

FLOTATION OF FELDSPAR, SPODUMENE,
QUARTZ AND MICA FROM PEGMATITES IN
NORTH CAROLINA, USA

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ABSTRACT

North Carolina is the leading state in the USA in feldspar, mica, and spodumene production. Mixed feldspar, spodumene, mica and quartz are mined from hard rock, open pit deposits and recovered by flotation from the fresh pegmatite type ores. Potash feldspar, mica, clay and quartz are recovered from weathered decomposed pegmatites. The North Carolina State University has a Minerals Research Laboratory in Asheville with trained personnel and flexible pilot plant equipment. The flowsheets for the feldspar, spodumene and mica producing companies and for large phosphate and glass sand flotation plants were developed and tested in Asheville. Examples and problems of pegmatite flotation are demonstrated with flowsheets and slides.

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FROM PEGMATITES IN NORTH CAROLINA, USA

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The Spruce Pine area of North Carolina is the center of the USA feldspar production. Three companies, The Feldspar Corporation, Lawson-United Feldspar and Mineral Company, and IMC Chemical Group, produce glass and ceramic grade feldspar and by-product mica and quartz from hard rock alaskite type pegmatite ore. ^{1,2} In the same area, Harris Mining Company recovers scrap mica and primary clay, and Deneen Mica Company recovers only scrap mica from weathered, decomposed alaskite ore. ^{3,4} The Kings Mountain area of North Carolina is the center of U. S. spodumene production, with Lithium Corporation of America and Foote Mineral Company producing glass, ceramic, and chemical grade spodumene and by-product mica, feldspar and quartz from hard rock pegmatites. ^{5,6} Kings Mountain Mica and Silica Company is producing mica, ceramic and glass grade potash feldspar, quartz and brick clay from weathered pegmatites. ¹⁰ Figure 1 gives the approximate location of the two pegmatite mineral producing areas in North Carolina. The approximate ore and product tonnages are given in Table I.

TABLE I. APPROXIMATE DAILY ORE AND PEGMATITE PRODUCT TONNAGES IN NORTH CAROLINA

	Ore stpd	Spodumene	Feldspar	Mica	Quartz	Clay
Hard rock feldspar pegmatite Spruce Pine (3 plants)	3,000	-	1,550	75-120	700	-
Hard rock spodumene pegmatite Kings Mountain (2 plants)	3,400	680	680	50-70	400	-
Weathered pegmatite Spruce Pine and Kings Mountain (3 plants)	2,400	-	80-90	220	200	260
Total tonnage, stpd	8,800	680	2,320	345-410	1,300	260

The major pegmatite minerals concentrated from North Carolina ores and theoretical chemical compositions are tabulated on Table II.

TABLE II. NORTH CAROLINA USEFUL PEGMATITE MINERALS AND THEORETICAL COMPOSITIONS

<u>Mineral</u>	<u>Formula</u>	<u>Chemical Analysis</u>							<u>sp gr</u>
		<u>% K₂O</u>	<u>% Na₂O</u>	<u>% CaO</u>	<u>% Al₂O₃</u>	<u>% SiO₂</u>	<u>% Li₂O</u>	<u>% H₂O</u>	
Potash feldspar	K AlSi ₃ O ₈	16.9	-	-	18.3	64.7	-	-	2.54
Soda feldspar	Na AlSi ₃ O ₈	-	11.8	-	19.4	68.7	-	-	2.61
Lime feldspar	Ca Al ₂ Si ₂ O ₈	-	-	20.1	36.6	43.3	-	-	2.77
Spodumene	Li AlSi ₂ O ₆	-	-	-	27.4	64.6	8.0	-	3.2
Muscovite	H ₂ KAl ₃ (SiO ₄) ₃	11.8	-	-	38.4	45.2	-	4.5	2.78-2.88
Primary clay	H ₄ Al ₂ Si ₂ O ₉	-	-	-	39.6	46.5	-	13.9	2.6
Quartz	SiO ₂	-	-	-	-	100.0	-	-	2.65

