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AIR CLASSIFICATION OF FELDSPAR PEGMATITE FROM THAILAND

C J Mitchell, D A Briggs and D J Morgan

1. INTRODUCTION

The Takua Pit Thong mine, Rajburi, is situated along the border with Burma, about 200 km W of Bangkok. Mining started 18 years ago for tin which occurs with arsenopyrite near the contact between a granite and metamorphosed country rock. Pegmatitic veins associated with the granite are rich in microcline and microcline perthite. Beneficiation testwork on the granite and its associated pegmatitic phases by the Department of Mineral Resources (DMR), Bangkok, three years ago in response to the growing need for ceramic feldspar in Thailand, established the viability of feldspar production. At present, tin production (72% Sn) is running at about 9 tonnes/month and saleable feldspar concentrate in excess of 300 tonnes/month.

Feldspar is blasted from pegmatitic veins and essentially hand-selected, and liberated feldspars in the weathered granite are also concentrated by screening and hand-sorting. The feldspar concentrates (containing 11-13% K_2O, 1.5-2% Na_2O and 0.04-0.06% Fe_2O_3) are marketed in sized grades down to 3/4 inch, but this only represents about 30% of the potentially recoverable feldspar in the deposit. Below this size mica becomes a significant impurity (about 10%), imparting a poor colour to the fired material. Since 1987 when production started, all feldspar-rich material below 3/4 inch has been stockpiled until a simple method of eliminating mica is devised. Magnetic separation and flotation have been demonstrated to be reasonably successful but would be too costly to install at the scale required.

The mine was visited in November 1989 by D J Morgan with Dr Chanyavanich of the DMR and Mr Samrit Lelawongs, an ex-Director of Mining Engineering with DMR and the present owner of the mine. The possibility of using an air classification method to eliminate the mica was discussed and a 20 kg sample of the stockpiled material was collected for shipment to BGS for air classification trials.

This report describes the results of these air classification trials. The work was carried out as part of the ODA/BGS R&D project "Mineral Resource Development in the Third World".

2. MINERALOGY

The sample as received was composed predominantly of white to light grey feldspar crystals, generally angular to sub-rounded. The whiter grains are more angular, probably representing freshly broken material from blasting, whereas the greyer, more rounded feldspars probably come from the weathered tin-mineralised granite. Some quartz is present and muscovite mica occurs in small to large individual flakes or as books of flakes. The flakes are virtually transparent with a light green colour but the books are non-translucent with a silvery, metallic lustre. Small inclusions of mica are also present in the feldspar. A small proportion of a black mineral with a resinous lustre, probably tourmaline, occurs as small discrete grains or inclusions. An orange brown (iron ?) staining occurs on some of the grains, mostly those derived from the weathered granite.

Examination of the sample by x-ray diffraction confirmed the feldspar to be microcline and the presence of quartz in a substantial amount (>25%). The main mica present is muscovite, and the tourmaline of the dravite variety was also confirmed to be present.

3. SIZE ANALYSIS

The sample was split into quarters, and one of these was dried overnight in a moisture-extraction oven at 55 ^{o}C (moisture content as received was about 0.5 %). The quarter sample was screened on 6.35 mm, 5 mm, 4 mm, 2.8 mm, 2 mm, 1mm, 500 µm, 250 µm and 125 µm sieves, using a Fritsch analysette 18 rotary sieve shaker and thus was split into ten size fractions. The size distribution is shown in Figure 1 and detailed in Table 1.

Examination of the +4 mm size fractions under a binocular microscope indicated that there was virtually no mica present, except for a few small inclusions and mica books, mostly in the -5 +4 mm fraction. As the mica content of these fractions was only of the order of 1%, they could already be taken to be of concentrate grade without any further processing (see Table 1).

Below 4 mm, the mica content of the sized fractions gradually increased with decrease in size, from a moderate 2-3% in the -4 +2 mm range to around 10-20% in the size range down to 0.5 mm (500 µm). At sizes below 500 µm, the mica contents were again high, but as the total weight of this material represented only 1.8% of the total sample it could be excluded from further consideration without any significant loss in feldspar recovery.

Attention was therefore focussed on the material between 4 mm and 500 µm, and the four sized fractions in this range were then subjected to separation by air classification.

