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**MINERALOGICAL APPRAISAL AND
BENEFICIATION TESTS ON SOME
INDUSTRIAL MINERALS FROM ZAMBIA**

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**MINERALOGICAL APPRAISAL AND BENEFICIATION TESTS
ON SOME INDUSTRIAL MINERALS FROM ZAMBIA**

D A Briggs and C J Mitchell

1. INTRODUCTION

In March 1990, a visit to Zambia was made by D A Briggs of the Mineralogy and Petrology Group on behalf of the British Geological Survey/Overseas Development Administration project "Minerals for Development". The visit, which was described in Technical Report No. WG/90/15R, aimed to establish contact with the Geological Survey Department and other organisations concerned with minerals in Zambia to offer assistance in the field of mineral resource development. This primarily involved discussions with Mr N J Money and Mr J G G Tether, respectively Director and Deputy Director of the Geological Survey department and their colleagues. The Ministry of Mines and the Mineral Exploration Department (Minex) of the Zambia Industrial and Mining Corporation and other bodies were also involved in the discussions.

As a result, a short programme of field visits was arranged in collaboration with the Geological Survey and Minex, and 22 samples, mainly of clays and industrial minerals, were collected in the field or otherwise submitted for mineralogical appraisal. A detailed sample list is included in BGS Technical Report No. WG/90/15R. The samples were generally of interest as promising prospects where some mineralogical evaluation and processing testwork needed to be done. It was agreed that this work should be done in the laboratories of the British Geological Survey at Keyworth, and that the results then be communicated to interested parties in Zambia. The purpose of this present report is to describe work carried out on the industrial minerals; a further report, No. WG/91/5R, describes the specialised investigation of the clay samples.

2. SAMPLES FROM MINDECO

Four industrial mineral samples were sent on the last day of the visit by Mr N Munkanta, General Manager of Mindeco Small Mines Limited. Unfortunately no background information on the location, occurrence or prospective use was supplied with the samples, but approximately 1.5 kg of fluorspar, feldspar, limestone and gypsum were submitted. Brief examinations of these have been made, and the results are as follows.

2.1. Fluorspar (CJM 19)

This sample consisted of coarsely crystalline lumps about 1–2 inches in diameter of essentially light green material, with occasional zones pale grey–mauve in colour, which was clearly good quality fluorspar. The fluorspar had a clean resinous lustre, although a few surfaces showed signs of slight weathering. It was

often cut by minor veinlets of quartz.

The sample was crushed lightly, and broke easily into clean fragments of fluor spar, fully liberated as individual mineral particles at around 1mm or so in diameter. The quartz tended to be finer grained, but this was fully released at a grain size of about 0.5 mm. On further grinding, the sample reduced to a clean, whitish powder. Examination by X-ray diffraction showed that the sample consisted of fluor spar with minor quartz; no other impurities were detected.

Chemical analysis confirmed that the sample was a high-purity fluor spar CaF_2 , with K_2O , Al_2O_3 and Fe_2O_3 contents of the order of 0.1%, but the quartz content was reflected in the SiO_2 content of 13.1%. This corresponded to the amount of free quartz which was separated from sized fractions of the ground -1 mm material in bromoform (SG 2.9). The bromoform sinks fractions consisted of clean, fully liberated fluor spar concentrates.

The CaF_2 content of this material could be upgraded by removing the quartz impurity. This might be achieved by means of shaking tables to concentrate the fluor spar by exploiting its higher (3.15) specific gravity than that of the quartz impurity (2.65). In some processing plants, froth flotation is used to obtain greater selectivity of separation. Flotation would be necessary to produce high purity, i.e. acid grade fluor spar, as high silica content would be detrimental to metallurgical use.

2.2. Feldspar (CJM 20)

This sample was received in the form of 1 to 2 inch lumps of light pink mineral readily identifiable as an alkali feldspar derived from pegmatitic material. There was little evidence of veining by impurities, but there were occasional clumps of clean quartz, and some muscovite mica, both of these of coarse (+1 mm) grain size.

The sample crushed readily to give a good clean pinkish-white product. Most impurities could be removed easily by hand.