The commercially sold pegmatite products are mixtures of above tabulated pegmatite minerals. A mixture of potash, soda and lime feldspar in the size range minus 20 plus 200 mesh (Tyler) is sold as glass grade feldspar to the container glass industry. Feldspar high in potash content and low in iron content and ground to minus 200 mesh or other specifications is sold as pottery spar to the ceramic industry. A mixture of feldspar and quartz is sold as feldspatic sand to the glass companies.^{7,8,9} Spodumene concentrates with high Li₂O content, low Fe₂O₃ content, in the size range minus 20 plus 200 mesh are sold to the glass and ceramic industry. A lower grade spodumene concentrate is used in the chemical plants close to the mines. Mica concentrates from weathered, decomposed ores are sold, after wet grinding to minus 200 mesh, to paint, rubber, plastic and building industries. Highly delaminated mica of fine size, with high gloss and sheen, with white color and low bulk weight is premium priced. Large quantities of a lower grade, dry ground mica of relative coarse size, concentrated as by-product from the lithium and feldspar flotation plants, are sold to the oil industry for use in drill mud and as roofing mica.^{24,25} Small tonnages of quartz of extreme purity are sold for fusing. A lower grade quartz is sold to the container glass industry and larger tonnages are moved locally for building and recreation purposes. The clays from one operation are sold as ceramic clays to the insulation and sanitary porcelain industry, while another company uses the clay for its own brick plant, where an attractive white brick is produced.

Pertinent data on pegmatite minerals produced in North Carolina are presented on Table III.

HARD ROCK FELDSPAR, QUARTZ AND MICA
FLOTATION IN SPRUCE PINE AREA

Three companies are mining and processing a coarse grained granite, or fine grained pegmatite, called alaskite, near Spruce Pine. The ore reserves are many million tons and practically unlimited. ¹¹ The Spruce Pine alaskite is a quite uniform feldspar ore nearly liberated at below 20 mesh (Tyler). The average chemical and mineral composition is shown on Table IV.

TABLE IV. SPRUCE PINE ALASKITE TYPE FELDSPAR ORE

<u>Chemical Analysis (% Wt)</u>		<u>Mineral Content (% Wt)</u>	
Na ₂ O	5.1	Soda feldspar	42.9
K ₂ O	3.4	Potash feldspar	14.7
CaO	0.9	Lime feldspar	6.4
Al ₂ O ₃	15.4	Quartz	28.0
SiO ₂	74.4	Muscovite	7.5
Fe ₂ O ₃	0.4	Iron minerals, garnet	0.5
Ign. Loss	0.4	Clay	very low

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 and stockpiled, and wet ground to minus 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 minus 200 mesh material (waste slimes) with cyclones or rake classifiers. The flotation process consists of three consecutive steps. 1) Cationic flotation of muscovite mica in acid circuit after controlled conditioning at approximately the following conditions. (A in Figure 2).

	<u>Mica Conditioning</u>	<u>Flotation</u>
% Solids	55-60	20-30
Time, min	3-5	2-4
pH	2.5-2.7	3.0-3.3
Reagent, lb/T of feed:		
Sulfuric acid	1.5	none
Tallow amine acetate	0.25	none
Fuel oil	1.0	none
Frother	0.1	none

Flotation is accomplished in wooden, acid-proof, supercharged Denver-DR flotation machines with level control. The 50 cu ft cell in open-trough banks of at least five cells is in general use in North Carolina. The mica flotation product is cleaned by flotation and wet screened on 80 mesh. The plus 80 mesh mica is sold wet to mica processing plants. 2) Anionic flotation removal of garnet, iron minerals and residual mica in acid circuit after dewatering and conditioning at approximately following conditions. (B in Figure 2).

	<u>Iron Mineral Conditioning</u>	<u>Flotation</u>
% Solids	65-75	20-30
Time, min	5	5
pH	2.2-2.5	2.8-3.2
Reagent, lb/T of feed:		
Sulfuric acid	0.4	none
Petroleum sulfonate	0.5	none
Frother	0.05	none

The garnet-iron minerals are removed as waste by flotation in supercharged Denver DR-type, open trough flotation machines. 3) Cationic separation of feldspar from quartz in HF circuit. The pulp is dewatered after the anionic flotation step and conditioned for separation of feldspar and quartz at approximately the following conditions. (C in Figure 2).

	<u>Feldspar Conditioning</u>	<u>Flotation</u>
% Solids	50-55	20-30
Time, min	3	5
pH	2.5	3.0-3.5
Reagent, lb/T of feed:		
Hydrofluoric acid	1.2	none
Tallow amine acetate	0.4	none
Kerosene	0.1	none
Frother	0.05	none

Flotation is accomplished in Denver DR-type open trough, supercharged machines. The feldspar product is dewatered on filters or in drain bins and dried in rotary driers 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.