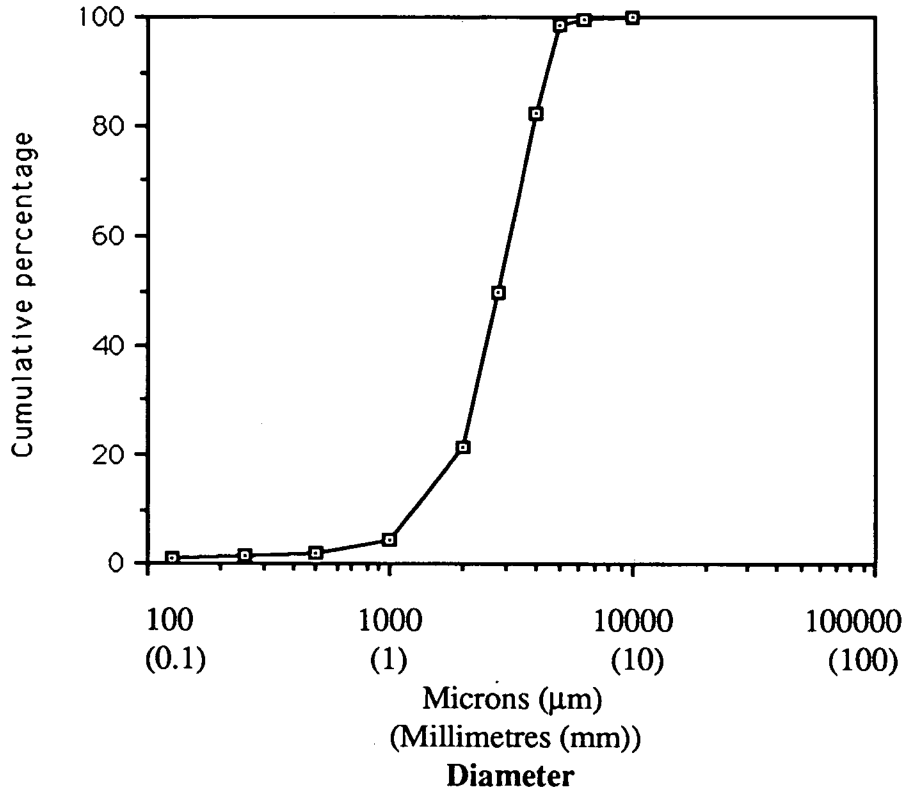

Figure 1. : Grain size distribution of Thailand feldspar pegmatite.

This is incidentally the optimum size range in which air classification functions most efficiently, so the size distribution of this feldspar/mica sample provides encouragement that successful beneficiation can be achieved.

4. AIR CLASSIFICATION TRIALS

4.1. Description of Alpine zig-zag air classifier

The machine used was the Multi-Plex Laboratory Classifier Type 1-40 MZM, which is the smallest version available, (see Figure 2). However, it is capable of throughputs up to 100 kg/hour, and the results can be matched on the scaled-up pilot and full-size production classifiers. The laboratory machine can rapidly handle batch samples of 1 kg; attachments for continuous running are available.

Essentially, the classifier consists of a long zig-zag column through which is passed a current of air which can be controlled by means of a throttle. Material fed into the upper part of the zig-zag tube is then separated into two fractions by the upward current of air. The fraction passing downwards (underflow) through the airstream is coarse, granular and of higher density, and that carried up (overflow) - and discharged through a cyclone - is finer in particle size, of lower specific gravity, and also tends to include any flatter, platy particles. The movement of the particles in the classifying tube can be directly observed through the plexiglass cover and adjustments made to achieve the separation by simply varying the setting of the air throttle, while the machine is running. The two fractions are collected separately in 1-litre glass bottles, these can be combined and repassed in a continuous run when the optimum conditions have been established by visual inspection of the products recovered at different settings of the throttle.

The classifier is capable of handling material in the size range 0.1 - 4 mm, and if presented with an unsized feed would simply separate coarse from fine particles. Repeated running at different settings would produce a series of fractions separated on the basis of particle size. However, it provides a method for the concentration of minerals from their host-rocks on the basis of differences in specific gravity and particle shape, provided that it is fed with individual fractions that have first been closely sized by screening. The separation of muscovite mica (density 2.8 g/cm^3) from K-feldspar (density 2.6 g/cm^3) does not represent the ideal situation where the platy material being lifted in the overflow is lighter than the granular material reporting to the underflow but it was hoped that the platy nature of the mica would outweigh the density factor.

4.2. Separation procedure

The fractions that were air-classified were the -4 +2.8 mm, -2.8 +2 mm, -2 +1 mm and -1 mm +500 μm size fractions.

