

PLANT AND LABORATORY PRACTICE  
IN NONMETALLIC MINERAL FLOTATION

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ABSTRACT

Important industrial minerals are separated and concentrated by froth flotation by industry today. The following descriptions are presented as an overview of the methods employed to separate and recover a few of these industrial minerals. The minerals described in this section of the book are not, by any means, the only important minerals treated by froth flotation. Other minerals, such as calcite, kaolin, wollastonite, rare earths and vermiculite were not included, primarily due to the confidential nature of the information held by the Minerals Research Laboratory and the Colorado School of Mines Research Institute.

Flotation of nonmetallic minerals is sometimes viewed as alchemy. However, the art is, in reality, based on sound chemistry, experience and a little luck in the treatment of new ores. In the flotation of nonmetallic minerals, as opposed to base metal sulfides, highly specific treatment conditions are required to accomplish separations.

The presentation of the treatment of each of the minerals described was outlined as follows:

DEPOSITS  
PROCESSING  
SPECIFICATIONS  
FLOWSHEETS (in some cases)

A presentation of the factors, often critical, which must be carefully investigated to accomplish successful flotation of nonmetallic minerals is presented in the section on Sulfonate Collectors, elsewhere in this volume.

BARITE

DEPOSITS

Barite is found in a variety of environments, either along with, or in combination with, such minerals as fluorite, celestite, quartz, galena and sphalerite. The three important types of barite deposits are classified as vein, residual and bedded. Impurities included with the deposits range from carbonates, to quartz, to clay and quartz mixtures with iron oxides. Over the history of barite production in the United States, more barite has been produced from the residual than from any other type of deposit. However, since 1944, the bedded types of deposits have accounted for the majority of the barite production.

PROCESSING

Fine grained deposits, or the rejects from gravity concentration operations, are ball mill ground to liberation, which could be as coarse as 40 mesh or as fine as 325 mesh. With coarse grinds, the ore may be deslimed in high pressure cyclones at 5 to 10 microns before conditioning. When a minus 325 mesh grind is employed, the ore is only densified, before feeding to the conditioners. Petroleum sulfonate, or mixtures of sulfonates, can be employed to float the barite from the gangue minerals of: calcite, dolomite, fluorite, silica, clay and iron minerals.

Conditioning takes place at 25 to 50% solids at 8.5 to 9.2 pH, with 0.25 to 0.75 kg/ton (0.5 to 1.5 lb/ton) of sulfonate or sulfonate mix collector. The amount of collector added depends upon the amount of barite in the pulp. Additionally, if the ore has not been

deslimed, the reagent requirements will be higher than with a deslimed pulp containing the same amount of barite. The conditioning usually takes place in two or more stages, with the pH adjustment reagents (NaOH or sodium silicate), added to the first conditioner and the collector added to the second conditioner. Frother is added as required, as is fuel oil, to stabilize the froth. After conditioning, the pulp is diluted to 25 to 30% solids and the barite is floated. The froth is cleaned one to three times with no additional reagents. The cleaned froth is thickened, filtered and dried.

If high brightness barite is required, the filter cake is bleached or leached to remove iron or carbon impurities. After processing, the final barite is dried and, if required, dry ground before packaging.

If the final barite product is to be used as a weighting agent in drilling, the flotation reagent must be destroyed, or it will cause frothing during drilling. To destroy sulfonate-type reagents, the temperature in the dryers is increased to 400 to 500 degrees Fahrenheit.

#### SPECIFICATIONS

Barite sold for drilling mud weighting agent is generally sold on the basis of specific gravity. A specific gravity of at least 4.00 and preferably 4.30 is generally required. The product should be free of soluble salts and be ground to at least 90% -325 mesh.

For chemical use, barite concentrates should contain at least 95% BaSO<sub>4</sub> and preferably 98% BaSO<sub>4</sub>. The material should be low in SiO<sub>2</sub>, less than 1% Fe<sub>2</sub>O<sub>3</sub>, only trace amounts of fluorine and, in the case of pharmaceutical grades, less than 1% SrSO<sub>4</sub>.

Barite for glass and ceramic uses requires additional cleaning of the flotation product to remove other contaminants by either magnetic separation, chemical leaching or a combination of both.

### BORATES

#### DEPOSITS

The average concentration of boron in the earth's crust is estimated at only 3 ppm and 4.6 ppm in seawater. There are, however, concentrations of boron in evaporate deposits where mining

operations can extract borates. Minerals such as borax (sodium borate), ulexite (calcium-sodium borate) and colemanite (calcium borate) are mined and concentrated, but at present, only colemanite has been concentrated by flotation.

#### PROCESSING

Colemanite ores containing 20 to 40% B<sub>2</sub>O<sub>3</sub> can be crushed and ground to pass 20 mesh in standard crushing and ball mill grinding circuits. The ground ore should then be deslimed in high pressure cyclones in two stages. Where high clay contents are encountered, the deslimed pulp is scrubbed and deslimed again. Conditioning of the deslimed pulp can be conducted at low pulp density, 20 to 40% solids (to prevent scrubbing the collector off the surface of the colemanite grains), with 0.5 to 1.0 kg/ton (1 to 2 lb/ton) of feed of a mixture of sulfonate collectors. Additions of starch, dextrin and quebracho can be employed to depress carbonates. No frother is needed, and flotation takes place at a natural pH of about 8 to 9. After flotation, the colemanite froth is cleaned to upgrade the concentrate to above 45% B<sub>2</sub>O<sub>3</sub>. Cleaner tailings are analyzed and, depending upon the grade, are recirculated or rejected with the rougher flotation tailings.

If the flotation feed has not been thoroughly deslimed, the froth during cleaner and rougher flotation will be difficult to control.

#### SPECIFICATIONS

The major use for colemanite is in the manufacture of fiberglass. The following specifications are typical for colemanite:

Table 1. Specifications for colemanite for fiberglass manufacture

	Maximum %	Minimum %
B <sub>2</sub> O <sub>3</sub>	44.0	36.0
SiO <sub>2</sub>	2.5	--
Fe <sub>2</sub> O <sub>3</sub>	0.5	--
Al <sub>2</sub> O <sub>3</sub>	1.0	--
CaO	32.5	31.0
MgO	1.0	--
Na <sub>2</sub> O & K <sub>2</sub> O	1.0	--
SrO	1.9	--
SO <sub>3</sub>	1.5	--
H <sub>2</sub> O (free)	1.0	--
As (ppm)	100	--
MnO (ppm)	<10	--
Cr <sub>2</sub> O <sub>3</sub> (ppm)	<10	--
Ni (ppm)	<10	--
Co (ppm)	<10	--
Cu (ppm)	<10	--
V (ppm)	<10	--
Refractory		
Heavy Minerals	NONE	--
<u>Size</u>		
+40 mesh	<1	--
+70 mesh	<7	--
+200 mesh	<65	--
-325 mesh	--	60

## FELDSPAR AND BY-PRODUCT MICA AND QUARTZ

DEPOSITS

Glass grade and ceramic grade feldspar products are produced from hard rock, coarse-grained, relatively uniform granite-type ore called alaskite or from more variable pegmatites. The alaskite ores in Spruce Pine, North Carolina, where the three largest feldspar producers in the U.S.A. are located, have the following chemical analysis and mineral content:

Table 2. Typical chemical analysis of Spruce Pine Alaskite

	Wt %
Na <sub>2</sub> O	5.1
K <sub>2</sub> O	3.4
CaO	0.9
Al <sub>2</sub> O <sub>3</sub>	15.4
SiO <sub>2</sub>	74.4
Fe <sub>2</sub> O <sub>3</sub>	0.4
Loss on Ignition	0.4

Table 3. Typical mineralogical analysis of Spruce Pine Alaskite

Mineral	Wt %
Soda Feldspar	42.9
Potash Feldspar	14.7
Lime Feldspar	6.4
Quartz	28.0
Muscovite	7.5
Iron-garnet Minerals	0.5
Clay	very low

The reserves are practically unlimited.