One operation re-treats the combined waste by finer size cyclone desliming, high intensity wet magnetic separation, and mica and feldspar flotation, and recovers an appreciable amount of fine mica, feldspar and quartz which was formerly wasted. 12,13

Another operation produces a small quantity of extreme high grade quartz by further processing to exact size and chemical specifications which is used in the production of fused quartz glass.

A schematic flowsheet of a Spruce Pine feldspar flotation plant is given in Figure 2. 28,29

HARD ROCK SPODUMENE, MICA, FELDSPAR AND QUARTZ FLOTATION IN KINGS MOUNTAIN AREA

The two spodumene producing companies mine a typical pegmatite ore in open pits after removing amphibolite or mica schist overburden. The ore reserves around Kings Mountain are many million tons, though not unlimited.³⁰ The average chemical and mineral analysis of the spodumene pegmatite is as follows:

TABLE V. KINGS MOUNTAIN SPODUMENE PEGMATITE ORE

<u>Chemical Analysis (% Wt)</u>		<u>Mineral Content (% Wt)</u>	
Li ₂ O	1.4-1.5	Spodumene	15-25
Na ₂ O	1.2-3.8	Potash feldspar	12-15
K ₂ O	2.2-2.7	Soda feldspar	28-33
CaO	0.26-0.46	Quartz	25-35
Al ₂ O ₃	12.2-17.9	Muscovite and other associated minerals	5-15
SiO ₂	73.2-74.0		
Fe ₂ O ₃	0.51-0.97		
Ign. Loss	0.50-0.76		

The ore is crushed to about 1-inch where rod mill grinding is employed, and to 5/8-inch where ball mills are used to grind further to liberation. The Asheville Minerals Research Laboratory assisted Lithium Corporation in the change from originally rod milling to ball milling, and to flotation down to 15 micron in size to increase recovery and obtain chemical grade concentrate. The flotation circuit at that company is as follows. The ore is ball mill ground, with 0.5 lb/ton of feed of NaOH, in closed circuit with hydrocyclones, to all minus 65 mesh. The cyclone overflow is diluted and recycled to remove minus 400 mesh fines, the thickened cyclone underflow is scrubbed, diluted and deslimed again at 400 mesh in cyclones. The cyclone overflows from both 400 mesh desliming steps are recycled at about 15 microns. The minus 15 micron slimes go to

waste. The plus 15 micron material is combined with the plus 400 mesh deslimed material and conditioned at 55% solids at neutral pH, with 1.5 lb/ton of feed of tall oil-type fatty acid with 5-7% rosin acid content, and glycol-type frother. The conditioned pulp is floated at about 30% solids and cleaned and recleaned. The results of such flotation are presented in Table VI.^{14,26,27}

TABLE VI. SPODUMENE FLOTATION RESULTS (PILOT PLANT RUN 6)

	<u>% Wt</u>	<u>% Li₂O</u>	<u>Li₂O Distr.</u>	<u>Flot.Recovery</u>
-65 Mesh +15 Micron Concentrate	20.9	6.34	88.4	94.5
-65 Mesh +15 Micron Tailings	69.7	0.12	5.1	5.5
-15 Micron Slimes	7.4	1.43	6.5	-
Head Feed	100.0	1.64	100.0	93.5

The flotation concentrate is dewatered on a belt filter and trucked wet to the chemical plant.

The flotation tailings are dewatered and reconditioned for iron mineral and mica removal with petroleum sulfonate in acid circuit. The low iron tailing sand is sold as feldspatic sand to glass companies. The Minerals Research Laboratory has piloted the separation of feldspar and quartz using a new non-hydrofluoric acid reagent system, and also the separation and cleaning of very white mica from the mica-iron mineral flotation product.¹⁵ Figure 3 shows the schematic flowsheet of the spodumene flotation circuit with by-product feldspar-quartz and mica recovery flowsheet as developed for a lithium company at the Asheville Minerals Research Laboratory.

