay minerals—the dominantly illite group representing deeper, incompletely leached sand, the group equal in illite and chlorite-vermiculite coming from shallower sand, and the dominantly chlorite-vermiculite group being from the shallowest, most weathered sand. This possibility cannot be verified by the samples used in this study because they represent thick intervals that may be affected by slumping.

TABLE 5—CHEMICAL ANALYSES OF THE < 48- AND > 200-MESH SAND

Sample number	% of original weight	Analyses (%)						
		K_2O	Na_2O	CaO	Al_2O_3	SiO_2	Fe_2O_3	TiO_2
K-1	89.26	1.42	0.98	1.45	5.11	83.0	1.17	0.17
K-3	84.15	1.49	1.01	1.30	4.94	85.6	1.14	0.17
K-4	93.41	1.88	1.13	0.23	5.55	86.4	1.17	0.23
K-5	92.22	1.51	0.99	0.67	5.80	81.9	1.63	0.18
K-6	86.81	1.45	0.91	1.20	4.69	86.8	1.12	0.16
K-7	56.90	1.48	0.84	0.57	5.60	84.5	1.86	0.27
K-8	93.08	1.45	0.84	0.50	4.63	85.8	0.70	0.09
K-9	90.81	1.64	0.82	0.36	5.00	82.4	0.96	0.12
K-10	85.96	1.34	0.72	0.47	4.93	84.6	1.03	0.17
K-11	90.06	1.49	0.79	0.38	5.12	81.7	1.21	0.12
K-12	75.70	1.32	0.73	0.44	5.09	87.1	0.83	0.07
K-13	90.26	1.26	0.84	0.63	5.26	90.2	1.47	0.21
K-14	94.06	1.41	0.94	0.67	4.70	85.0	1.35	0.17



(Illinois State Geological Survey, 1974)

Fig. 2 - Schematic flowsheet of the beneficiation processes used to separate the feldspar from the dune sands. The circled numbers refer to the sample fractions listed on tables 6 and 7.

The only samples (K-1, K-3, and K-4) in this study found to be calcareous are from a roadcut through a dune (fig. 1, table 1) that exposes about 25 feet of sand. In this dune, carbonates have been completely leached from the sand to a depth of about 10 feet. Sample K-3 contained the most carbonate (less than 4 percent), effervescing freely when treated with acid and losing more weight than the other acidized samples. Samples K-1 and K-4 effervesced only slightly. The petrographic microscope revealed both calcite and dolomite in these three samples.

The grain sizes shown in table 4 reveal that the sand is well sorted and varies from medium to fine, a conclusion that agrees very closely with the physical description of dune sands given by Willman (1942, p. 15-19). Some larger grains are well rounded, but the sand as a whole is subrounded, and roundness decreases rapidly with grain size. The sand with the greatest average grain size (K-7) has the lowest feldspar content, and the sand with the finest average grain size (K-4) contains the highest percentage of feldspar (tables 3 and 4). Although this relation did not exist for all of the intermediate size samples, in nearly every sieve fraction of individual samples the feldspar content increased with decreasing grain size. Decrease in grain size also was accompanied by an increase in heavy mineral grains and a decrease in feldspathic rock fragments. Tables 2 and 4 show that the samples with fine average grain sizes have the highest iron and titanium oxide contents. We therefore decided to eliminate the coarser than 48-mesh sand because of its low alumina content and the finer than 200-mesh sand (even though it is high in alumina) because of its high iron and titanium oxide content. This practice would also provide a uniform product, which is very important for optimum plant operation. The chemical analyses of the material from finer than 48- to coarser than 200-mesh are shown in table 5.

BENEFICIATION

Samples K-1 and K-12 were selected for detailed beneficiation tests after the chemical and mineralogical results of the 13 sand samples had been compared and the locations from which they were obtained in the dune field had been examined. Both samples came from areas that have sufficient reserves to sustain an operation, and hauling expense to the plant would not be prohibitive. K-1 contains more feldspar than K-12, but they are sufficiently representative of the dune field to allow the results of this study to be used to evaluate the area.