PROCESSING

The alaskite ore is mined in large, open pits, trucked to the mills and reduced to about 3/4 inch by primary jaw and secondary Symons cone crushing. The crushed ore is blended, stockpiled and wet ground to 20 mesh in rod mills in closed circuit with trommel screens. The concentration of mica, removal of undesirable iron-garnet minerals and feldspar-quartz separation are accomplished by flotation after nearly complete removal of -200 mesh material with cyclones or rake classifiers. The -200 mesh material, although it contains feldspar, is discarded as waste.

FLOTATION

The flotation process consists of three consecutive steps:

1. Cationic flotation of muscovite mica in an acid circuit after conditioning as follows (approximately):

	Mica Conditioning	Mica Flotation
Solids (%)	55-60	20-30
Time (min.)	3-5	2-4
pH	2.5-2.7	3.0-3.3
Reagents (g/ton of feed)		
Sulfuric acid	750	none
Tallow amine acetate	125	none
Fuel oil	500	none
Frother	50	none

Flotation is accomplished in wooden, acid-proof, supercharged Denver DR-type flotation machines with level control. The 50 ft<sup>3</sup> cells in open trough banks of at least five cells are generally used in North Carolina. The mica flotation product is cleaned by flotation and wet screened on 80 mesh. The +80 mesh mica is sold in a "drip dry" condition to mica producers for further processing.

2. Anionic flotation removal of iron-garnet minerals and residual mica in an acid circuit after dewatering and conditioning as follows (approximately):

	Iron Conditioning	Iron Flotation
Solids (%)	65-75	20-30
Time (min.)	5	5
pH	2.2-2.5	2.8-3.2
Reagents (g/t of feed)		
Sulfuric acid	200	none
Petroleum sulfonate	250	none
Frother	25	none

The iron-garnet minerals are removed as waste by flotation in wooden, acid-proof, supercharged Denver DR-type flotation machines with level control.

3. Cationic separation of feldspar from quartz is conducted in an HF circuit. The pulp is dewatered after the anionic iron-garnet mineral flotation step and conditioned for flotation of feldspar at approximately the following conditions:

	Feldspar Conditioning	Feldspar Flotation
Solids (%)	50-60	20-30
Time (min.)	3	5
pH	2.5	3.0-3.5
Reagents (g/t of feed)		
Hydrofluoric acid	600	none
Tallow amine acetate	200	none
Kerosene	50	none
Frother	25	none

Flotation is accomplished in wooden, acid-proof, supercharged Denver DR-type flotation machines with level control. The feldspar product is dewatered by filters or in drain bins, dried in rotary dryers and shipped in bulk as 20 mesh glass grade feldspar. A small amount is sold as pottery spar after treatment by dry, high intensity magnetic separation for further iron removal and after dry grinding in pebble mills with ceramic grinding media in closed circuit with air classifiers.

Retreatment of the combined waste streams by finer size cyclone desliming, high intensity wet magnetic separation and mica and feldspar flotation can recover additional fine mica, feldspar and quartz. However, this is not a common practice, as most of the waste streams are discarded. Interest is increasing in retreatment of the quartz stream from feldspar flotation by exact sizing and chemical cleaning to produce a product for fused quartz utilization.

## FLWSHEET

Figure 1 outlines the processing steps for recovering feldspar, mica and quartz by flotation in the Spruce Pine, North Carolina district.

### MICA, CLAY, FELDSPAR AND QUARTZ RECOVERY FROM WEATHERED PEGMATITES

#### DEPOSITS

Highly weathered pegmatites and mica schists of varying mineral content were mined for many years, mainly for the small scrap mica content.

#### PROCESSING

The weathered ore is mined by self-propelled, bottom-dump scraper loaders, stockpiled, blunged in an autogenous mill or crushed in a jaw crusher to -1 inch, and deslimed and ground in a rod mill. A very coarse, fairly pure mica is recovered on a trommel screen equipped with 1/8 inch mesh wire after differential grinding. The -1/8 inch material is treated for mica recovery on Humphrey spirals. By shape factor, the flat mica moves to the outside and the granular material reports to the inside of the spiral where it is removed through portholes or adjustable splitters. The spiral mica can be cleaned for sale by flotation in an acid circuit with short chain oleylamine acetate. The granular material, containing mainly high potash feldspar and quartz, is dewatered, blended and stockpiled for further mica flotation and feldspar-quartz separation. The stockpiled material is metered to a high intensity attrition scrubber, after which it is deslimed in a cyclone and conditioned for fine mica flotation. An alkaline fatty acid-amine flotation procedure and dispersion in lignin sulfonate is used to recover fine white mica. After desliming in a cyclone and conditioning with hydrofluoric acid and tallow amine acetate, the feldspar-quartz separation is made. The high potash feldspar is filtered on a belt filter and dried. The quartz is dewatered and stockpiled wet. Feldspar is sold as is, after drying and magnetic separation, for specialty glass, or ground to specifications in a ceramic-lined mill as pottery feldspar. The quartz is dried, sized and sold as container glass sand.

The +1/8 inch mica concentrate from differential grinding and screening, and the concentrate from the Humphrey spirals are wet ground to high quality mica products. Flotation mica is ground in fluid energy mills and sold as dry-ground

products.

The combined slimes from the mica and feldspar operations are thickened, filtered and partially dried in a rotary kiln for uses as "white brick" clay. Halloysite-type clay dispersed at high pH is recovered in the Spruce Pine area from weathered alaskite-type pegmatites. It is degritted by multiple classification steps and then is finally screened on a 200 mesh screen. The clay is then flocculated by lowering the pH (4.5) with sulfuric acid. It is then filtered and dried on a perforated metal belt dryer, and sold as porcelain and sanitary ware clay.

FLWSHEET

Figure 2 outlines the processing steps for recovering mica, feldspar, quartz and clay processing of a weathered, decomposed pegmatite in the Kings Mountain District, North Carolina.

FLUORSPAR

DEPOSITS

Fluorspar deposits occur on every continent, and are present in a wide variety of rocks. Fluorspar is often associated with quartz, barite, calcite and other carbonates, and as a minor and a major constituent in metallic ore deposits with minerals such as galena and sphalerite. Ore deposits in production include veins, bedded replacement bodies and deposits in solution slump breccias. Vein deposits are particularly common where faults have a considerable displacement, whereas replacement deposits tend to follow groups of small fractures or minor faults. Residual deposits have been less important producers, but have yielded some high quality fluorspar. These "gravel spar" deposits have extents ranging as much as 60 feet wide and hundreds of feet in depth.

PROCESSING

Very little fluorspar occurs naturally which is pure enough to be marketed without some degree of concentration. In some cases, the concentration is limited to crushing and hand sorting, but in most cases, the concentration requires gravity and/or flotation concentration. In a typical plant, the incoming ore is washed and sized on trommel screens. Minus 10 mesh material is prepared for flotation or shaking tables, while the +10 mesh material is sent to heavy media operations. The flotation feed material

is ball mill ground to a nominal 100 mesh and conditioned at 55 to 85 degrees Celsius. Typical reagent additions include: 0.5 to 3.5 kg/ton (1 to 7 lb/ton) of Na<sub>2</sub>CO<sub>3</sub> and NH<sub>4</sub>CO<sub>3</sub> for dispersion of the clay slimes and 0.25 to 0.5 kg/ton (0.5 to 1.0 lb/ton) of quebracho to depress carbonate minerals. After a 5 to 10 minute conditioning time, 0.25 to 1.0 kg/ton (0.5 to 2 lb/ton) fatty acid collector is added for an additional 5 to 10 minute conditioning. After conditioning, the pulp is diluted and the fluorspar is floated. The froth is cleaned up to 10 times. During the conditioning and flotation stages, the pulp is maintained at an elevated temperature with the introduction of live steam.

Some laboratory studies have been conducted employing a saponified fatty acid at lower temperature. Comparable results have been obtained, especially for the ores where the gangue minerals were siliceous instead of carbonate.

SPECIFICATIONS

Fluorspar is produced in three grades: acid, ceramic and metallurgical. The following table summarizes the requirements and specifications typical for each grade.