MICA, CLAY, FELDSPAR AND QUARTZ RECOVERY FROM WEATHERED PEGMATITE IN SPRUCE PINE AND KINGS MOUNTAIN AREAS

The highly weathered pegmatites of varying mineral content were mined for many years mainly for the small scrap mica content. At Kings Mountain Mica Company uses for all the formerly wasted materials, such as clay, feldspar and silica, have been found after reliable processing methods were developed by the Asheville Minerals Research Laboratory.¹⁶ An example of reduction of waste from 20 tons per ton of salable product to one ton of waste to 20 tons of salable product is given by discussing the flowsheet of Kings Mountain Mica-Silica-Brick Companies. See Figures 4 and 5.

The weathered ore is mined by self-propelled, bottom-dump scraper loaders, is stockpiled, blunged in an autogenous mill or crushed in a jaw crusher to minus 1-inch, and is deslimed and ground in a rod mill. A very coarse, fairly pure mica is recovered on a trommel screen on 1/8-inch mesh after differential grinding. The minus 1/8-inch material is treated for mica recovery on Humphreys spirals.¹⁷ By shape factor, the flat mica moves to the outside and the granular material is removed in the inside through the ports of the spirals. The spiral mica can be cleaned for sale by flotation in acid circuit with shortchain oleyl-amineacetate. The granular material, containing mainly high potash feldspar and quartz, is dewatered, blended and stockpiled for mica flotation recovery 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 with lignin sulfonate is used to recover fine white mica.