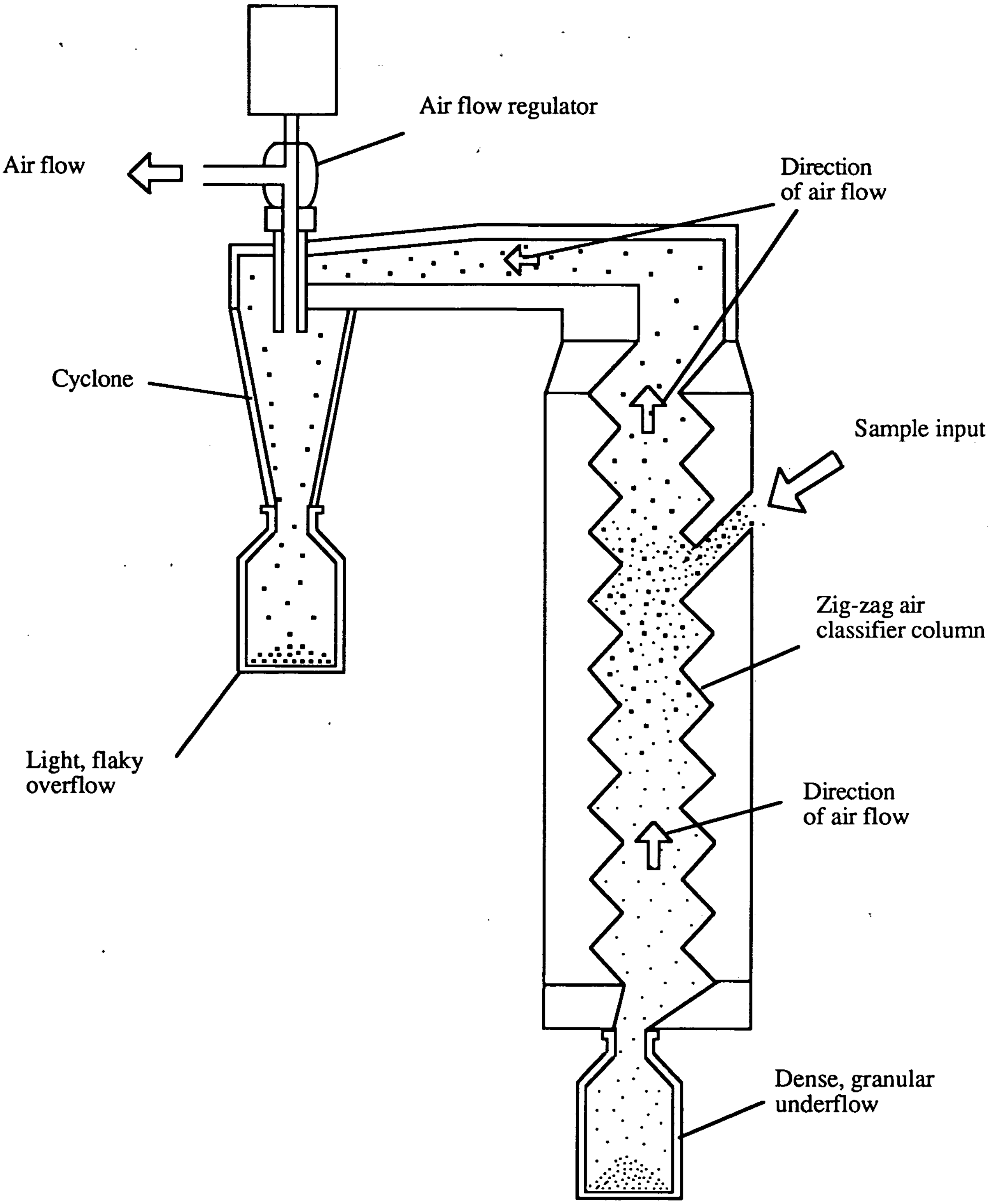

Figure 2. : Zig-zag air classifier.

The principal aim of air classification was to produce feldspar concentrates as free of mica as possible. To this end, each of the sized fractions was passed in turn through the air classifier, first at a relatively low rate of air flow and secondly at an increased rate. The airflow rates were carefully adjusted between passes to obtain optimum results, and generally lower rates were required for finer-sized material.

The first pass separated free mica flakes into the overflow and thus produced a tailing. It was fairly easy to obtain a clean mica product in this way for each size fraction, except in the case of the coarse -4 +2.8 mm material, where the mica was still locked with the feldspar in composite particles. The second pass was of underflow material from the first pass, and this removed much of the remaining impurities and composite particles into the overflow or middling product. The final product was an underflow which was in effect a feldspar concentrate, but this also contained quartz. Ideally the tail and concentrate would contain clean mica and clean feldspar / quartz respectively, but generally the difficulty was to minimise the amount of feldspar in the middling fraction thus achieving high feldspar recovery.

Preliminary evaluation of all products was made by heavy liquid separation in bromoform diluted with triethylorthophosphate to a density of 2.7 g/cm^3, that is midway between feldspar and muscovite mica. Thus it was possible to obtain a mineralogical 'assay' for feldspar content of all products simply by subtracting the percentage mica content obtained as a 2.7 g/cm^3 'sink' product from the total.

4.3. Results

Detailed results of the sizing and air classification tests are given in Table 1. The size fractions which were air classified have produced concentrates with 'feldspar' (including quartz) contents in the range 93-99%. Combined, these concentrates contain 71.7% of the original feed, with a combined 'feldspar' grade of 98% at a recovery of 72.8% of the feldspar in the head. The combined middlings and tails rejected from these classifications represent the loss of only 7.3% of the total feldspar content.