Further grinding produced a whitish product, and the brightness of this was

602 filter	603 filter	605 filter	606 filter
76.5	77.1	79.0	80.8

X-ray diffraction confirmed that the sample was dominantly microcline feldspar, with minor quartz and muscovite, and a trace of tourmaline.

Chemical analysis showed that the sample was essentially a potassium-feldspar, containing 11.6% K_2O , 2.6% Na_2O and 18.7% Al_2O_3 . The sample showed very low calcium oxide (0.2%) and iron (0.1% Fe_2O_3).

values. The material is thus a high-grade alkali feldspar which could be readily used for glass and ceramic purposes.

2.3. Limestone (CJM 21)

This sample, in the form of 1 to 2 inch lumps, consisted of a massive white marble with a sugary appearance. The sample was extremely clean, of a consistent texture, and contained no obvious impurities.

The body colour was excellent, and on crushing the sample broke down to a clean white granular product. Further grinding produced a white powder. The brightness of this was measured and was found to be:

602 filter	603 filter	605 filter	606 filter
94.8	94.6	94.6	95.3

This is an exceptionally high whiteness value.

Examination by X-ray diffraction showed that the sample consisted dominantly of calcite with minor dolomite.

The powder was also subjected to thermogravimetric analysis, which showed the composition to be 92.1% calcite and 7.1% dolomite. No other carbonate mineral was present.

Chemical analysis confirmed the high purity of this sample. The CaO content was 50.4% and that of MgO, 1.8%. Fe_2O_3 was of the order of 0.1%, and no other impurity was detected.

Naturally occurring calcium carbonates are versatile economic minerals with a wide range of industrial applications. This particular material would have many uses as a filler, for example in paints or plastics. It could possibly provide a low-cost alternative to kaolin (as no beneficiation apart from fine-grinding would be required) for use as filler - or even coating-grade material in the paper industry. The limestone might also find application in glass and ceramics manufacture, although a lower Fe_2O_3 content would be desirable.

If there are reasonably large reserves of this material, it would be worthwhile to assess its physical properties with a view to determining use in paper manufacture. It should be determined whether it is possible to produce fine grades containing 80-90% or so of $- 2 \mu\text{m}$ particles.

The presence of the dolomite does not seem to present any problem as a coloured impurity in view of the exceptionally high whiteness of the powder.

2.4. Gypsum (CJM 22)

This sample consisted of aggregates of brownish-green clay containing coarse bladed crystals of buffish-white gypsum. The gypsum was often clustered in 'desert roses' up to several millimetres in size. Some quartz was also present, mainly in the finer sizes below 2 mm. It was understood that Mindeco were treating the gypsum deposit by hand washing to disperse the clay matrix, and recovering the clean gypsum by screening out the washed crystals.

The sample submitted was thoroughly dispersed in water and wet-screened on a series of sieves from 2 mm downwards. The products were recovered, carefully air-dried and weighed. This resulted in 44.0% of the total weight being retained on the 2mm sieve, and 37.9% passing through the finest (63 μm aperture) sieve.

On inspection it was readily apparent that the +2 mm fraction contained good clean gypsum with a quartz impurity of the order of 5%. The finer fractions contained progressively more quartz, and the -63 μm fines contained most of the clay which had been dispersed and washed from the gypsum and quartz fractions.

Each sized fraction was sub-sampled and ground fine prior to thermogravimetric analysis to determine gypsum content. The results of the analysis, and also the size distribution of the washed sample are given below.

Table 1. Particle-size analyses and gypsum contents of sample CJM 22.

Size fraction	Wt %	Gypsum	
		% assay	% distribution
+2 mm	44.0	94.4	91.3
-2 +1 mm	4.4	44.9	4.3
-1 mm +500 μm	4.5	26.3	2.6
-500 +250 μm	4.5	16.7	1.7
-250 +125 μm	2.7	1.9	0.1
-125 +63 μm	2.0	-	-
- 63 μm	37.9	-	-
Total	100.0		100.0
Head assay		(45.5)	

These results show that the sample has an overall gypsum content of 45.5%, and that the bulk of this, 91.3%, occurs in the +2 mm material. This indicates that it would not be practical to attempt to recover gypsum finer than this size, as it becomes increasingly swamped by the quartz content and would be difficult to recover at any grade of purity.