^{18,19} After desliming in a cyclone, and conditioning with sulfuric acid and petroleum sulfonate, low grade mica and iron minerals are removed by flotation. After further desliming in a cyclone, and conditioning with hydrofluoric acid and tallow amine acetate, the feldspar quartz separation is achieved. 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.^{20,21}

The plus 1/8-inch mica concentrate from differential grinding and screening, and the concentrate from the Humphreys spirals are wet ground to high quality mica products with excellent sheen, color and fine size.²² Differential flocculation of mica and dispersion of clay and silicious minerals upgrade the wet ground mica before dewatering, drying and sizing on sifter-type screens.²³ Flotation mica is micronized in jet mills and sold as dry-ground products.

The combined slimes from mica and feldspar operations are thickened, filtered and partially dried in a rotary kiln for uses as white brick clay in Kings Mountain Brick Company's plant. Halloysite-type clay dispersed at high pH is recovered in the Spruce Pine area from weathered alaskite-type pegmatites.²⁴ It is degrittied by multiple settling and screening on 200 mesh. The clay is then flocculated after lowering of pH with sulfuric acid, filtered and dried in a wandering grate dryer, and sold as porcelain and sanitary ware clay.

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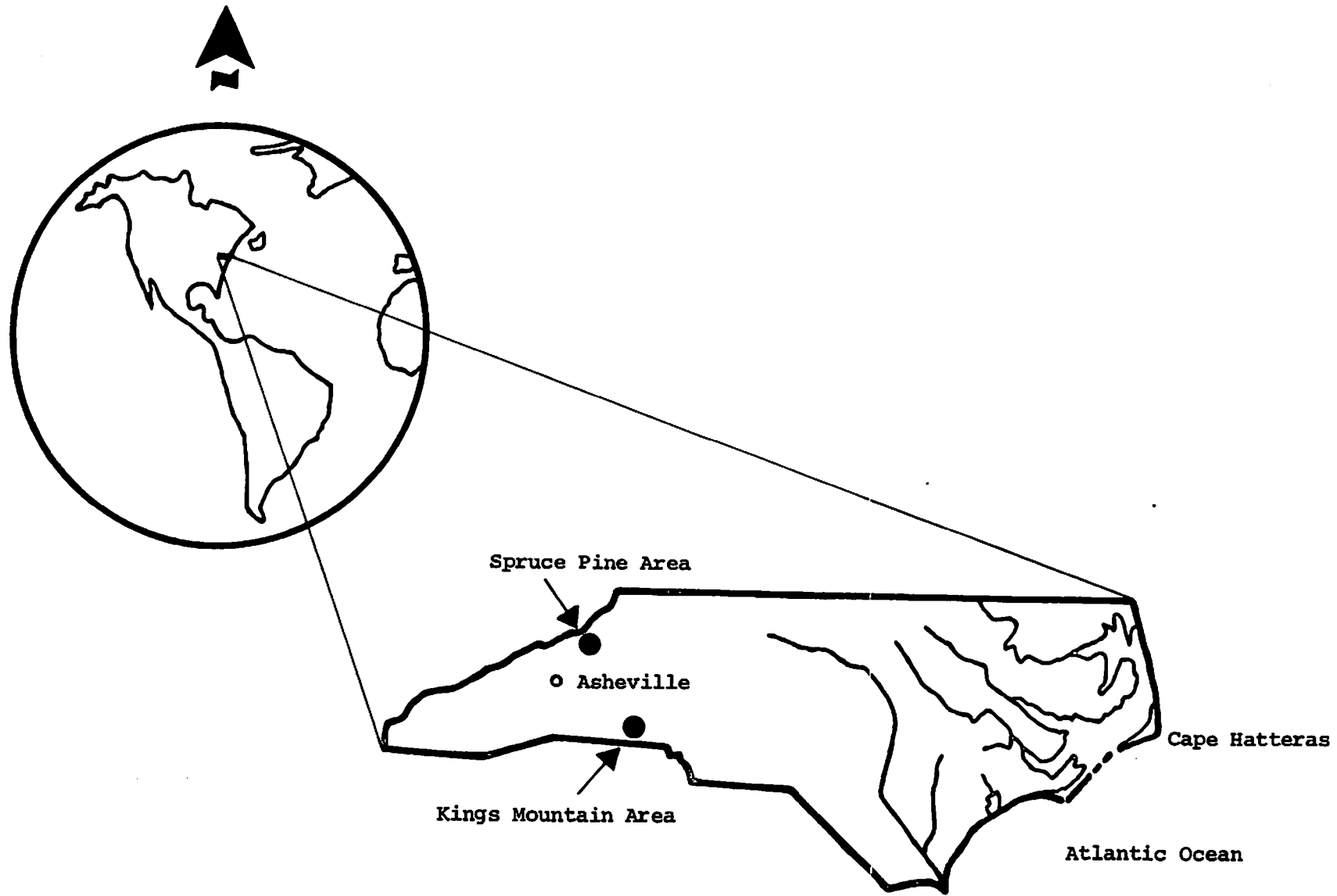