Taken together with all the unclassified material coarser than 4 mm which is already of acceptable feldspar grade, this gives an overall grade of 91.8% in 89.5% of the total weight. This represents an excellent result, and further confirms that the -500 µm material, which contains much mica impurity, can be rejected without making much difference to the overall recovery.

Table 1 : Zig-zag air classification of Thailand feldspar.

Size Fraction	WEIGHT Fraction %	Head %	'FELDSPAR' Assay %	Distribution % fraction	% head
+6.35mm	unseparated.	0.3	99.0	100.0	0.31
-6.35+5mm	unseparated.	1.4	99.0	100.0	1.44
-5+4mm	unseparated.	16.1	98.9	100.0	16.6
-4+2.8mm	100.0	32.3	97.9	100.0	32.9
Conc.	97.9	31.6	98.3	98.3	32.3
Mid.	2.1	0.7	80.8	1.7	0.6
-2.8+2mm	100.0	28.4	96.8	100.0	28.6
Conc.	85.7	24.3	99.0	86.8	24.8
Mid.	13.1	3.7	92.7	12.5	3.6
Tail	1.3	0.4	51.1	0.7	0.2
-2+1mm	100.0	16.9	92.5	100.0	16.2
Conc.	79.8	13.5	96.2	83.0	13.5
Mid	17.6	3.0	87.1	16.6	2.7
Tail	2.6	0.4	16.4	0.5	0.1
-1mm+500μm	100.0	2.8	83.2	100.0	2.4
Conc.	82.7	2.3	93.0	92.4	2.2
Mid.	6.5	0.2	70.8	5.5	0.1
Tail	10.9	0.3	15.6	2.1	0.1
-500+250μm	unseparated.	0.4	77.6	100.0	0.3
-250+125μm	unseparated.	0.3	82.1	100.0	0.3
-125μm	unseparated.	1.1	91.6	100.0	1.1
TOTAL	-	100.0	-	-	100.0
Head assay			96.3		
Combined concentrates	Y	G		R	
>2.8mm		49.4	98.5		50.6
>2mm		73.7	98.7		75.4
>1mm		87.2	98.3		88.8
>500μm		89.5	98.2		91.1

5. FURTHER TESTWORK

Air tabling was considered as an alternative to air classification in the separation of mica from feldspar. Air tables work best on feeds which are finer than 1 mm in particle size and which have been closely sized.

5.1. Preparation of feed

Two of the remaining quarters were sieved on 2 mm, and the oversize material was ground so that it was also finer than 2 mm. A small residue was not readily grindable through the 2 mm sieve, and this was found to be almost pure mica.The ground material was screened on 1 mm, and the -2 +1 mm fraction was passed over an air table. No effective separation was obtained, so the sample was re-ground so that it was all finer than 1 mm, and screened on 0.5 mm. The -1 +0.5 mm (500 μm) material was then used for further tests on the air table, and also on the air classifier for the purpose of comparison.

5.2. Description of air-table

The machine used was a Kipp Kelly V-135 gravity table which consists of a separation deck covered by a fine gauze; this deck can be oriented in any horizontal plane (see Figure 3). For this work the deck was inclined from the feed chute down to the discharge edge (adjusted by the deck side slope control), and also sloping down to the left as seen from the discharge end (which can be adjusted by the deck end slope control from 0-8°). The deck was vibrated to continually agitate the feed, freeing the platy from the granular material, and a current of air was blown through the gauze to lift the platy material off the surface of the deck. The amount of air was controlled by adjusting the speed of the fan, and opening and closing the control gate of the air inlet. During separation the granular material migrates upslope across to the right hand side of the deck, due to the nature of the reciprocal vibration, which was controlled by adjusting the eccentric drive speed. The platy material being held aloft by the air current was unaffected by the pull of this vibration and migrated straight down the left hand side of the deck. Thus the platy and granular material could be separated.

5.3. Separation procedure

Even by adjusting the deck slopes in both directions, the air flow and the feed rate, no separation was obtainable on the -2 +1 mm feed as this was too coarse. However the -1 +0.5 mm responded very well, and a mica-rich tailing was easily obtained, leaving a rough concentrate of feldspar. The rough concentrate was repassed to produce a small middling fraction containing most of the remaining mica and composite material, and an upgraded feldspar concentrate. A portion of the untreated -1 +0.5 mm material was also