The beneficiation procedure used on samples K-1 and K-12 is illustrated on the schematic flowsheet (fig. 2), which is essentially an outline of the following discussion. However, it should be noted that the last conditioner and classifier steps enclosed in dashed lines represent laboratory conditions and not simulated plant conditions.

Tables 6 and 7 present chemical analyses and recoveries of the beneficiation products of K-1 and K-12 that were progressively removed from the raw sands to produce the final feldspar concentrates. Each step is listed on the tables, and numbers key them to figure 2. The beneficiation treatment of the samples included attrition, removal of the coarser than 48- and finer than 200-

TABLE 6—BENEFICIATION DATA FOR SAMPLE K-1, TEST B-II

		Dry weight		Analysis (%)							Recoveries (% of sample)						
No.*	Product	Grams	% Total	K_2O	Na_2O	CaO	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	K_2O	Na_2O	CaO	Al_2O_3	SiO_2	Fe_2O_3	TiO_2
1	Calculated feed	6011.2	100.00	1.63	0.94	1.26	4.43	83.57	1.27	0.18	100.0	100.0	100.0	100.0	100.0	100.0	100.0
2	Combined slimes	149.7	2.49	2.40	0.71	5.06	13.62	45.67	8.64	0.54	3.7	1.9	10.0	7.6	1.4	17.0	7.3
3	> 48-mesh sand	709.3	11.80	0.84	0.55	0.67	2.85	89.89	0.23	0.03	6.1	6.9	6.3	7.6	12.7	2.1	1.9
4	< 200-mesh sand	22.2	0.37	2.25	1.80	4.47	7.22	73.94	0.38	0.15	0.5	0.7	1.3	0.6	0.3	0.1	0.3
5	Combined gravity	181.1	3.02	0.84	0.77	6.42	7.02	50.23	19.04	4.05	1.6	2.5	15.4	4.8	1.8	45.3	66.5
6	Combined magnetics	288.9	4.80	1.56	1.69	3.76	9.00	66.42	5.55	0.61	4.6	8.7	14.3	9.7	3.8	21.0	15.9
7	Flotation feed	4660.0	77.52	1.76	0.96	0.86	3.98	86.33	0.24	0.02	83.5	79.3	52.7	69.7	80.0	14.5	8.1
8	Rougher tailing	3427.7	57.02	0.10	0.24	0.31	0.44	93.53	0.13	0.02	3.4	14.6	14.0	5.8	63.8	5.8	6.2
9	Rougher concentrate	1232.3	20.50	6.37	2.95	2.38	13.84	65.93	0.53	0.02	80.1	64.7	38.7	63.9	16.2	8.7	1.9
10	Cleaner tailing	399.1	6.64	1.86	1.17	3.91	5.44	75.46	0.65	0.02	7.6	8.3	20.6	8.1	6.0	3.4	0.7
11	Cleaner concentrate	833.2	13.86	8.53	3.80	1.65	17.86	61.36	0.48	0.02	72.5	56.4	18.1	55.8	10.1	5.3	1.2
12	Feldspar magnetics	9.4	0.16	4.96	3.34	3.05	16.72	57.29	2.83	0.51	0.5	0.6	0.4	0.6	0.1	0.4	0.4
13	Feldspar concentrate	823.8	13.70	8.57	3.81	1.63	17.87	61.41	0.45	0.01	72.0	55.8	17.7	55.2	10.1	4.9	0.8

* Number indicates the location of the product on the schematic flowsheet (fig. 2). Weights and recoveries of product 1 equal those of products 2 + 3 + 4 + 5 + 6 + 8 + 10 + 12 + 13; weights and recoveries of product 7 equal those of products 8 + 9; weights and recoveries of product 9 equal those of products 10 + 11; and those of product 11 are equal to those of products 12 + 13.