Table 4. Fluorspar grade specifications

	<u>Analysis (Wt. %)</u>			
	<u>Acid</u>	<u>Ceramic</u>		<u>Metallurgical</u>
		<u>No. 1</u>	<u>No. 2</u>	
CaF <sub>2</sub>	97	95-96	80-90+	60(effective)
SiO <sub>2</sub>	<1.5	<3.0	<3.0	<15
S	<0.1	--	--	<0.3
Fe <sub>2</sub> O <sub>3</sub>	--	<0.12	<0.12	--
Pb	trace	--	--	<0.5

$\% \text{ Effective CaF}_2 = \% \text{ CaF}_2 - 2.5 \times \% \text{ SiO}_2$

GLASS SANDS

DEPOSITS

Few, if any, sand deposits are of sufficient chemical purity to be used in glass manufacturing without beneficiation. It is also rare to find a natural deposit of sand which contains just the right size distribution of sand grains to be suitable as glass furnace feed. Sand for glass utilization can be obtained from a variety of rock types and

geologic ages. The principal sources are found along existing or ancient river channels, in glaciated areas, marine and lake deposits, and altered geologic formations.

### PROCESSING

Processing of raw feed material depends upon the occurrence of the ore in the ground. In the case of hard rock or cemented sandstone, the mined rock is crushed and ground to liberation or natural grain size. In cases where the cementing material is weak, crushing and breaking in a trommel screen may be all that is required. In dry/wet-pit operations, the material is scalped to remove the rocks and vegetable matter. After scalping, the sand is washed to remove primary slimes. Desliming is generally carried out with cyclones or a combination of screw classifiers and cyclones. The deslimed sand is further sized to provide material for markets other than glass, or reground to provide additional glass sand sized material. Figures 3 and 4 outline the general manner in which sands are cleaned and sized. Where purity of the natural deposit is sufficient, the sized and washed sand is dried and shipped. However, where high levels of carbonates, iron minerals or refractory heavy minerals are present, gravity or flotation beneficiation is conducted.

Froth flotation of the impurities from a glass sand is divided into two common groups, consisting of treatment in an acid circuit or treatment in a basic circuit. In some cases, the glass sand grains are floated from the impurities. To prepare the grains for flotation, attrition scrubbing is conducted at high percent solids, generally from 70 to 80% solids, followed by additional desliming. The scrubbed sand is conditioned with a pH modifier, followed by the collector. Frothers are added to the last cell of the conditioner, or just before dilution and flotation.

Petroleum sulfonate is added to a pulp in which the pH has been adjusted to about 2.0-2.5. Conditioning is generally conducted at high pulp densities of 70 to 75% solids. The amount of sulfonate required varies from about 0.25 to about 1 kg/metric ton (0.5 to 2.0 lb/short ton), depending upon the ore and the amount of impurities present. A frother is added just before the end of the conditioning. Water-soluble glycol frothers are finding wide use in this system. Reagent requirements for the frothers range from 0.05 to 0.10 kg/metric ton (0.10 to 0.20 lb/short ton) of feed. Fuel oil is added in cases

where slimes are excessive. After conditioning, the pulp is diluted to 20 to 40% solids for flotation.

Fatty acid is added to the conditioner where the pulp, at 68 to 75% solids, has been adjusted to a pH of 9.5-10.5. The amount of fatty acid necessary varies from ore to ore, but is generally about 0.5 kg/metric ton (1 lb/short ton). A frother is added just before the end of conditioning. Frothers used in industry range from water-soluble glycols to pine oils to alcohol-type frothers. Fuel oil is added in some cases to help disperse the fatty acid and to control excess frothing. Solubilizing the raw fatty acid with sodium hydroxide has allowed conditioning at lower pulp density than used with raw fatty acid or fuel oil/fatty acid emulsions. Conditioning at too low a pulp density has been one of the major reasons for unselective quartz flotation with fatty acid. After conditioning, the pulp is diluted to 20 to 40% solids for flotation.

The selection of either a fatty acid circuit (caustic circuit) or a sulfonate circuit (acid circuit) is dependent upon the quality of products required, the impurities present and the results of laboratory testing. Ores with high amounts of carbonates lend themselves to the caustic fatty acid circuits, while ores with high amounts of refractory heavy minerals rely more upon the acid sulfonate circuits.

Flotation is conducted in conventional flotation cells. As the pulp at this point has few fines to help support the coarser particles, the pulp density must be carefully adjusted to prevent sanding in the cells. Depending on the operating pulp density and amounts of impurities to be floated, retention times will range from less than 5 minutes to over 20 minutes.

The froth from flotation contains iron minerals, heavily stained quartz and the refractory heavy minerals. This stream is sent to waste in most plants, but is being considered as a possible by-product by some large producers. Figure 4 outlines the general manner in which sands are prepared for flotation.

In cases where quartz is separated from the impurities by flotation of the quartz mineral, conditioning with primary amine collectors at rates of 0.05 to 0.2 kg/metric ton (0.10 to 0.40 lb/short ton) is conducted at a neutral or slightly acidic pH. Quartz is removed as the froth product with the machine discharge discarded as the tailing.

The clean sand is dewatered and sent to storage and drying. The dry sand may require secondary screening to insure meeting the customer's specifications.

### SPECIFICATIONS

For most container and float/flat glass uses, the final product should be finer than 20 mesh and coarser than 150 mesh in size. For selected industries, such as fused and optical grades, a closer sizing is preferred.

Chemical specifications are considered as tolerance rather than as absolute values. Exceptions to this rule are elements such as chromium, nickel, manganese, cobalt and copper, which produce color. Iron, although a colorant, has a somewhat greater tolerance level, especially in the manufacture of amber and green glass.

In addition to the above-mentioned chemical and physical requirements, the glass manufacturer is also concerned with other constituents which will affect the quality of his product. Certain types of foreign agents are objectionable to the glass technologist as individual particles. These contaminants include refractory minerals.

Refractory minerals may be naturally occurring minerals contained in trace quantities in the raw material, the result of contamination from mining or process equipment, or the result of chemical interaction during drying or calcining. Minerals such as sillimanite, kyanite, andalusite, zircon, spinel, corundum, chromite and cassiterite are detrimental to glass manufacturing because they do not melt in the glass furnace and cause stones and other imperfections in the finished glass. Numerous methods have been used to determine the amount of refractory heavy minerals present in samples, but time and space do not permit detailed descriptions. In general, on a weight basis, the sample sand should contain less than 4.4 ppm refractory heavy minerals greater in size than 60 mesh. On a count basis, from a 400 gram sample, there should be less than 2 particles greater than 40 mesh and less than 20 particles less than 40 mesh and greater than 60 mesh in size.

### FLWSHEET

Figures 3 and 4 outline the processing steps for washing, sizing and flotation in the production of glass grade sands.

## GRAPHITE

### DEPOSITS

Natural graphite deposits occur in many parts of the world and they are classified into three types: flake, vein and amorphous graphite. Flake graphite, the most valuable form, is found disseminated in metamorphosed quartz-mica-feldspar gneiss, schists and marbles. The average flake size is 0.5 mm and ore grades vary from a few percent to about 25% graphite. West Germany, Norway, Zimbabwe, Brazil, Malaysia, India, China, Korea and the USSR are the main producers of flake graphite. Flake graphite requires special processing to retain and control flake size and to obtain the highest purity of product.

Vein graphite is typically massive, found in veins from a few millimeters to over 2 meters thick, is fine-grained and nearly amorphous to coarse-grained and flaky.

Amorphous graphite is formed by metamorphosis of coal seams through magmatic intrusives. Amorphous graphite is soft, black, earthy and has less luster than crystalline graphite. Mexico, Austria, India and Korea are the main producers of amorphous graphite. The amorphous graphite deposits are usually high in carbon content and can be marketed after selective mining and a minimum of processing.

### PROCESSING (Flake Graphite Ore)

Flake graphite ore is carefully crushed and ground to liberation to avoid degradation of the coarse graphite flakes. Jaw crushing is usually followed by cone crushing down to about 20 to 25 mm (3/4 to 1 inch). Final liberation of flakes is accomplished by dry stage roll crushing or wet rod milling in closed circuit with screw classifiers. Alternately, screens are employed for gentle liberation of flakes or unit cell flotation in the grinding circuit can be employed for partial recovery of coarse flakes. The top size of grind is usually 10 to 16 Tyler mesh (1.7 to 1.0 mm).