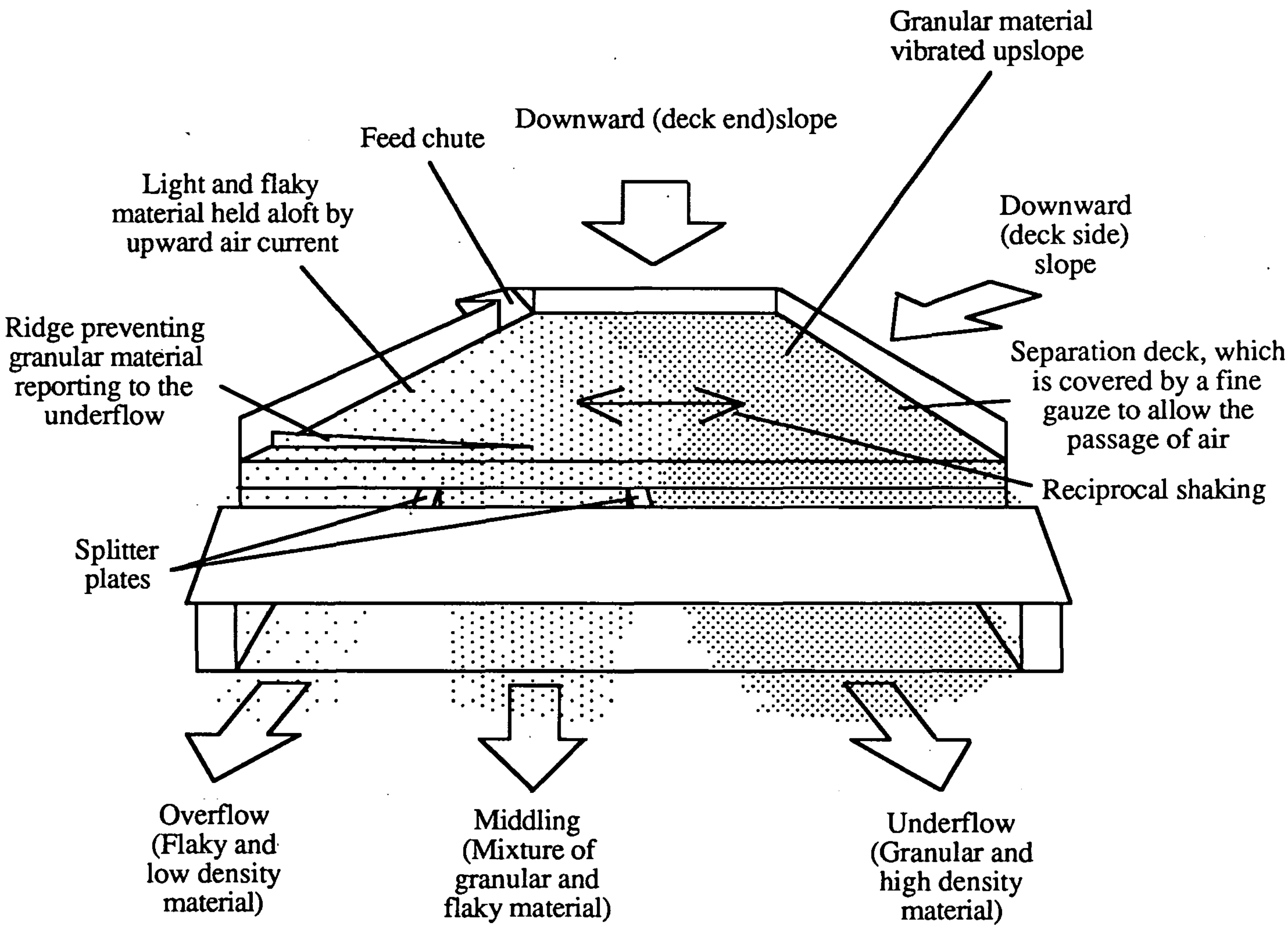

Figure 3. : Air table.

passed through the air classifier to produce similar concentrate, middling and tailing fractions as before. Both sets of products were weighed and subjected to heavy liquid separations to monitor their composition. The results are given in Table 2.

Table 2 : Comparison between a zig-zag air classified and an air tabled sample of Thailand feldspar (-1mm +500µm)

Sample	Weight	Feldspar grade	Feldspar recovery
Zig-zag air-classification			
Concentrate	82.8%	98.2%	84.7%
Middling	14.3%	94.5%	14.1%
Tail	2.9%	38.6%	1.2%
Air-tabling			
Concentrate	96.5%	97.1%	97.6%
Middling	1.4%	78.4%	1.2%
Tail	2.1%	58.4%	1.2%

5.4. Results

The comparison between zig-zag air classification and air-tabling on a crushed sample screened to -1 mm + 500 µm apparently shows the latter to produce a better result. The grade of the air-tabled concentrate, at 97.1%, is lower than the zig-zag concentrate, at 98.2%, but the recovery is significantly higher, 97.6% and 84.7% for the air-tabled and zig-zag concentrates respectively. However, if the zig-zag concentrate and middling are combined the resulting product has higher grade and recovery, 97.7% and 98.8% respectively, than the air-tabled concentrate. The air-tabled concentrate could be repassed to improve its grade but this would inevitably reduce its recovery. In short, air tabling provides no significant improvement over air classification.