FIGURE 1. LOCATION OF PEGMATITE MINERAL PRODUCTION IN NORTH CAROLINA

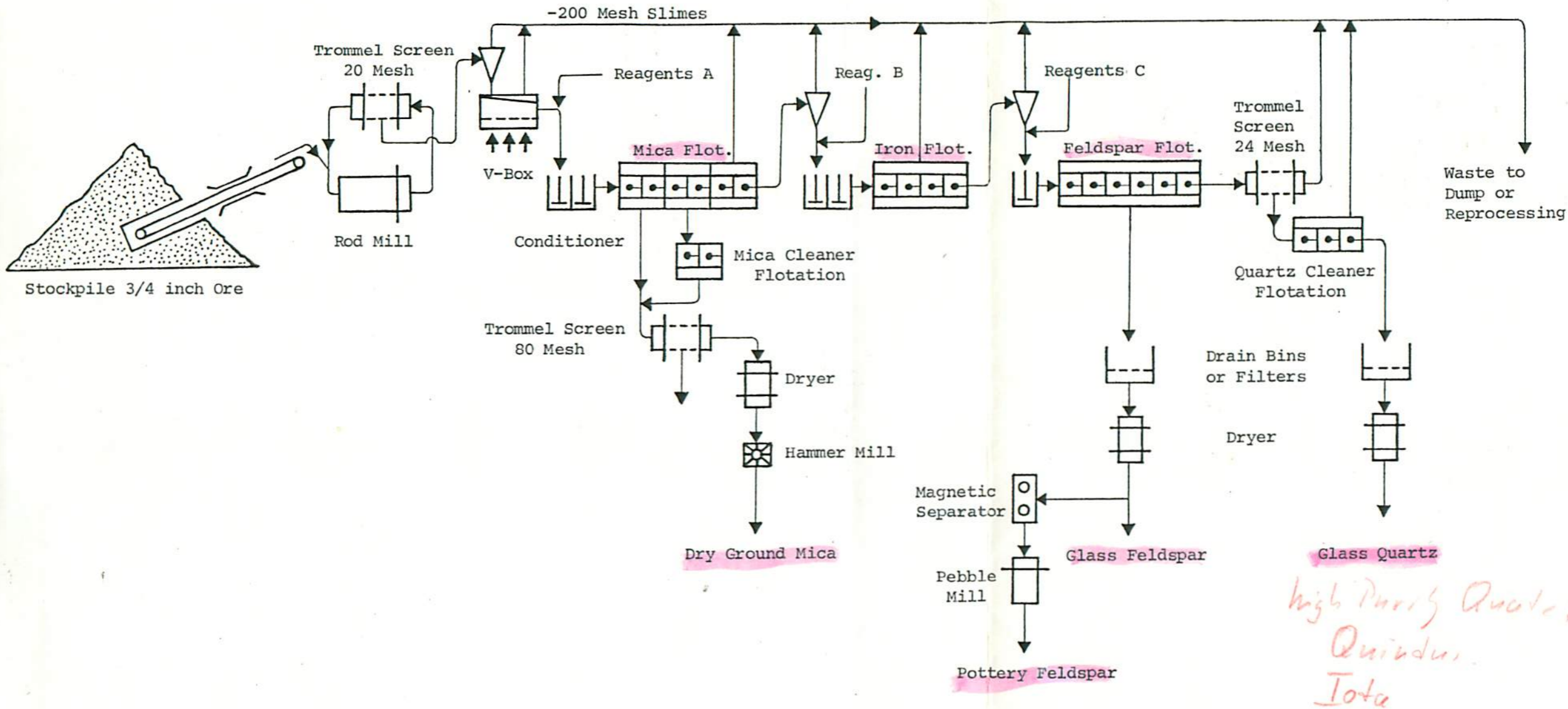


FIGURE 2. FELDSPAR, MICA AND QUARTZ FLOTATION FLOWSHEET (SCHEMATIC) SPRUCE PINE, NORTH CAROLINA

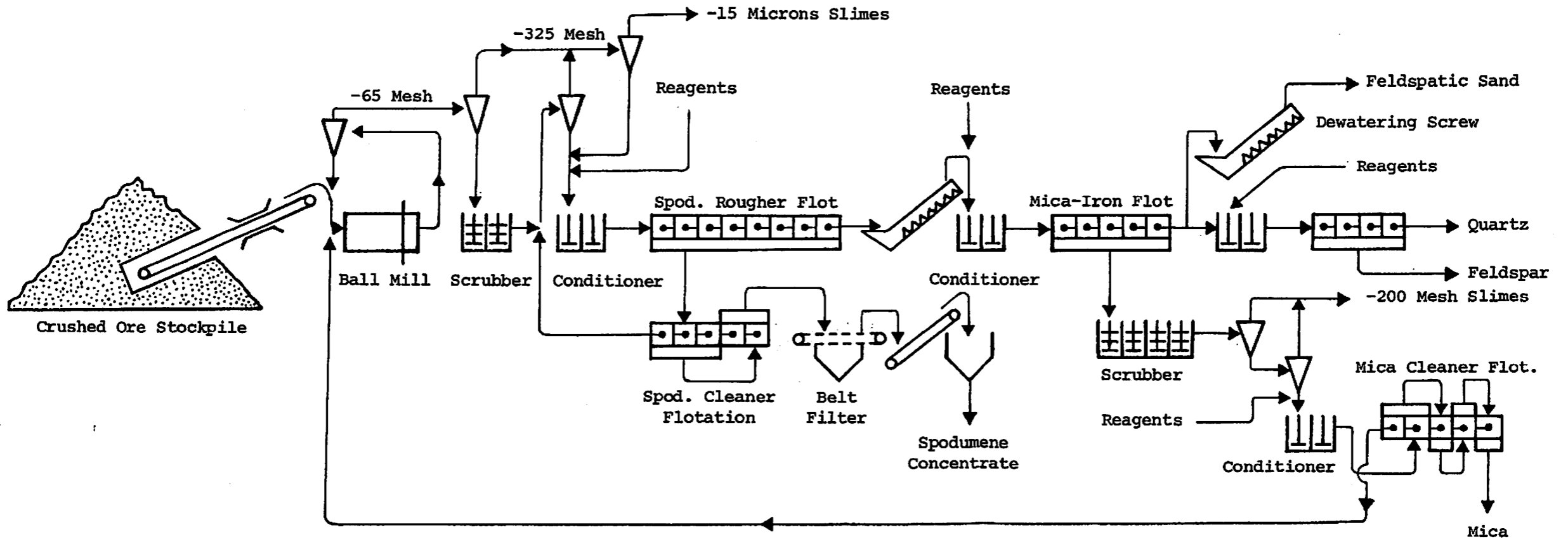


FIGURE 3. SPODUMENE AND BY-PRODUCT FELDSPAR-QUARTZ-MICA FLOTATION FLOWSHEET (SCHEMATIC) KINGS MOUNTAIN, NORTH CAROLINA

TABLE III. FELDSPAR, QUARTZ, SPODUMENE, MICA AND CLAY MINERALS RECOVERED AND SOLD FROM

Product Sold	Glass Spar		Pottery Spar			Feldspathic Sand
	Trade Name	F-20	K-40	NC-4	K-200	Foote Spar
Shipping Point	S.P.*	K.Mt.**	S.P.	K.Mt.	K.Mt.	K.Mt.
Chem. Analysis, % Wt						
SiO ₂	68.00	67.10	68.15	67.10	68.70	79.20
Al ₂ O ₃	19.00	18.30	18.88	18.30	19.27	12.10
Fe ₂ O ₃	0.07	0.07	0.07	0.07	0.06	0.06
CaO	1.85	0.36	1.60	0.36	tr	0.52
MgO	tr	tr	tr	tr	tr	tr
K ₂ O	3.75	10.10	4.50	10.10	3.69	2.62
Na ₂ O	7.15	3.80	6.70	3.80	7.91	4.80
Li ₂ O	-	-	-	-	0.08	0.35
Ign.Loss	0.13	0.26	0.10	0.26	0.25	0.35
Approx. Mineral Content, % Wt						
Potash Spar	22	60	26	60	22	16
Soda Spar	61	32	57	32	67	41
Lime Spar	9	2	8	2	-	2
Quartz	8	6	9	6	11	41
Spodumene	-	-	-	-	-	-
Clay Minerals	-	-	-	-	-	-
Muscovite	-	-	-	-	-	-
Size Analy., % Wt Retained						