Flake graphite is a naturally hydrophobic mineral and was the first mineral concentrated by flotation. The flotation separation from feldspar, quartz, mica and marble gangue is enhanced by the addition of small amounts of a neutral oil such as kerosene and by the addition of a frother such as pine

oil or an alcohol to the grinding circuit. Small amounts of caustic soda or lime are added to the grind to adjust the pH to between 7.5 and 8.5. Recovery of flake graphite in the rougher stage is usually very good. Cleaning of the rougher concentrate, even after repeated gentle, low percent solids regrinding with pebble mills in between cleaner flotation stages is difficult, because graphite smears easily and renders remaining gangua particles floatable. Also, some graphite flakes have a siliceous skeleton or are composed of a flaky layer of mica in between layers of flaky graphite, making it nearly impossible to obtain an ultra high grade product. By flotation and multiple cleaning, a grade of up to 97-98% carbon content can be achieved (deposits in Bavaria, West Germany). In order to obtain ultra high purity flake graphite with up to 99.98% carbon content for the nuclear industry, chemical digestion and removal of impurities by leaching is practiced.

Flotation reagent requirements and retention times depend entirely on the grade of the ore and ratio of concentration. Laboratory testing is always required to predict the requirements for production.

#### SPECIFICATIONS

The market for crucible manufacturing, refractory bricks, foundry facings, carbon raising in steel, lubrication, pencils, and other uses demands a multiple of grades in terms of carbon content, average flake size, size distribution and bulk weight. Ranges for some of the uses are as follows:

Table 5. Range of typical graphite specifications

Carbon content	70-99.98 percent
Average flake size	1.5-520 microns
Bulk weight	220-740 gr/1000 ml

#### KYANITE

#### DEPOSITS

Kyanite is an aluminum silicate used mainly for the production of high alumina refractories especially for the steel industry. Although there are a number of deposits in the southeastern United States, only two are presently being mined. Kyanite Mining Company operates a mine at Willis Mountain in Buckingham County, Virginia and Pasco Mining Company

operates a mine at Graves Mountain in Lincoln County, Georgia. Both deposits are kyanite-containing quartzites with small amounts of pyrite which can be recovered. The ore mined in the southeastern deposits contains about 15-30% kyanite. Other impurities are mainly quartz and other aluminum silicates such as mica, kaolin, pyrophyllite and small amounts of rutile and iron oxides. Liberation is usually complete at 65 Tyler mesh (212 microns). Kyanite is also produced in India, the USSR, Africa and, recently, in Sweden.

#### PROCESSING

Jaw crushing and cone crushing prepares a rod mill feed of -1 to -0.75 inch (25-20 mm). The crushed ore is stockpiled and then ground in rod mills to minus 35 mesh (425 microns) in closed circuit with vibrating screens or cyclones. After grinding, the pulp is deslimed at 200 to 325 mesh (75 to 45 microns) and then thickened for conditioning and flotation. To remove the pyrite, for sale as a coloring agent in the container glass industry, an anionic xanthate rougher and cleaner flotation step is first employed. Conditioning is conducted at neutral pH with 50 gr/ton (0.1 lb/ton) xanthate and 25 gr/ton (0.05 lb/ton) pine oil frother.

The second flotation step removes residual clay, mica and hydrated aluminum silicates (pyrophyllite). Cationic cocoamine acetate at 50 to 100 gr/ton (0.1 to 0.2 lb/ton) is added at neutral pH and the relatively small quantities removed as the froth.

Finally, the kyanite flotation recovery and concentration is conducted after intensive conditioning at high percent solids (approximately 70% solids) at a pH adjusted to 2.3 to 2.6 with sulfuric acid. Anionic petroleum sulfonate at a level of 1 to 1.5 kg/ton (2 to 3 lb/ton) is added to the conditioner after the pH is adjusted. Flotation takes place in acid-proof flotation cells. Usually 2 to 3 cleaner steps are employed with additions of sulfuric acid to keep the pH below 2.6. Middlings are recirculated to the rougher flotation step. After flotation, the kyanite concentrate is dereagentized, if needed, by conditioning with sodium silicate, dewatered and dried. Dry magnetic separation of the kyanite concentrate removes iron minerals and iron stained material, which float with the kyanite during petroleum sulfonate flotation. Overall kyanite recovery is generally 80 to 85% from the feed.



Some of the kyanite concentrate is converted to mullite by calcining in rotary kilns at 1,350 degrees Celsius. This results in a volume increase of 18%. Mullite is an important constituent of refractories because of its resistance to wear by slags, its low expansion coefficient and its high melting point of 1,800 degrees Celsius.

SPECIFICATIONS

The refractory market demands kyanite with high alumina content, low iron and alkali content and low free quartz content. Chemical analysis of commercial kyanite products from the southeast United States are reported in Table 6.

PHOSPHATE

DEPOSITS

Most of the phosphate used for fertilizer production and industrial use is produced from unconsolidated or consolidated sedimentary deposits. The United States is still the largest phosphate producer, followed by Morocco. There are igneous phosphate deposits exploited in the USSR, Finland, South Africa and Brazil. Most phosphate deposits are close to the surface and are mined by open pit methods, mainly drag line excavators and slurry pumps in unconsolidated matrix (Florida, North Carolina, Africa) and loader and truck haulage in consolidated material (Idaho, Utah, Montana). The commercial sedimentary phosphate ore bodies are usually composed of coarse calcium phosphate pebbles, fine calcium phosphate grains diluted with quartz sand and very fine clay slimes containing weathered, very fine phosphates of calcium, iron, alumina and other contaminants. The calcium phosphate pebbles and fine phosphate grains usually occur as collophanite, a fluorapatite carbonate with substitutions in the lattice. The

clear collophanite pebble usually has 31 to 36% P<sub>2</sub>O<sub>5</sub> content.

PROCESSING

Feed Preparation Slurried pulp pumped from the unconsolidated matrix is agitated and scrubbed by log washers or attrition scrubbers and separated by screening and cyclone desliming to produce +1.5 mm pebble phosphate (saleable product in Florida), -1.5 mm +0.5 mm agglomeration flotation feed, -0.5 mm +0.1 mm double flotation feed and -0.1 mm waste slimes. The consolidated phosphate ore has to be crushed and ground to liberation and scrubbed for sizing, desliming and flotation where needed. Most washed and sized hard rock phosphate is of saleable grade without need for flotation. The coarse agglomeration flotation feeds and finer double flotation feeds are usually diluted by large amounts of quartz sand and minor amounts of free calcium and magnesium carbonate. Selective mining has to keep free calcium and magnesium carbonate at a minimum in the flotation feed.

Flotation The flotation of calcium phosphate from diluting quartz material utilizes fatty acids and derivatives of fatty acids in the form of tall oils; by-products of the paper industry. The anionic fatty acids have a high affinity for calcium and attach themselves to the calcium ion on the surface of the collophanite pebble, forming a water repellent, hydrophobic surface layer. For good dispersion of the fatty acid, presaponification with NaOH or ammonia, or the addition of either to the conditioner at high pH and high percent solids is practiced. The hydrophobic surface layer is fortified with lower cost nonpolar hydrocarbons such as fuel oil. The hydrophobic phosphate particle is lifted to the surface by air bubbles in the flotation machine and skimmed off as concentrate. Some fine quartz

Table 6. Chemical analysis of kyanite concentrates.