TABLE 7—BENEFICIATION DATA FOR SAMPLE K-12, TEST B-IV

		Dry weight		Analysis (%)							Recoveries (% of sample)						
No.*	Product	Grams	% Total	K_2O	Na_2O	CaO	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	K_2O	Na_2O	CaO	Al_2O_3	SiO_2	Fe_2O_3	TiO_2
1	Calculated feed	6022.8	100.00	1.44	0.74	0.40	3.80	90.58	0.83	0.11	100.0	100.0	100.0	100.0	100.0	100.0	100.0
2a	Primary slime	123.9	2.06	2.33	1.21	0.84	18.65	54.30	8.19	0.77	3.4	3.4	4.3	10.1	1.2	20.3	14.7
2b	Secondary slime	19.8	0.33	2.40	2.08	1.22	14.45	67.30	6.80	0.73	0.5	0.9	1.0	1.3	0.2	2.7	2.2
3	> 48-mesh sand	1378.1	22.88	0.96	0.57	0.31	2.94	95.15	0.46	0.03	15.3	17.6	17.5	17.7	24.1	12.6	6.4
4	< 200-mesh sand	7.0	0.11	1.75	1.95	2.53	8.55	73.39	9.04	2.08	0.1	0.3	0.7	0.2	0.1	1.2	2.1
5	Gravity concentrate	129.4	2.15	1.30	0.74	2.34	5.89	77.12	9.24	2.01	1.9	2.1	12.5	3.3	1.8	23.8	40.0
6	Magnetic concentrate	116.7	1.94	1.70	1.63	3.07	8.92	73.45	7.15	0.82	2.3	4.3	14.8	4.6	1.6	16.7	14.7
7	Flotation feed	4247.9	70.53	1.56	0.75	0.28	3.38	91.18	0.27	0.03	76.5	71.4	49.2	62.8	71.0	22.7	19.9
8	Rougher tailing	3570.5	59.29	0.11	0.09	0.08	0.60	96.84	0.21	0.03	4.6	7.2	11.6	9.4	63.4	14.9	16.6
9	Rougher concentrate	677.4	11.24	9.18	4.24	1.35	18.04	61.31	0.57	0.03	71.9	64.2	37.6	53.4	7.6	7.8	3.3
10	Cleaner tailing	28.6	0.47	2.28	1.93	0.65	6.19	80.15	0.69	0.06	0.7	1.2	0.8	0.8	0.4	0.4	0.3
11	Feldspar concentrate	648.8	10.77	9.50	4.34	1.38	18.56	60.49	0.57	0.03	71.2	63.0	36.8	52.6	7.2	7.4	3.0

* Number indicates the location of each product on the schematic flowsheet (fig. 2). Weights and recoveries of product 1 equal those of products 2a + 2b + 3 + 4 + 5 + 6 + 8 + 10 + 11; weights and recoveries for product 7 equal those of products 8 + 9; weights and recoveries for product 9 equal those of products 10 + 11.

mesh sand, gravity separation, magnetic separation, rough flotation, milling, and cleaner flotation. An additional magnetic separation was added for the feldspar concentrate of sample K-1.

The experience gained in the two previous feldspar beneficiation studies of this series by Ehrlinger, ten Kate, and Jackman (1969) and Ehrlinger and Jackman (1970), prompted us to subject the raw dune sand (fig. 2, no. 1) to two attrition stages. One pound of sulfuric acid was used per ton of sand in each stage. Attrition is an established commercial process in which the grains are driven against each other in a slurry to produce a scrubbing action that, aided by the sulfuric acid, disaggregates the clays and removes most of the hydrated iron oxides from the surface of the sand grains, both of which results are necessary prior to subsequent beneficiation. The removed slimes (fig. 2, no. 2) have a high alumina content, but they are basically clay, have a high iron oxide content, and would not be marketable as part of the feldspar product. The pound of sulfuric acid used per ton of sand in each stage of attrition is not a rigid ratio, and operating plants should determine the optimum quantity by experimentation.