The -63 μm fines fraction was also subjected to analysis by X-ray diffraction, and this showed that it consisted mainly of quartz, kaolinite and illite. A -5 μm clay fraction was also prepared from this material, and revealed a similar mineralogical composition. The clay was obviously too impure (only about 30% kaolinite) to be of any practical interest, except possibly as a brick clay if large quantities were available.

To summarise, the raw material must be thoroughly washed, and all the -2 mm material must be screened out to give a gypsum product of adequate purity.

3. OTHER SAMPLES

3.1. Chilembwe phosphate rock (CJM 3)

An occurrence of high-grade phosphate rock had been reported by Minex in the course of their investigation of a series of mainly alkaline rocks at Chilembwe, near Petauke in Zambia's Eastern province. This was visited, guided by geologists from Minex and the Geological Survey of Zambia. Access was difficult, but a good outcrop was located on a small hill standing up among thick bush where exposure was generally poor.

The rock was coarsely crystalline and large apatite grains of a light greenish hue were readily identified. Apatite crystals, some up to 2 millimetres in size, were abundant in a finer grained matrix of quartz. In thin section, the rock displayed an unusual pneumatolytic texture suggesting crystallisation from a volatile-saturated magma. The apatite crystals were large and hexagonal, averaging about a millimetre in size, and were surrounded by a matrix of fine-grained quartz about 50-100 μm in particle size. No feldspar was present, but there was a few percent of a darkish green amphibole, probably actinolite, and occasional traces of pink garnet and magnetite. Sphene was a minor accessory, and the occasional grain of zircon was also noted. However the rock was essentially composed of quartz (40%) and apatite (60%). This was confirmed by X-ray diffraction.

Chemical analysis showed that the rock contained about 45% SiO_2 , 25% CaO and 25% P_2O_5 . Na_2O and K_2O were low, but about 6% Fe_2O_3 was present. Also detected were about 0.3% of cerium, 0.2% of strontium, and around 200 ppm of yttrium. The rare earths were presumably present in the sphene and the apatite. The analysis roughly corresponded to 40% quartz and 60% apatite, confirming the mineralogical observations above.

3.1.1. Separation tests

A 2 kg bulk sample was jaw-crushed, and screened on a series of sieves starting at 2 mm. The +2mm oversize was examined and found to contain some composite particles of locked quartz and apatite. The oversize was carefully ground through 1 mm and the -1 mm +500 μm fraction examined under a binocular microscope. This size fraction, although still containing some composite grains, was more substantially liberated into individual particles of clean quartz and apatite. All the ground material was re-screened on sieves down to 63 μm and the products were weighed. The size distribution is given in Table 2 below.

Sub-samples of each size fraction above 63 μm were then separated in the heavy liquid bromoform (SG 2.9). The sinks fractions were then re-separated in methylene iodide (SG 3.3). All products were washed with acetone, dried and weighed. These results are also given in Table 2.

Table 2. Results of heavy liquid separations on sized products of sample CJM 3.

Size fraction	Wt %	Wt% <2.9	Wt% 2.9-3.3	Wt% >3.3
-1 mm +500 μm	41.7	54.5	45.3	0.2
-500 +250 μm	24.3	38.8	60.5	0.7
-250 +125 μm	16.9	35.1	63.0	1.9
-125 +63 μm	8.1	39.6	58.0	2.4
-63 μm	9.0			
Total	100.0			

Grinding the sample finer than 1 mm has resulted in 90% of the weight reporting to the sand sizes coarser than 63 μm . Finer grinding through 500 μm would have produced a higher proportion of -63 μm fines which would be more difficult to process in any operations to recover upgraded apatite concentrates. Heavy liquid separation of sub-samples of the individual size fractions effected suitable fractionation of the material into quartz (SG <2.9), apatite (SG 2.9-3.3) and heavy minerals (SG >3.3). Microscopic examination of these products confirmed that good clean separations had been made.