on 20 M (Tyler)	0.1	-	ground	ground	0.1	ground
on 48 M (Tyler)	42.0	-	to pass	to pass	na	to spe
on 100 M (Tyler)	85.5	56.15	170,200	120,170	35.1	
on 200 M (Tyler)	97.2	90.05	or 250	200,250	75.1	
on 325 M (Tyler)	-	-	mesh	mesh	-	
Bulk Weight, lbs/cu ft	90	80-85	50-55	55-60	80	85-90
PCE	9	-	9	-	-	-
\$/st fob (1980)	25.50	46	38.25	64.00	24.00	12.30

* Spruce Pine

** Kings Mountain

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Spodumene			Quartz Sand		Clay	
Glass & Chem. K.Mt.	Ceramic K.Mt.	Low Iron K.Mt.	Glass S.P.	K-30 K.Mt.	China Clay S.P.	KM-25 K.Mt.
63	64.12	64.80	92-98	99.30	47.90	53.8
24.7	26.50	26.25	0.5-3.0	0.32	36.91	32.10
1.7	0.90-max	0.10	0.1-0.15	0.02	0.70	1.40
tr	tr	tr	-	tr	n.a.	tr
tr	tr	tr	-	tr	n.a.	tr
0.50	0.27	0.14	0.5-2.0	0.23	1.05	2.20
0.30	0.32	0.35	-	0.08	0.25	0.13
5.6-6.5	7.22	6.83	-	-	-	0.08
0.30	0.50	n.a.	wet	0.11	13.50	10.30
3	2	1	2	-	3	5
3	3	3	4	-	2	1
-	-	-	-	-	-	-
9	5	6	90-95	+99	2	10
85	90	90	-	-	-	-
-	9	-	-	-	90	80
-	-	-	-	-	3	4
-	ground	-	-	-	-	-
1.5	to -20	-	-	43.2	-	-
20.0	+140 or	0.5	-	82.1	-	2.2
50.0	-200	90.0	100	97.5	tr	14.4
-	-	-	-	-	1.0	30.1
n.a.	n.a.	n.a.	n.a.	n.a.	25-26	-
-	-	-	-	-	32-33	31-32½
124	n.a.	n.a.	2.5	n.a.	78-100	n.a.