	<u>% Al<sub>2</sub>O<sub>3</sub></u>	<u>% SiO<sub>2</sub></u>	<u>% Fe<sub>2</sub>O<sub>3</sub></u>	<u>% TiO<sub>2</sub></u>	<u>% CaO</u>	<u>% MgO</u>	<u>% Alkali</u>	<u>P.C.E.</u>
Kyanite Rough								
Georgia	56.6	40.0	1.0	1.0	0.5	0.5	trace	36-37
Virginia	59.0	36.5	0.2	0.7	0.03	0.01	0.18	36-37
Virginia	61.8	38.7	0.9	0.9	0.05	0.06	0.42	36-37
Sweden	59.8	35.8	0.15*	0.6	0.2	0.2	trace	N/A
Mullite								
Georgia	56.6	40.0	1.0	1.0	0.5	0.5	trace	36-37

\* Only HCl soluble Fe.

particles are usually mechanically entrapped in the phosphate containing froth. Also, larger quartz particles with stains of phosphate on the surface or in crevices behave like hydrophobic phosphate particles and report in the fatty acid phosphate concentrate. In order to remove the fine quartz and stained quartz and obtain a low insol/high P<sub>2</sub>O<sub>5</sub> concentrate, the fatty acid concentrate is deoiled at low pH with sulfuric or fluosilicic acid, washed and refloated to remove these quartz contaminants with cationic amine reagents. The positive amine reagents have an affinity for the negatively charged quartz surface and form a water repellent hydrophobic surface. The remaining quartz is then lifted to the surface by air bubbles and is skimmed off as waste. This so-called double flotation procedure was developed by Arthur Crago in Florida in 1940 and is used extensively for phosphate flotation because it yields high grades with high recoveries in open circuit operation.

The coarse -1.5 mm +0.5 mm fraction is gently conditioned in drums or zigzag conditioners to effect reagent attachment (fatty acid and fuel oil) without generation of fines and slimes. The agglomeration flotation separation is performed on spirals, belt separators, shaking tables, Lang Launderers or in specially designed air flotation cells. Recovery and grades are inferior to the fine flotation circuit, and occasionally the agglomerated concentrate is cleaned by adding it to the deoiling and amine flotation step in the fine double flotation circuits.

#### Reagents and Amounts

##### Fatty Acid Conditioning for Phosphate Flotation

Fatty Acid - 0.4 to 1 kg/ton (0.8 to 2.0 lb/ton) flotation feed.  
 NaOH or Ammonia - 1/10 of fatty acid or to pH of 8-9 in the conditioner.  
 Fuel Oil - 0.5 to 2.0 kg/ton (1.0 to 4.0 lb/ton) flotation feed.

##### Deoiling

Sulfuric or Fluosilicic Acid to pH 3-4.

##### Amine for Silica Flotation

Amine - 0.05 to 0.1 kg/ton (0.10 to 0.20 lb/ton) of feed to amine

flotation.

Kerosene - 25 to 150 gr/ton (0.05 to 0.30 lb/ton) of feed to amine flotation.

#### Conditions

Fatty acid conditioning	5-8 minutes at 50-70% solids
Fatty acid flotation	3-6 minutes at 20-30% solids
Deoiling	3-5 minutes at 50-60% solids
Amine conditioning and flotation	3-6 minutes at 25-30% solids

#### SPECIAL CONSIDERATION

In phosphate flotation, feed preparation with respect to sizing and desliming after attritioning and washing is important, as the clay size fractions will increase the reagent requirements. The large surface areas of the fine particles absorb the collector reagents and reduce their availability for attachment to the phosphate.

#### SPECIFICATIONS

Phosphate concentrates from different locations show widely different properties. Since most phosphate is used to produce phosphoric acid by wet processing for fertilizer manufacturing, the following properties need to be considered:

1. P<sub>2</sub>O<sub>5</sub> content - as high as possible, preferably 31-38% P<sub>2</sub>O<sub>5</sub>.
2. Reactivity and Sulfuric Acid Requirements - influenced by grain size and carbonate level. As a rule, CaO/P<sub>2</sub>O<sub>5</sub> ratio should be between 1.5 and 1.6. Some phosphate concentrates require grinding before acidulation.
3. Filtration rates and P<sub>2</sub>O<sub>5</sub> losses in digestion systems - gypsum filtration rates are influenced by reactivity rate and impurities (Al-Fe-Na-Mg-K-SiO<sub>2</sub>-Fluorite).
4. Foaming - organic material, together with CO<sub>2</sub> evolution causes foaming. Calcining the concentrate to eliminate organic material completely and reduce CO<sub>2</sub> content may be required. Calcined phosphate generally produces a cleaner phosphoric acid.
5. Corrosiveness - chlorides and sulfides should be very low as they react with the sulfuric acid and cause corrosion of the equipment.
6. Magnesium - magnesium of more than

0.6 to 0.8% MgO can produce a phosphoric acid unsuitable for super phosphoric acid production.

### FLWSHEET

Figure 5 outlines the treatment of a phosphate ore through flotation.

## POTASH

### DEPOSITS

The word "potash" has at least two meanings in the fertilizer industry. One definition designates potash as  $K_2O$ , signifying any potassium containing salt. However, a more restrictive meaning to the word potash designates fertilizer grade potassium chloride. Potash is found throughout the world in both soluble and insoluble (primarily silicate) forms. At the present time, only the soluble forms are economically attractive to process. The soluble forms occur primarily as chlorides and sulphates, although other salts such as nitrates occur and are extracted. Potassium chloride is by far the most important potash salt extracted and used today.

The mineral deposits of potash resulted from the evaporation of water from ancient landlocked seas. Two cases are possible; either ocean water became isolated from the main oceanic body and gradually deposited its salines, or inland seas were evaporated. Almost all deposits of saline minerals have been formed by the evaporation of brines. Salts generally crystallize in inverse order of their solubilities, however, temperature and the presence of other dissolved salts may modify the order of deposition. The order of deposition is usually calcium carbonate, magnesium carbonate, calcium sulphate, sodium chloride, magnesium sulphate, magnesium chloride, potassium chloride.

The principal and most important potash ore is sylvite, due to its availability and high  $K_2O$  content. As found mixed with common salt in the deposit, it is called "sylvinite". A typical analysis of sylvinite ore is 23% KCl, 72% NaCl and 4% others including clays, iron oxides and silica. Other ores which have been worked are carnallite, langbeinite, niter and kainite.

### PROCESSING

The original process for flotation concentration of potash involved the flotation of halite (NaCl) from sylvinite

(KCl). In this method, anionic organic reagents and fatty acids are employed as collectors in the presence of activators (lead or bismuth ions). Large quantities of the collecting agent were required per ton of KCl produced. Concentrates analyzing over 60%  $K_2O$  have been produced by this technique.

Today, the important flotation process in the potash industry involves the flotation of sylvite from the sylvinite, with the halite discarded in the tailings. The steps in the process include:

1. Dry crushing and classifying the ore.
  2. Slurrying the crushed ore in a brine saturated with NaCl and KCl to produce a pulp containing 50 to 75% solids.
  3. Wet grinding the ore to liberate the sylvite and halite.
- Liberation size varies depending upon the average crystal size of the ore and can vary between the 4 and 65 mesh.
4. Addition of clay depressing agent, such as starch. The amount of depressant and dispersant vary depending on the grade of the ore.
  5. Conditioning with the collector. Collectors for sylvite are generally primary aliphatic amines of about C-6 to C-24 carbon chain lengths. The amine is usually added as a 1 to 2.5% water solution. Additions of 0.25 to 1 kg/ton (0.5 to 2 lb/ton) of feed are common. Additions of fuel oil and soluble frothers are used to control the froth.
  6. Dilution of the conditioned pulp with brine to 20 to 35% solids.
  7. Rougher flotation of the sylvite. Flotation is quick, requiring less than 3 minutes in the laboratory.
  8. Cleaner flotation of the rougher froth. Cleaner stages range from one to as many as three.
  9. The flotation concentrate is then thickened, washed with KCl, saturated brine or fresh water and dried.
  10. The final KCl product is compacted, broken and sized, in order to produce a marketable granular product.

In some cases, the crushed ore is classified into coarse and fine particle size ranges, with each being processed in separate flotation circuits, since slightly different techniques are

employed for each size.

### SPECIAL CONSIDERATIONS

In the flotation process, the desliming, conditioning, flotation and thickening is conducted in saturated brine. During laboratory studies of potash flotation, the calculation of brine content on the final filtered products weigh heavily on the final calculations of recovery and grades.