The -1 mm +500 μm size fraction still contained some locked particles of quartz and apatite, but overall liberation was virtually complete for the practical purposes of separation. Table 2 records that around 60% of the weight of the size fractions between 500 μm and 63 μm reported to the specific gravity range between 2.9 and 3.3, and this is in good agreement with the apatite content determined by earlier

mineralogical and chemical observations. These apatite concentrates were examined under the binocular microscope, and were seen to consist of very clean apatite, plus a little ferromagnesian mineral which was easily removed magnetically. The lightest SG <2.9 fractions were composed of quartz with a little apatite in the coarsest size fraction. The heavy mineral concentrates consisted of actinolite, garnet, sphene, zircon and magnetite.

The Chilembwe phosphate rock, a potentially high-grade source of apatite, is coarsely crystalline and the minerals are well liberated from each other at around 0.5–1 mm particle size. It will therefore easily respond to beneficiation and a simple gravity separation on a shaking table should reject the quartz impurity and upgrade the apatite content. Alternatively, froth flotation could be employed using a fatty acid collector. Flotation is a more selective process and would be expected to produce concentrates of very high purity. However, the rock would have to be ground much finer, to less than 250 μm , to bring it into the size range appropriate to froth flotation. Although grades of around 40% P_2O_5 could be expected to be attained, this might be at the expense of a lower recovery, as some of the apatite would inevitably be ground into the finer size ranges which are untreatable by normal beneficiation methods. The overall conclusion is that the rock is worthy of serious consideration as a fertiliser raw material.

3.2. Sugar Loaf phosphate (Mumbwa North) (CJM 7)

This deposit is part of a carbonatite complex near the town of Mumbwa in the Central Province of Zambia. At the time of the visit, Minex were engaged in the exploration of this area where high phosphate values had been discovered during a geochemical survey. Pitting and trenching were in progress, and a sample of apparently high-grade phosphate rock was collected for laboratory examination.

The sample was of a pinkish buff colour and had a massive homogeneous texture, not of crystalline appearance to the naked eye. The only other feature of note was the presence of numerous cracks carrying a darker coloured infill. In thin section the sample consisted of aggregates of individual grains of apatite about 50 μm in diameter, criss-crossed with fine cracks containing iron-stained quartz. X-ray diffraction confirmed that the sample consisted dominantly of apatite, with minor quartz, haematite and goethite the only impurities. Chemical analysis showed that over 30% P_2O_5 was present, and that silica (around 10%) and iron oxides (about 5%) were the only other substantial impurities.

The sample was crushed, ground, screened and separated in heavy liquids in the same way as the Chilembwe sample, and the results of these operations are tabulated below.

Table 3. Results of heavy liquid separations on sized products of sample CJM 7.

Size fraction	Wt%	Wt% <2.9	Wt% 2.9–3.3	Wt% >3.3
-1 mm +500 μm	23.6	9.4	86.3	4.3
-500 +250 μm	24.6	9.8	85.7	4.5
-250 +125 μm	20.5	11.4	84.1	4.5
-125 +63 μm	13.9	0.7	98.2	1.1
-63 μm	17.4			
Total	100.0			

The SG 2.9–3.3 fractions consist almost entirely of apatite and indicate that this particular sample of the Sugar Loaf phosphate rock is of unusually high grade, and needs very little in the way of beneficiation to provide a raw material which could possibly be used as a direct application fertiliser. It is as yet unknown, however, to what extent this sample is representative of the deposit as a whole.

Some further work needs to be done on the investigation of the different types of phosphate rocks occurring at Chilembwe and Sugar Loaf. If suitable resources occur, it would be worthwhile to conduct larger-scale separation trials on these materials, using gravity separation or possibly froth flotation. New reagents are available for the selective flotation of apatite, and it would be useful to try these out on Chilembwe, Sugar Loaf, and indeed the apatite-bearing soils from the Nkombwa Hill and Kaluwe carbonatites which were not visited during these current investigations.

3.3. Chasefu barite (CJM 5)

The locality in Eastern Zambia was not visited, but a sample of massive barite was submitted by the Geological Survey of Zambia for appraisal. The sample was coarsely crystalline and had a good white body colour, although some surfaces had a light staining.