6. CHEMICAL ANALYSIS

Selected products from the air classification trials were analysed chemically by X-ray fluorescence (see Table 3). These were: as received material, combined +4 mm material from sieving, the four zig-zag air-classification concentrates, +2 mm mica (grind product) and a pure feldspar (hand-picked from the light fraction of heavy liquid separation of the -4 +2 mm concentrate). For comparative purposes, chemical analysis of two commercial grades of potassium feldspar have been included in Table 4.

The 'pure feldspar' analysis has a high silica content, with correspondingly depressed values of the other oxides, which suggests that quartz is present. This had been noted in the sample as received but the exact amount occurring was not ascertained. Assuming approximately 32% quartz occurs in the 'pure feldspar', the results can be recalculated to give an approximation of the actual feldspar composition (see 'recalculated feldspar' in Table 3). The 'recalculated feldspar' analysis corresponds to an orthoclase feldspar, and the 'pure mica' analysis to that of an iron-rich muscovite.

Comparing the analysis for 'pure feldspar' and 'pure mica' shows that virtually all the TiO_2, Fe_2O_3, MgO and MnO present in the samples are derived from the mica. These oxides are likely to be those causing the discolouration of ceramic material on firing, and therefore the low levels of these oxides occurring in the 'pure feldspar' should be sought in the air-classification concentrates. The 'pure feldspar' compares very favourably with the commercial grades which are used in ceramics, although the K_2O/Na_2O values are low due to the high SiO_2 content. The 'as received' material contains about 0.53 % of these deleterious oxides combined, the +4 mm contains about half that level and the amount in the concentrates increases from 0.32 to 0.76 % with decreasing grain size. This indicates higher mica contents at finer grain sizes, Table 1 confirms this, with the mica content increasing from 1 % in the +4 mm up to 7 % in the -1 mm +500 μm concentrate as determined by heavy liquid separation.

Individually the +4 mm and zig-zag air-classification concentrates have higher levels of these deleterious oxides than the commercially available products. Combined, the overall values are 0.02% TiO_2, 0.33% Fe_2O_3, 0.01% MgO and 0.02% MnO, which are lower than those for the 'as received' material, but over twice the level desired.

Table 4 : Chemical composition of the feldspar, zig-zag air classification concentrates, and commercial feldspar products

Oxide (wt%)	As received	+4 mm	-4 +2mm	-2.8 +2mm	-2 +1mm	-1mm +500μm
SiO_2	79.19	81.61	80.92	80.36	76.89	71.37
Al_2O_3	11.24	9.95	10.38	10.72	12.67	16.11
TiO_2	0.02	0.01	0.01	0.02	0.02	0.03
Fe_2O_3	0.44	0.25	0.30	0.37	0.40	0.68
MgO	0.03	0.00	0.00	0.00	0.03	0.01
CaO	0.17	0.13	0.15	0.16	0.18	0.28
Na_2O	2.07	1.65	1.85	2.01	2.49	3.95
K_2O	5.72	5.69	5.65	5.56	6.35	6.37
MnO	0.04	0.00	0.01	0.01	0.05	0.04
P_2O_5	0.06	0.04	0.04	0.03	0.06	0.06
LOI	0.60	0.33	0.28	0.35	0.50	0.63
Total	99.56	99.64	99.58	99.59	99.64	99.53

Oxide (wt%)	Pure mica	Pure feldspar	Recalc. feldspar	P.E.Hines "Polar"	Brazilian feldspar
SiO_2	46.45	76.93	66.44	66.70	66.1
Al_2O_3	32.97	12.43	18.38	18.20	18.6
TiO_2	0.27	0.00	0.00	-	0.01
Fe_2O_3	4.79	0.11	0.16	0.10	0.03
MgO	0.17	0.00	0.00	0.05	0.01
CaO	0.09	0.14	0.21	0.15	0.10
Na_2O	0.6	2.09	3.09	3.00	3.3
K_2O	10.16	7.51	11.11	11.50	11.3
MnO	0.16	0.00	0.00	-	0.00
P_2O_5	0.00	0.07	0.10	-	0.19
LOI	4.42	0.35	0.52	0.30	0.2
Total	100.08	99.61	100.01	100.0	99.84

7. CONCLUSIONS

As mentioned previously, the separation of mica from feldspar by air classification is hampered by the higher density of the mica, the separation relying entirely on the platy nature of the mica. However, the mica not only occurs as flakes but as books of flakes also; these are effectively granular and would therefore be expected to report with the feldspar in the underflow product of zig-zag air classification. The heavy liquid separation carried out on the air-classification products revealed this to be the case; the small amount of mica removed from the feldspar concentrates was entirely mica books, with the middling product containing smaller and thinner books and the tail was composed almost entirely of mica flakes. Theoretically the mica books could be removed from the feldspar concentrates by repassing them at higher flowrates, so that all the feldspar reported to the overflow, leaving the mica books to drop out in the underflow.