In certain areas, sylvinitic is found associated with significant amounts of carnallite ( $\text{KCl} \cdot \text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ ). This type of ore, when subjected to froth flotation, will result in the sylvite concentrate containing substantially all of the carnallite in the ore. In order to be a saleable product, the sylvite is required to be at least 95% KCl (60%  $\text{K}_2\text{O}$ ) and special leaching processes are employed.

### SPECIFICATIONS

Quality is measured by size and grade. All "red" flotation products must be 60%  $\text{K}_2\text{O}$  or better. This is controlled by leaching the flotation concentrate, adjusting the cleaner and recleaner circuits, or blending with a higher grade crystallizer product.

Products are screened into -6+14 mesh granular, -8+20 mesh coarse, -14+48 mesh standard and -35+150 mesh special standard. Mesh overlap of the products is due to operating requirements and screening efficiency. Product size is controlled by re-screening, dedusting and blending of material one size above "spec". Fines and standard product are fed to high pressure rolls for compacting into flake, up to 16 mm thick (5/8 inch). The flake is crushed in impactors and screened into the premium coarse and granular products.

### SPODUMENE AND BY-PRODUCTS

#### DEPOSITS

Two spodumene producing companies in North Carolina mine a typical pegmatite ore in open pits after removal of amphibolite and mica schist overburden. The ore reserves around Kings Mountain, North Carolina are in the million ton range, but are not unlimited. The average chemical and mineralogical analysis of the spodumene pegmatite is as follows:

Table 7. Typical chemical analysis of Kings Mountain spodumene ore

	<u>Wt %</u>
$\text{Li}_2\text{O}$	1.4 - 1.5
$\text{Na}_2\text{O}$	3.2 - 3.8
$\text{K}_2\text{O}$	2.2 - 2.7
CaO	0.26 - 0.46
$\text{Al}_2\text{O}_3$	12.2 - 17.9
$\text{SiO}_2$	73.2 - 74.0
$\text{Fe}_2\text{O}_3$	0.51 - 0.97
Loss on Ignition	0.50 - 0.76

Table 8. Typical mineralogical analysis of Kings Mountain spodumene ore

<u>Mineral</u>	<u>Wt %</u>
Spodumene	15-25
Potash feldspar	12-15
Soda feldspar	28-33
Quartz	25-35
Muscovite and other minerals	5-15

### PROCESSING

Ore is jaw and cone crushed to about -1 inch where rod mill grinding is employed, and to -5/8 inch where ball mills are employed to grind the ore to flotation size. NaOH is added to the mill at approximately 0.25 kg/ton (0.5 lb/ton) of feed. The mill product is in closed circuit with hydrocyclones making a 65 mesh size split. The cyclone overflow is diluted and recycled to remove the -400 mesh fines and thickened. The thickened cyclone underflow is scrubbed, diluted and deslimed again at 400 mesh in cyclones. The cyclone overflows from both the 400 mesh desliming steps are combined, diluted and recycled to approximately 15 microns. The -15 micron material goes to waste, while the +15 micron material is combined with the +400 mesh scrubbed and deslimed material and sent to conditioning. Conditioning takes place at 55% solids, a neutral pH, with 0.75 kg/ton (1.5 lb/ton) of feed of tall oil-type fatty acid having 5 to 7% rosin acid content and a glycol-type frother. The conditioned pulp is floated at about 30% solids and cleaned and recleaned several times. The flotation concentrate is dewatered on a belt filter and trucked wet to chemical treatment plants.

Flotation tailings are dewatered and conditioned for iron mineral and mica removal with petroleum sulfonate in an acid circuit. The low iron sand tailing

is sold as a feldspathic sand to glass companies. Flotation of a clean white mica from the iron mineral froth is conducted, as the market for mica requires. The separation of feldspar and quartz using a standard HF amine flotation procedure has also been practiced. (Details of the HF flotation procedure are covered in a separate portion of this paper.)

### SPECIFICATIONS

Product specifications are shown in Table 9 along with the feldspar, quartz and mica specifications.

### FLWSHEET

Figure 6 presents the schematic for the processing and recovery of spodumene, mica and quartz from a typical Kings Mountain, North Carolina operation.

## TALC

### DEPOSITS

Talc deposits of commercial importance occur in sedimentary rocks altered by regional or contact metamorphism, and in ultramafic igneous rocks which have been serpentized. Contact metamorphism of dolomite by intrusions of granite or diabase, with infusions of hot hydrothermal solutions charged with silica, is a common way in which talc is formed. Most deposits do not approach the theoretical composition, but instead are a mixture of silicates which contain appreciable proportions of magnesia. In such mixtures, the mineral talc is commonly a major constituent. Other minerals commonly present in ore deposits include serpentine, chlorites, tremolite, diopside, quartz, calcite, dolomite, magnetite and, in some cases, nickel and iron sulfides, as well as chromite.

### PROCESSING

Where flotation is required, talc ore is crushed and ground in steel ball mills or ceramic pebble mills to from 65 to 200 mesh, conditioned with a frother and floated. Although talc is often considered a natural hydrophobic mineral, similar to graphite, the mineral may require mixtures of frother and fuel oil to complete the flotation recovery. Conditioning time is generally short and the frother/collector may be stage added to feed boxes between stages of flotation cells.

In situations where only carbonate minerals are the associated gangue, small

amounts of amine collectors will improve the recovery of talc. However, if the gangue contains mica, tremolite or quartz, amines should be avoided. Where nickel and/or chrome minerals are present, they can be removed by shaking tables or other gravity separation equipment prior to the flotation of talc.

Sulfides carried into the flotation circuit must be depressed, as some sulfides show a natural hydrophobic tendency and will float with the talc. Citric acid and pH adjustments with lime have shown some success in depressing sulfides. If the pH climbs to above 12, talc can be depressed and the flotation of graphite from the talc can be accomplished.

Brightness and mineralogical purity can be further increased by magnetic separation and acid leaching after flotation. Fine grinding in ball or pebble mills and jet mills also increases the brightness of talc concentrates coarser than 325 mesh.

### SPECIFICATIONS

Although talc is generally considered a filler, talc is also employed in such non-filler applications as talcum powders, cosmetics, ceramics and mold release compounds. The most significant requirements for talc in filler applications are determined by particle size, brightness, mineral and chemical composition, abrasiveness and softness.

Particle sizes for talc filler utilization have a wide range, with top sizes ranging from 100 mesh to as fine as 10 microns and smaller.

Brightness, or reflectance at specific wavelengths of light, are the highest for the grades of talc employed in the health care and cosmetics industries, where GE brightness values of greater than 95% are typical. The paper, paint and plastic industries require a slightly lower reflectance of 88 to 95%. For off-grade filler, dusting compounds and for mold release, the brightness may not be a specification.

Mineralogical and chemical composition is of great importance in applications in the paper, plastics and cosmetics industries where acid environments may cause leaching of impurities. Minerals other than talc generally are harder than talc and their presence can cause abrasiveness and excess wear of paper manufacturing equipment. For the paper and other industries, the Valley Abrasion method will produce a value suitable for

grading the abrasiveness of a talc.