A thin section confirmed that the sample consisted of almost pure barite occurring as white sugary crystals generally about 1 to 3 mm in diameter. A little quartz occurred in thin veins as small crystals from 50 to 250 μm in size. There was also a little calcite present as similarly sized crystals, but both impurities in the barite totalled less than 2%. X-ray diffraction confirmed that barite was dominant, with minor traces of quartz and calcite as the only impurities. Chemical analysis showed that the barite was at least 95% pure. The only notable impurity was 0.6% of strontium, which was not unexpected, and the iron content was

below 0.1% Fe₂O₃.

The brightness of a pressed disc of the powdered barite was determined, and this gave values as follows:

602 filter	603 filter	605 filter	606 filter
74.8	74.5	75.0	76.1

The Chasefu barite is of high purity and has good brightness values. It is sufficiently good to find a variety of uses as an industrial mineral, and could for example be used in paint manufacture without the necessity of any beneficiation treatment. The quartz and calcite impurities present totalled only about 2%, as confirmed by separation in heavy liquids, and this is probably an acceptable level for many uses for the barite. A little iron-stained barite is present, but this probably derives from the slight surface weathering observed in the sample supplied.

3.4. Ndabala barite (CJM 16)

This deposit near the Zaire border in central Zambia was visited, and was found to be fairly rich in barite, but unfortunately of poor colour. The deposit was heavily brecciated and it was clear that it had been veined by dark brownish material which suggested the presence of iron and manganese oxides. Although much cleanish white barite was to be found in patches up to 2 inches across, it was intergrown with the dark brown material which appeared to be heavily stained barite of lower grade. It was possible to hand-pick separate samples of the cleaner and the stained material, but there was little prospect of any selective mining to obtain barite of high purity.

The higher grade, lighter coloured material was examined in thin section and found to consist of 1 mm - 0.1 mm crystals of barite of around 90% purity with some calcite. This was confirmed by X-ray diffraction, and by chemical analysis which however gave an iron content of about 0.2% Fe₂O₃. About 1% strontium was also present, but no silica was detected.

The lower-grade dark stained material showed in thin section that the barite was heavily intergrown with quartz, which was predominant. Some clear barite and quartz of sizes similar to the above were present, but the dominant material present was a fine-grained (50-100 μm) groundmass of quartz heavily coloured with iron and manganese oxides. X-ray diffraction confirmed that quartz and barite were the main minerals present. Chemical analysis showed that 59% of silica was present (as against virtually nil in the higher grade material), and that the barite content was around 30-40%. The iron content was much higher at 3.5% Fe₂O₃, and 1.0% MnO was also present.

Heavy liquid separations were carried out on $-250 \mu\text{m} + 125 \mu\text{m}$ size fractions of ground samples of both types of material. The following weight distributions resulted from separations in bromoform (SG 2.9) and methylene iodide (SG 3.3).

Table 4. Heavy liquid separation of sample CJM 16.

	High-grade Wt%	Brown stained Wt%
<2.9 float	3.8	52.1
2.9-3.3	2.1	35.6
>3.3 sink	94.1	12.3
	-----	-----
	100.0	100.0

Examination of the products under a binocular microscope showed that the dominant contaminant was a dark, cokey aggregate consisting of iron and manganese-stained, fine-grained quartz intergrown to greater or lesser degrees with barite. This material occurred dominantly in the 2.9-3.3 fractions and 2.9 float fractions, accompanied in the latter by some clean quartz and calcite. It even occurred in 3.3 sink fraction of the stained sample with some clean barite but this was generally a poor product. The 3.3 sink product from the high-grade material however was a good concentrate of clean, glassy, off-white and fully liberated barite. However, this product contained a few cokey grains which spoiled the colour.

The poor colour, and contamination of the barite by silica, iron and manganese impurities make it apparent that the possibilities of extracting good barite from the exposed part of the deposit seen are somewhat remote. The quality of the barite may improve deeper into the main body of the vein, and if this is so, there may be possibilities of finding less contaminated material which could be subjected to some degree of beneficiation.

3.5. Kapiri Mposhi glass sand (CJM 3)

The glassworks at Kapiri Mposhi was visited and samples of the raw sand and the glass sand product, which had been treated by screening and froth flotation, were collected.