Chemical analyses reveal that the +4 mm and zig-zag air-classification concentrates combined have a relatively high level of the deleterious oxides TiO_2, Fe_2O_3, MgO and MnO, 0.38% compared to commercially available products with 0.1% or lower. Therefore air-classification has only partially reduced the problem of ceramic feed contamination, and further processing might be required to upgrade the feldspar to the required level.

The simplest form of processing for the feldspar material would involve screening at 2 mm, retaining the +2 mm material and rejecting the -2 mm material. This would produce a +2 mm product with an overall grade of 97.8% feldspar, representing 78.5% of the overall sample and a recovery of 79.7% of the total feldspar content. The -2 mm product would contain 9.2% mica, represent 21.5% of the total weight of material, and contain 52.6% of the total mica. Figure 4 shows the processing carried out in this investigation.

The best scheme for air-classification of the feldspar material (see Figure 5) would involve zig-zag air classification of the -4 +0.5 mm size fractions. Air-tabling does not produce any marked improvement in grades and recoveries. Additional crushing and grinding would only introduce an unnecessary complication of the processing scheme and result in the production of excessive fines. The material would be sieved on 4 mm, 2.8 mm, 2 mm, 1 mm and 500 µm aperture screens, with the +4 mm retained as concentrate grade feldspar, and the -500 µm material rejected as too mica-rich. Air-classification would be carried out on the intermediate size fractions, with the concentrates grouped with the +4 mm material, and the middling and tail products rejected. This would result in a concentrate with a feldspar grade and recovery of 98.2% and 91.2% respectively.