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Table 9 Feldspar, quartz, spodumene, mica and clay minerals recovered and sold from North Carolina pegmatites 1977

Product Sold	Glass Spar		Pottery Spar		Feldspatic Sand		Spodumene		Quartz Sand		Clay		Ground Mica					
	F-20 S.P.*	K-40 K.Mt.**	NC-4 S.P.	K-200 K.Mt.	Footc Spar K.Mt.	K.Mt.	Glass Chem. K.Mt.	Ceramic K.Mt.	Low Iron K.Mt.	Glass S.P.	K-30 K.Mt.	Halloysite S.P.	K.Mt.	325 Wet S.P.	P-80 Dry S.P.	Oil Well S.P.	1200 Dry S.P.	
Shipping Point																		
Chem. Anal. % Wt.																		
SiO <sub>2</sub>	68.00	67.10	68.15	67.10	68.70	79.20	63	64.12	64.80	92.98	99.30	47.90	53.8	46.5	44-48	44-48	49.4	
Al <sub>2</sub> O <sub>3</sub>	19.00	18.30	18.88	18.30	19.27	12.10	24.7	26.50	26.25	0.5-3.0	0.32	36.91	32.10	34.0	31-38	31-38	29.7	
Fe <sub>2</sub> O <sub>3</sub>	0.07	0.07	0.07	0.07	0.06	0.52	1.7	0.90-max	0.10	0.1-0.15	0.02	0.30	1.40	4.0	5-max	5-max	4.8	
CaO	1.85	0.36	1.60	0.36	tr	0.52	tr	tr	tr	tr	tr	n.a.	tr	tr	tr	tr	tr	
MgO	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	tr	n.a.	tr	tr	tr	tr	tr	
K <sub>2</sub> O	3.75	10.10	4.50	10.10	3.69	2.62	0.50	0.27	0.14	0.5-2.0	0.23	1.05	2.20	9.45	9-max	9-max	10.2	
Na <sub>2</sub> O	7.15	3.80	6.70	3.80	7.91	4.80	0.30	0.32	0.35	0.08	0.08	0.25	0.13	0.45	0.5-2.5	0.5-2.5	1.1	
Li <sub>2</sub> O	-	-	-	-	0.08	0.35	5.6-6.5	7.22	6.83	-	-	-	0.08	-	-	-	-	-
Ign. Loss	0.13	0.26	0.10	0.26	0.25	0.35	0.30	0.50	n.a.	wet	0.11	13.50	10.30	5.00	4-5.5	4-5.5	4.8	
Approx. Miner. Cont. % Wt.																		
Potash Spar	22	60	26	60	22	16	3	2	1	2	-	3	5	-	5	5	2.5	
Soda Spar	61	32	57	32	67	41	3	3	3	4	-	2	1	-	-	-	-	
Lime Spar	9	2	8	2	-	2	-	-	-	-	-	-	-	-	-	-	-	
Quartz	8	6	9	6	11	41	9	5	6	90-95	+99	2	10	-	5	5	1.2	
Spodumene	-	-	-	-	-	-	85	90	90	-	-	-	-	-	-	-	-	
Clay Minerals	-	-	-	-	-	-	-	-	-	-	-	90	80	3-5	10	10	-	
Muscovite	-	-	-	-	-	-	-	-	-	-	-	3	4	95-98	80	80	96	
Sure Analy. % Wt. retained on 20 mesh (Tyler)	0.1	-	ground to pass	ground to pass	0.1	ground to specs	-	ground to +140 or -200	-	43.2	-	-	-	-	-	-	-	
on 48	42.0	-	170/200	120/170	na	35.1	1.5	20.0	0.5	82.1	-	-	2.2	tr	1-2	10-70	-	
on 100	85.5	56.15	or 250	200/250	75.1	90.0	90.0	90.0	90.0	97.5	tr	1.0	14.4	1.0-4.0	13-18	70-90	-	
on 200	97.2	90.05	mesh	mesh	-	85-90	n.a.	n.a.	n.a.	n.a.	n.a.	25-26	30.1	3.0-10.0	78	10-30	-	
on 325	-	80-85	9	55-60	80	12-20	108	181.50	n.a.	n.a.	n.a.	32-33	31-32.5	to 12	20-25	25-28	13.5-14	
Bulk Wt lbs/cu ft	90	29	28.75	41.00	n.a.	18.75	18.75	18.75	n.a.	1.5	n.a.	85	n.a.	220	85	58	85	
PCE	9	29	9	9	n.a.	12-20	108	181.50	n.a.	1.5	n.a.	85	n.a.	220	85	58	85	
\$ /ret lob (1977)	18.75	29	28.75	41.00	n.a.	12-20	108	181.50	n.a.	1.5	n.a.	85	n.a.	220	85	58	85	

\* Spruce Pines, \*\* Knight Mountain



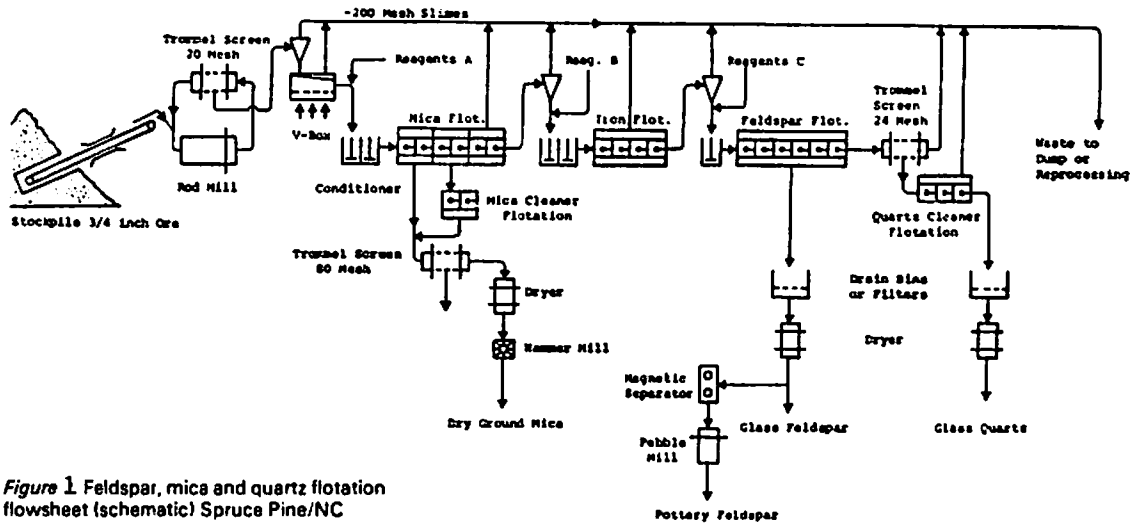


Figure 1 Feldspar, mica and quartz flotation flowsheet (schematic) Spruce Pine/NC

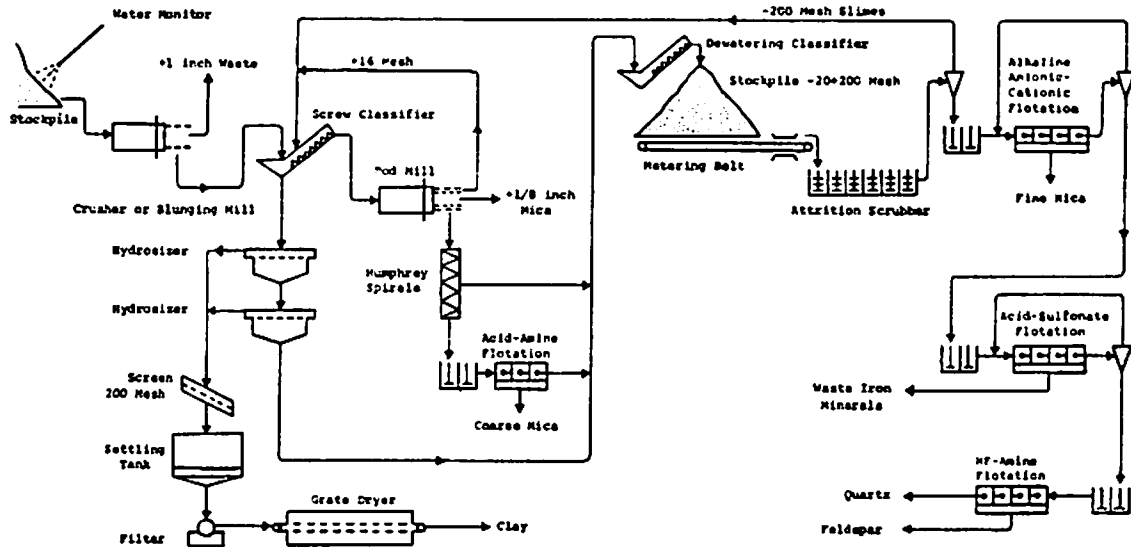
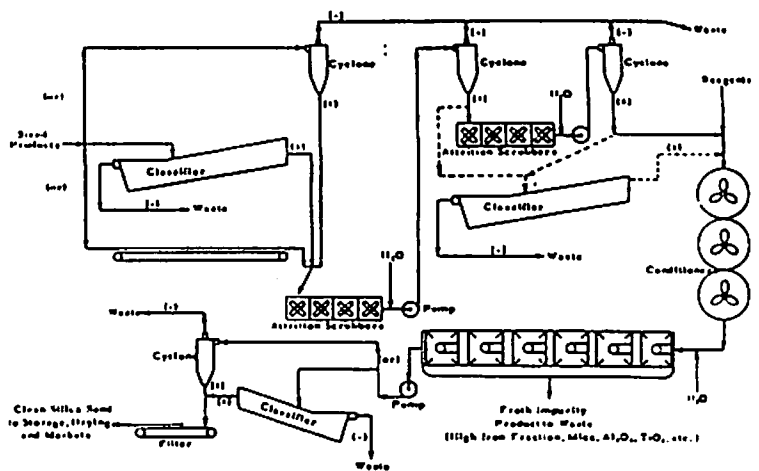
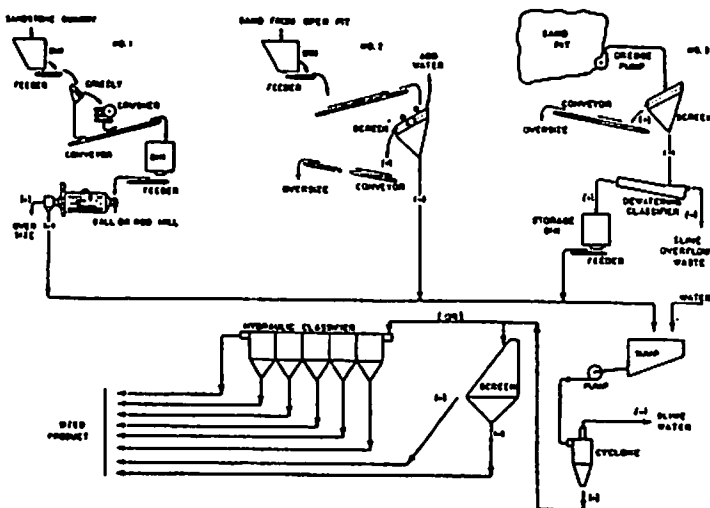