TABLE III. FELDSPAR, QUARTZ, SPODUMENE, MICA AND CLAY MINERALS RECOVERED AND SOLD FROM

Product Sold Trade Name	Glass Spar		Pottery Spar			Feldspatic Sand
	F-20	K-40	NC-4	K-200	Foote Spar	
Shipping Point	S.P.*	K.Mt.**	S.P.	K.Mt.	K.Mt.	K.Mt.
Chem. Analysis, % Wt						
SiO ₂	68.00	67.10	68.15	67.10	68.70	79.20
Al ₂ O ₃	19.00	18.30	18.88	18.30	19.27	12.10
Fe ₂ O ₃	0.07	0.07	0.07	0.07	0.06	0.06
CaO	1.85	0.36	1.60	0.36	tr	0.52
MgO	tr	tr	tr	tr	tr	tr
K ₂ O	3.75	10.10	4.50	10.10	3.69	2.62
Na ₂ O	7.15	3.80	6.70	3.80	7.91	4.80
Li ₂ O	-	-	-	-	0.08	0.35
Ign. Loss	0.13	0.26	0.10	0.26	0.25	0.35
Approx. Mineral Content, % Wt						
Potash Spar	22	60	26	60	22	16
Soda Spar	61	32	57	32	67	41
Lime Spar	9	2	8	2	-	2
Quartz	8	6	9	6	11	41
Spodumene	-	-	-	-	-	-
Clay Minerals	-	-	-	-	-	-
Muscovite	-	-	-	-	-	-
Size Analy., % Wt Retained						
on 20 M (Tyler)	0.1	-	ground	ground	0.1	ground
on 48 M (Tyler)	42.0	-	to pass	to pass	na	to specs
on 100 M (Tyler)	85.5	56.15	170,200	120,170	35.1	
on 200 M (Tyler)	97.2	90.05	or 250	200,250	75.1	
on 325 M (Tyler)	-	-	mesh	mesh	-	
Bulk Weight, lbs/cu ft	90	80-85	50-55	55-60	80	85-90
PCE	9	-	9	-	-	-
\$/st fob (19 80)	25.50	46	38.25	64.00	24.00	12.30

* Spruce Pine

** Kings Mountain

NORTH CAROLINA PEGMATITES 1980

Spodumene			Quartz Sand		Clay	
Glass & Chem. K.Mt.	Ceramic K.Mt.	Low Iron K.Mt.	Glass S.P.	K-30 K.Mt.	China Clay S.P.	KM-25 K.Mt.
63	64.12	64.80	92-98	99.30	47.90	53.8
24.7	26.50	26.25	0.5-3.0	0.32	36.91	32.10
1.7	0.90-max	0.10	0.1-0.15	0.02	0.70	1.40
tr	tr	tr	-	tr	n.a.	tr
tr	tr	tr	-	tr	n.a.	tr
0.50	0.27	0.14	0.5-2.0	0.23	1.05	2.20
0.30	0.32	0.35	-	0.08	0.25	0.13
5.6-6.5	7.22	6.83	-	-	-	0.08
0.30	0.50	n.a.	wet	0.11	13.50	10.30
3	2	1	2	-	3	5
3	3	3	4	-	2	1
-	-	-	-	-	-	-
9	5	6	90-95	+99	2	10
85	90	90	-	-	-	-
-	9	-	-	-	90	80
-	-	-	-	-	3	4
-	ground	-	-	-	-	-
1.5	to -20	-	-	43.2	-	-
20.0	+140 or	0.5	-	82.1	-	2.2
50.0	-200	90.0	100	97.5	tr	14.4
-	-	-	-	-	1.0	30.1
n.a.	n.a.	n.a.	n.a.	n.a.	25-26	-
-	-	-	-	-	32-33	31-32½
124	n.a.	n.a.	2.5	n.a.	78-100	n.a.

Ground Mica

325 Wet	P-80 Dry	011 Well	1200 Dry
S.P.	S.P.	S.P.	S.P.
46.5	44-48	44-48	49.4
34.0	31-38	31-38	29.7
4.0	5-max	5-max	4.8
nil	-	-	nil
nil	-	-	nil
9.45	9-max	9-max	10.2
0.45	0.5-2.5	0.5-2.5	1.1
-	-	-	-
5.00	4-5.5	4-5.5	4.8
-	} 5	} 5	} 2.5
-	-	-	-
-	5	5	1.2
-	-	-	-
3-5	10	10	-
95-98	80	80	96
-	-	-	-
-	-	-	-
tr	1-2	10-70	-
1.0-4.0	13-18	70-90	-
3.0-10.0	78	10-30	-
8.2-12.0	-	-	-
to 12	20-25	25-28	13.5-14
-	-	-	-
260	140	110	146