Following the two attrition steps, the coarser than 48-mesh material (fig. 2, no. 3) was removed. This relatively low-alumina product could be sold as a clean, washed, sized sand. It is also quite low in iron and titanium oxide content. The finer than 200-mesh sand (fig. 2, no. 4) also was removed at this time. Heavy minerals could be separated from this fraction and sold with the gravity concentrate removed at step 5 (fig. 2) as a raw, heavy mineral product. In step 5, the deslimed sands (finer than 48- to coarser than 200-mesh) were subjected to a gravity separation process for the removal of heavy minerals. Humphreys spirals or shaking tables would be most applicable for this process, which removes heavy mineral grains that contain calcium, magnesium, iron, or titanium. In test K-1 (table 6) the gravity concentrate was responsible for only 3.02 percent of the sample's original weight, yet it contained 15.4 percent of the original calcium oxide content, 45.3 percent of the original iron oxide content, and 66.5 percent of the original titanium oxide content. About 75 percent of the gravity concentrate consists of, in order of abundance, hornblende, ilmenite, garnet, magnetite, and rock fragments. The more valuable heavy minerals, such as zircon, rutile, and monazite, make up less than 5 percent of the concentrate. Any marketable, heavy mineral product would come from the gravity concentrate, possibly combined with heavy minerals from the finer than 200-mesh sand fraction, because the bulk of the purer heavy mineral grains is concentrated in these two by-products. As gravity separation is a low-cost operation, it should receive favorable consideration in a plant flowsheet.

The tailings from the gravity separation were next subjected to a wet magnetic process. In the laboratory test the sands were passed through a Carpco Wet Magnetic Separator, Model MWL 3465, at field current settings of 0.25, 1.00, 2.50, and 5.00 amperes. In a plant operation, no more than two intensities, and perhaps only one, would be required. The combined magnetic concentrate of sample K-1 (table 6) included 14.3 percent of the calcium oxide content, 21.0 percent of the iron oxide content, and 15.9 percent of the titanium oxide content, although it accounted for only 4.80 percent of the original weight. Nearly 80 percent of the magnetic concentrate consists of hornblende and rock fragments and a smaller amount of magnetite.

At this point the beneficiation of the flotation feed was completed. The chemical analyses of the K-1 and K-12 flotation feeds are given in step 7 of tables 6 and 7, respectively. Each step leading up to this point, with the exception of the removal of the coarser than 48-mesh material, significantly reduces the calcium, iron, and titanium oxide contents. The arrangement of the beneficiation steps from the attrited feed to the flotation feed is not critical to the subsequent flotation steps, but it is critical if specific by-products, such as the gravity concentrate, are to be sold.

The flotation feed (fig. 2, no. 7) is a nearly pure quartz-feldspar sand that could be added just as it is to the sand used in glass making, the quantity used depending on the chemical requirements of individual operations. The residual iron oxide content of two small splits from K-1 and K-12 flotation feed samples was reduced to less than 0.005 percent by acid leaching without reducing the alumina content.

The last major process in beneficiation is the separation of the feldspar from the quartz by flotation (fig. 2, nos. 8 through 11). The pulp was conditioned with one pound of concentrated (48 percent) hydrofluoric acid per ton for 8 minutes, next with 0.5 pounds of Delamate 81 Reagent (Hercules) per ton for 4 minutes, and finally floated with methyl isobutyl carbinol, as needed, for 8 minutes. The rougher tailing is a very clean quartz concentrate (fig. 2, no. 8) that should be marketable for various uses, such as a high-quality concrete sand.

The rougher concentrate (fig. 2, no. 9) is slurried at a high solid to liquid ratio and ground for 20 minutes with ceramic grinding balls in a ceramic mill. This step is designed not to break grains but to further scrub the surfaces of the feldspar grains. The rougher concentrate was again conditioned with hydrofluoric acid and Delamate 81 and then floated without frother to produce the cleaner tailing (fig. 2, no. 10) and cleaner concentrate (fig. 2, no. 11). After it was dried, the cleaner concentrate was passed through a Carpco Induced Roll Magnetic Separator, Model M 127, from which a very small percentage of slightly magnetic grains were removed (fig. 2, no. 12).