Each sample was subjected to wet screening. The recovered size fractions were dried, weighed, and then separated in bromoform, (SG 2.9) and the heavy fractions from this re-separated in methylene iodide (SG 3.3).

Table 5. Particle-size analysis and heavy liquid separation of sample CJM 3.

Size fraction	Wt%	%<2.9	%2.9-3.3	%>3.3
(a) Raw material				
+1 mm	9.7	99.8	0.1	0.1
-1 mm +500 μm	25.6	99.8	0.1	0.1
-500 +250 μm	27.0	99.5	0.25	0.25
-250 +125 μm	20.7	99.3	0.35	0.35
-125 +63 μm	8.8	98.5	0.7	0.8
-63 μm	8.2			
Total	100.0			
(b) Final Product				
+1 mm	0.1	100		
-1 mm +500 μm	14.8	100		
-500 +250 μm	45.4	100		
-250 +125 μm	34.4	100		
-125 +63 μm	5.3	100		
-63 μm	0.0			
Total	100.0			

These results show that the flotation of the raw material, mainly in the sizes between 1 mm and 125 μm , has been totally successful in removing the heavy minerals. The heavy minerals recovered from the raw material consisted mainly of zircon, garnet and iron oxides, and were only present in very low proportions - except perhaps in the -63 μm fraction, which had been removed from the feed to the flotation plant. They were in themselves of no commercial interest, but the glassworks are clearly producing a high-purity sand for the manufacture of colourless glass.

3.6. Mushishi talc (CJM 21)

This deposit was near Ndola on the Copperbelt, and was actually being worked by a private company, Talc Zambia Limited. Three grades of talc were being extracted from an open pit for local markets and were distinguished by colour, namely yellow, off-white and pure white talc. Additionally, the last-named was being exported to Zimbabwe, where it was considered superior to a local talc which was said to contain undesirable fibrous particles.

Samples of each type of the talc were collected for appraisal; they seemed to be very alike in their high grade, the off-white and pure white appeared to be undistinguishable but the yellow was markedly different only in colour. It was thought that the variations might be due to superficial staining and that purity could possibly be improved by simple processing using hydrocyclones, or perhaps ultimately by froth flotation. The only processing carried out at the works at Ndola was grinding in air-swept hammer mills to give a product finer than 150 microns.

Some unusual cubic crystals of around 1 cm^3 were found in a band just above the talc. These were thought to be goethite/haematite pseudomorphs after pyrite, and this was confirmed later by X-ray diffraction.

The three talc samples were sub-sampled, ground through $150 \mu\text{m}$ and examined by X-ray diffractometry. All were confirmed to be high-grade talc samples with traces of quartz and very minor traces of magnesite. The talc contents were determined by means of thermogravimetry, and the highest grade was obtained on the off-white sample at 96.8% talc. The pure white contained 92.6% talc, and the yellow contained 90.6% talc.

A kilogramme of each sample was then subjected to wet-screen analysis on a series of sieves from 1 mm down to $125 \mu\text{m}$. In addition, a further kilogramme of the yellow talc was attrition-scrubbed for 2 hours to see if the additional cleaning action could improve the colour of the talc. This fourth portion was then wet-screened in the same way. All screened products were recovered, dried and weighed, except for the $-125 \mu\text{m}$ material which was retained in slurry form, and its dry weight calculated by difference. The results are shown in Table 6.

The screened products were inspected, and it was observed that the coarser talc particles were often slightly discoloured by the presence of a thin film of iron oxide even in the cases of the white and the off-white talcs. The finer size fractions were generally cleaner. The yellow talc particles had intractable staining and improved very little even after attrition scrubbing. The scrubbing did have the effect of reducing a greater proportion of the weight into the $-125 \mu\text{m}$ size material.

Table 6. Size distribution of wet-screened talcs.