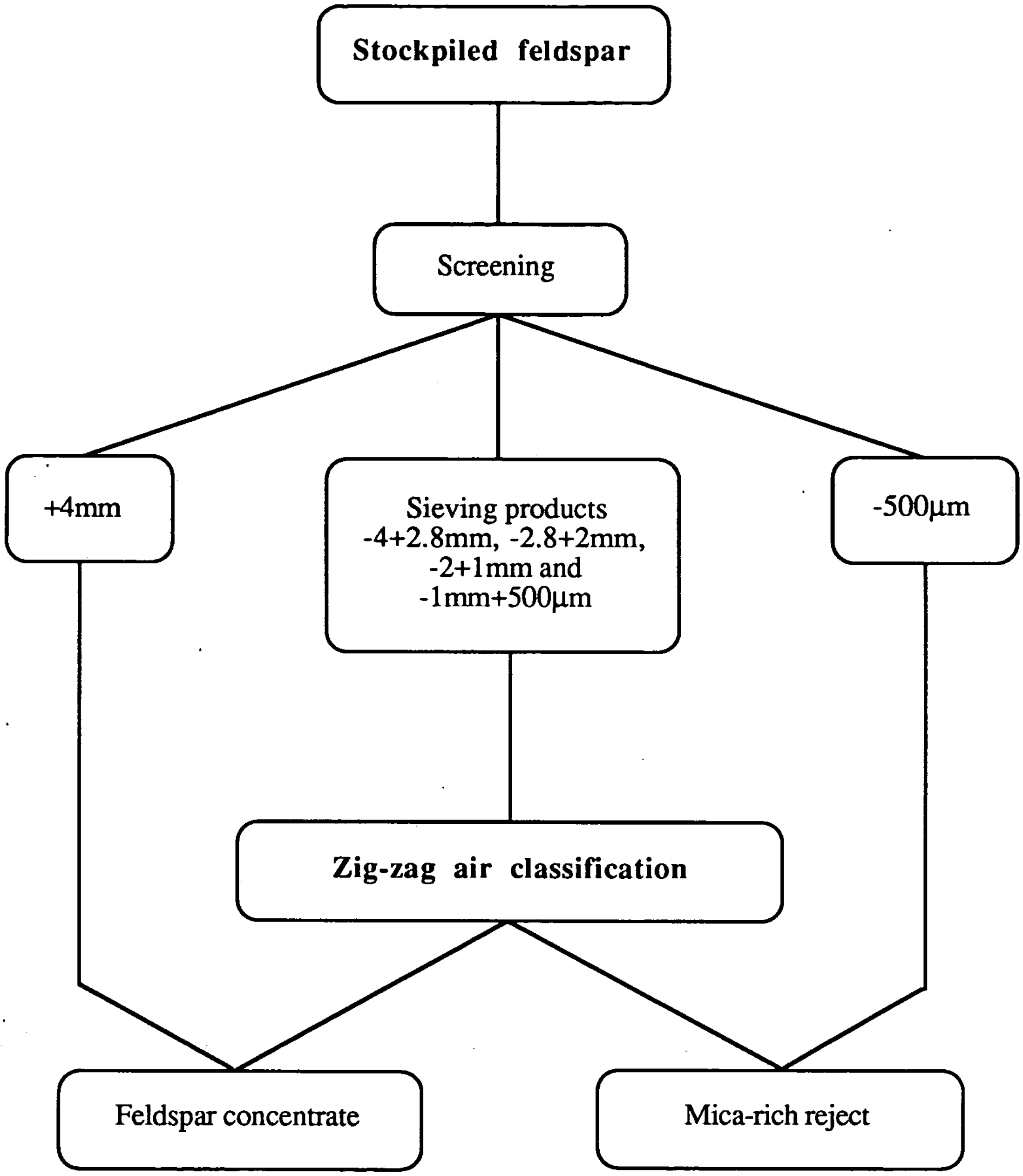

Figure 5. : Flowsheet of processing recommended for stockpiled Thailand feldspar.

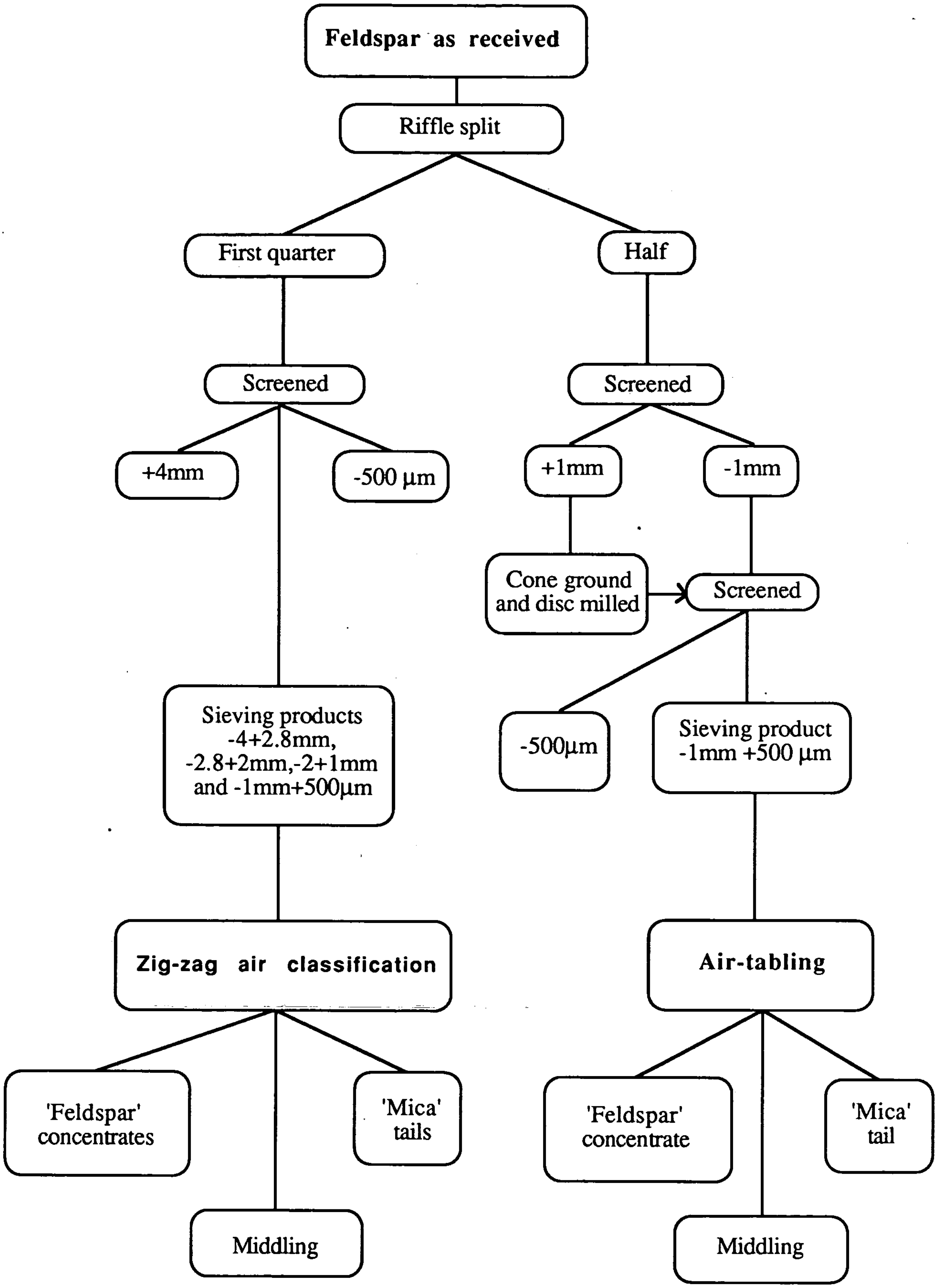

Figure 4 : Summary of processing carried out on Thailand feldspar