The feldspar concentrate from test K-1, B-II (table 6, no. 13) at this point had the following chemical analysis (in percent): potassium oxide, 8.57; sodium oxide, 3.81; calcium oxide, 1.63; alumina, 17.87; silica, 61.41; iron oxide, 0.45; and titanium oxide, 0.01. The ratio of concentration (R/C) was 7.30; it represents the number of tons of raw sand required to produce one ton of feldspar concentrate.

With the exception of the iron oxide content, the material left at no. 13 is quite a high quality feldspar concentrate, and, as pointed out by Ehrlinger, ten Kate, and Jackman (1969), there is an adequate market for feldspar in northeastern Illinois. The problem of reducing iron oxide content without reducing the alumina content has arisen in all past feldspar studies of Illinois sand (Willman, 1942, p. 13; Hunter, 1965, p. 5; Ehrlinger, ten Kate, and Jackman, 1969, p. 16; and Ehrlinger and Jackman, 1970, p. 8). Willman (1942, p. 16) and Hunter (1965, p. 5) had significantly reduced the iron oxide content of sand samples by using an acid treatment. During this study the residual iron oxide content of several flotation feeds and quartz and feldspar concentrates was lowered considerably by acid leaching while the alumina

TABLE 8—COMPOSITION OF SELECTED FELDSPAR CONCENTRATES

Sample and test	Chemical analyses (%)							
	K_2O	Na_2O	CaO	Al_2O_3	SiO_2	Fe_2O_3	TiO_2	R/C
a K-12, C-I	8.99	3.65	1.06	17.5	59.6	0.28	0.02	8.15
b K-12, C-II	8.60	4.11	1.29	20.4	61.5	0.33	0.03	8.37
c K-12, C-III (> 65 m only)	9.70	3.96	1.24	19.4	64.2	0.21	0.04	29.49
d K-12, C-III (65 to 200 m)	9.15	3.90	1.36	19.3	63.0	0.24	0.06	18.01
e K-12, C-III (c + d)	9.33	3.92	1.32	19.3	63.5	0.24	0.05	11.18

content remained stable. For example, a sample of the K-1, B-II, final feldspar concentrate was treated under laboratory conditions for 15 minutes in a hot (approximately 90° C) acid solution containing 20 percent by volume of concentrated hydrochloric acid and 5 percent by weight of stannous chloride (Krumbein and Pettijohn, 1938, p. 48). The sample was then reanalyzed for iron and was found to contain only 0.04 percent, well below the maximum allowable in glass of flint grade, while the alumina content remained stable.

Although this precise treatment may not prove economical, it does indicate that most of the iron oxide in the quartz and feldspar concentrates occurs in a residual surface coating. This fact had been suspected because binocular microscope observations of feldspar concentrates under oblique illumination had revealed that some patches of orange-red grain coatings remained in the surface irregularities of some grains. Hunter (1965, p. 8-9) clearly illustrated that some feldspar grains contain inclusions of iron-bearing minerals and alteration products. However, our study has shown that most of those grains were rejected during the magnetic separation stages of beneficiation. Therefore, further experimentation with methods convertible to plant scale is highly recommended for this phase of beneficiation of feldspar from Illinois.

The feldspar concentrate from test K-12, B-IV (table 7, no. 11) had a chemical analysis similar to that of sample K-1. Percentages were: potassium oxide, 9.50; sodium oxide, 4.34; calcium oxide, 1.38; alumina, 18.56; silica, 60.49; iron oxide, 0.57; and titanium oxide, 0.03. The ratio of concentration was 9.28. The iron oxide content of this feldspar concentrate was reduced to 0.18 percent by the hydrochloric-stannous chloride treatment with no reduction in alumina content. In this test the dry magnetic separation after final flotation was eliminated, which might account for the fact that K-12 had a final iron oxide content higher than that of K-1.