Size fraction	White talc	Off-white talc	Yellow talc	Scrubbed yellow talc
	wt%	wt%	wt%	wt%
+1 mm	12.0	16.4	3.4	1.6
-1 mm +500 μm	3.9	4.4	1.2	1.8
-500 +250 μm	11.9	9.8	8.7	6.9
-250 +125 μm	11.2	9.3	20.6	10.9
-125 μm	61.0	60.1	66.1	78.8
Total	100.0	100.0	100.0	100.0

It was decided to treat the -125 μm fines further in each case. These were in turn passed through a 30 mm glass hydrocyclone to remove the -10 μm ultrafines in the cyclone overflows. The -125 μm +10 μm cyclone underflows were then subjected to froth flotation, using two drops of the long-chain alcohol frother iso-octanol as collecting agent. This resulted in the production of talc-rich flotation concentrates with the rejection of some talc in lower-grade material containing the remaining quartz and magnesite impurities into the flotation tailings, as was confirmed by X-ray diffraction.

Portions of the flotation concentrates, and also of the hydrocyclone underflows taken prior to flotation were sub-sampled out for analysis. These were first analysed by thermogravimetry for talc content, and the results of these, together with the talc contents of the untreated head materials, are given in Table 7.

Table 7. Comparison of talc contents (%) of head samples and products.

	White talc	Off-white talc	Yellow talc	Scrubbed yellow talc
Raw material	92.6	96.8	90.6	92.6
Unfloated cyclone underflow	94.7	98.9	92.6	94.7
Froth flotation concentrate	96.8	98.9	94.7	96.8

The brightness values were also measured on pressed discs of finely ground raw materials and flotation concentrates. The results, obtained by comparing brightness on a spectrophotometer against a standard of pure BaSO_4 , are shown in Table 8.

The talc contents of each sample have clearly been upgraded first by hydrocycloning, and then again by froth flotation. In addition, the yellow talc has been further upgraded by the scrubbing pre-treatment prior to the cycloning and flotation to give greater beneficiation. The brightness values of each of the three samples also increases significantly after treatment.

Table 8. Comparison of brightness values of talc head samples and flotation products.

	602 filter	603 filter	605 filter	606 filter
<u>Pure white talc</u>				
Raw material	71.0	72.4	76.2	76.6
Flotation concentrate	76.0	76.6	80.8	84.4
<u>Off-white talc</u>				
Raw material	75.2	75.5	80.5	84.1
Flotation concentrate	78.0	79.0	83.2	85.6
<u>Yellow talc</u>				
Raw material	43.2	43.2	57.9	67.1
Flotation concentrate	54.1	54.2	69.0	76.0
<u>Scrubbed yellow talc</u>				
Flotation concentrate	54.4	54.7	68.6	76.2

The white and the off-white samples are obviously excellent high-grade, high-brightness materials. Paradoxically, the so-called off-white talc has produced slightly superior figures all round. This is presumably due to errors in sampling, but equally these variations may indicate that there are larger resources of high-grade material available than originally thought.

The yellow material is also high in talc, and this has been further improved by attrition scrubbing, hydrocycloning and froth flotation. However, the brightness values are very low, and the scrubbing has not produced any improvement, although it has assisted in raising the talc content.

4. CONCLUSIONS AND RECOMMENDATIONS

1. The four Mindeco samples are all good quality raw materials, and it would be helpful to learn of their present uses and to discuss possible future markets. The fluorspar needs some beneficiation to remove the quartz impurity, and a larger sample is required for further testwork. It would also be desirable to visit the

locality from which the gypsum sample was taken to inspect the nature of the deposit and to assess if the washing process employed is adequate. It is understood that there is some difficulty in making good plaster from the gypsum, and although this may be due to poor calcination it may also be caused by failure to remove all the quartz and/or clay in the washing. The limestone and the feldspar are of excellent quality and possible markets should be investigated.

2. The samples from the Chilembwe and Sugar Loaf deposits are both high-grade phosphate rocks. Some further work is necessary to determine whether these samples are wholly representative of the deposits where they occur. Some further samples are required to carry out a more detailed investigation of the possibilities for beneficiation.

3. The Chasefu barite is a high-grade material which is suitable for a number of uses including paint manufacture, but the Ndabala material is of poor quality. It would be useful to check the possibility of finding higher-grade, cleaner barite at the latter locality.

4. A return visit to the Mushishi talc deposit would be of value to discuss the possibilities of higher-grade use for the off-white talc with the operators. Simple screening out of impurities prior to grinding would improve the product, and hydrocycloning followed by froth flotation would give even better results.

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