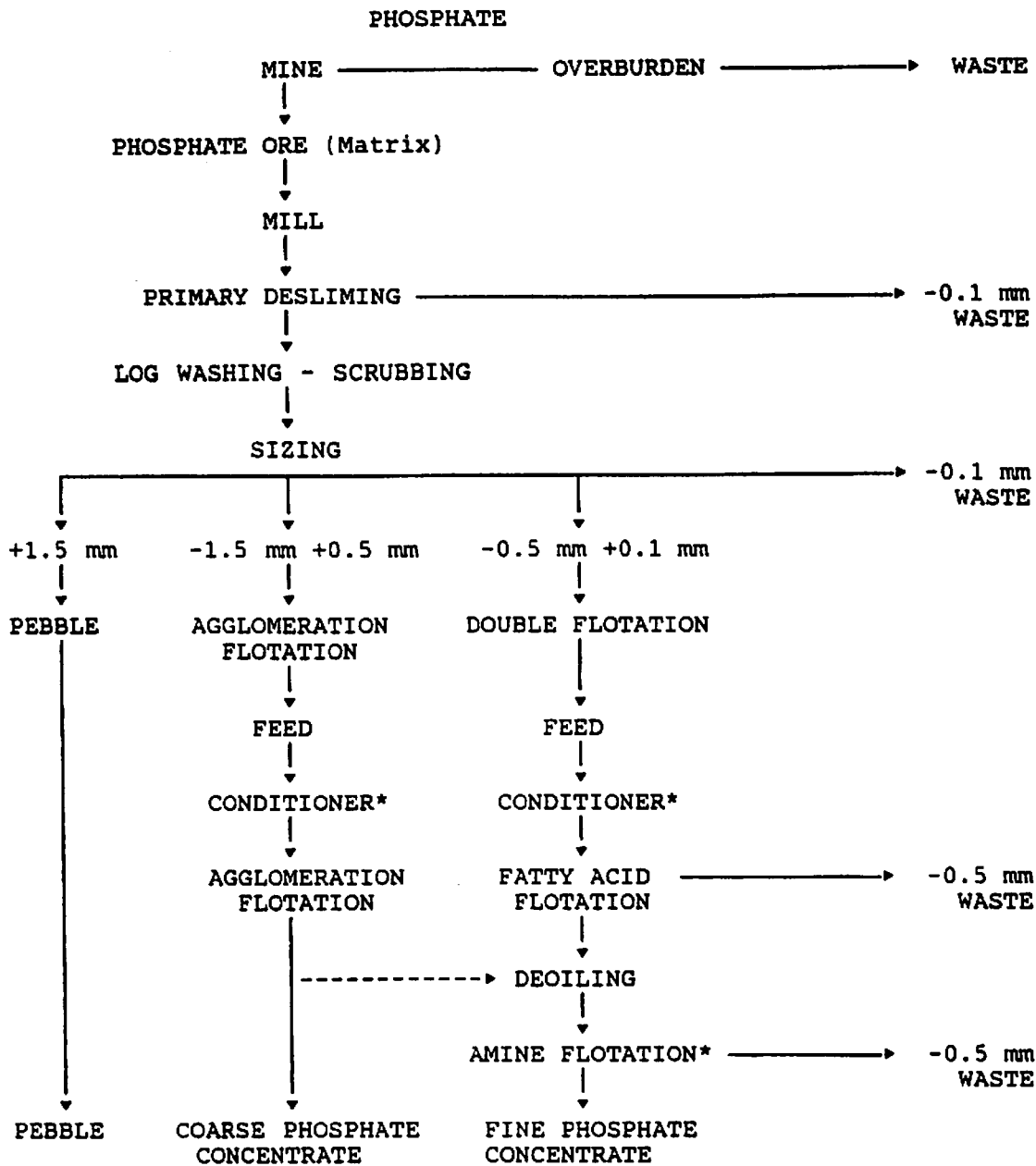
Figure 2 Weathered decomposed pegmatite processing (schematic) North Carolina

Figure 3 Typical processing flowsheet (schematic) for washing and sizing of glass grade sands.

Figure 4 Typical processing flowsheet (schematic) for washing and flotation of glass grade sands.



# CHEMICAL REAGENTS IN THE MINERAL PROCESSING INDUSTRY



### \* Reagent Additions

Figure 5 Typical phosphate processing flowsheet (schematic), Florida phosphate district, U.S.A.

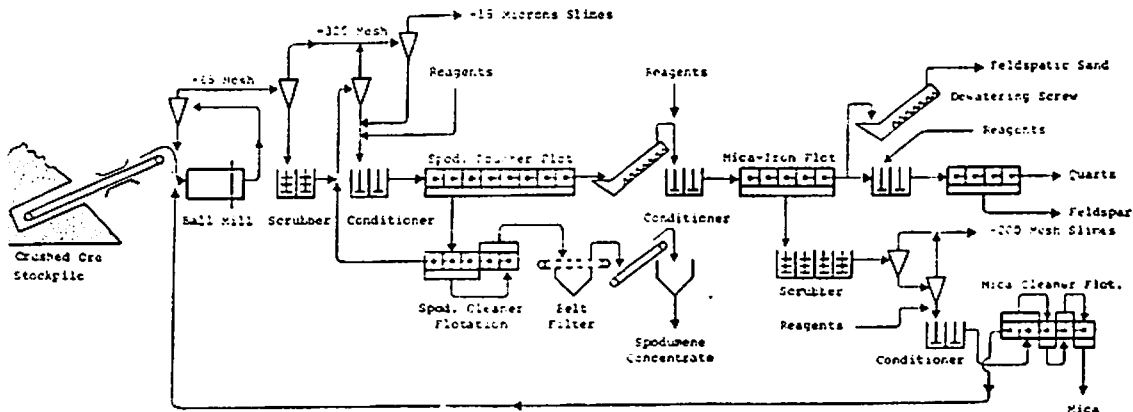


Figure 6 Spodumene and by-product feldspar-quartz-mica flotation flowsheet (schematic) Kings Mountain/NC