In the final phase of testing, another short series was run on sample K-12 with some variations not shown on the flowsheet (fig. 2). The coarser than 48-mesh sand was left in the feed and the finer than 150-mesh (rather than the finer than 200-mesh) sand was eliminated prior to flotation. The over-all quantity of coarser than 48-mesh sand in the dune field may be large enough to justify further beneficiation, since 24 percent of the total weight of sample K-12 (table 4) is in the coarser than 48-mesh fraction, which contains 14 percent feldspar. The resulting feldspar concentrates were as good as those of the preceding tests. Alumina was generally more plentiful and iron oxide less so than they were in the tests in which the finer than 200-mesh material was eliminated. The compositions of several feldspar concentrates derived by this procedure are shown in table 8. In most of these feldspar concentrates, later acidation resulted in iron oxide reductions similar to those reported in the preceding paragraphs.

PRODUCTION EFFECTS

A recent paper by Philip Loughman, "Feldspar Production Potential of Local Sand Dunes in Southeastern Kankakee County, Illinois," written for a landscape architecture project at the University of Illinois, is on file at the Illinois State Geological Survey. Using the product ratios given by Ehrlinger, ten Kate, and Jackman (1969), Loughman designated primary and secondary sites for a feldspar plant that could produce 100,000 tons of feldspar per year. The plant would have a productive life of 27.5 years, would be within a radius of 2 miles of the raw sand, would not detract from the beauty of the dunes, and would allow the natural resources to be developed without adding to existing railways and roads.

Loughman's estimated life for the plant considered only sand in the surficial dunes. The additional underlying sand deposit found during our study could increase the productive life of the plant to from 55 to 137 years.

CONCLUSIONS

The dune field of southeastern Kankakee County, which extends over an area of approximately 50 square miles, is an enormous potential source of feldspar. As a result of this study, the following conclusions about this natural resource can be drawn:

(1) The surficial sand is reasonably uniform in its feldspar content, and the feldspar content is related more to the grain-size distribution than to the sample location.

(2) The thick sand body underlying the surficial dune field increases previous estimates of the area's feldspar reserves two to five times.

(3) The sand's response to beneficiation techniques seems to be about the same in each area tested.

(4) As the testing program used scaled-down commercial processes, feldspar produced on a large scale in a commercial plant should be at least as good as the feldspar concentrates produced in this testing program.

(5) Additional acidation tests indicated that the iron oxide content of the feldspar concentrates

produced in this testing program can be greatly reduced with no reduction in alumina.

(6) Several by-products might be saleable. Included are a clean, washed sand separated by sieving before flotation and a quartz sand separated by flotation, both of which would possibly be marketable as concrete additives. The heavy mineral concentrates might be sold as a raw material to heavy minerals producers.

REFERENCES

Ehrlinger, H. P. III, W. G. ten Kate, and H. W. Jackman, 1969, Kankakee dune sands as a commercial source of feldspar: Illinois Geol. Survey Industrial Minerals Note 38, 17 p.

Ehrlinger, H. P. III, and H. W. Jackman, 1970, Lower Mississippi River terrace sands as a commercial source of feldspar: Illinois Geol. Survey Industrial Minerals Note 43, 18 p.

Gross, D. L., and S. R. Moran, 1970, A technique for the rapid determination of the light minerals of detrital sands: Jour. Sedimentary Petrology, v. 40, no. 2, p. 759-761.

Hunter, R. E., 1965, Feldspar in Illinois sands—A further study: Illinois Geol. Survey Circ. 391, 19 p.

Krumbein, W. C., and F. J. Pettijohn, 1938, Manual of sedimentary petrography: Appleton-Century-Crofts, New York, 549 p.

Reid, W. P., 1969, Mineral staining tests: Colorado School of Mines, Mineral Industries Bull., v. 12, no. 3, 20 p.

Willman, H. B., 1942, Feldspar in Illinois sands—A study of resources: Illinois Geol. Survey Rept. Inv. 79, 87 p.

Willman, H. B., and J. C. Frye, 1970, Pleistocene stratigraphy of Illinois: Illinois Geol. Survey Bull. 94, 204 p.

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