Mineral processing of mine and quarry waste

C.J. Mitchell & E.J. Evans
British Geological Survey, Nottingham, UK

Abstract

The Mineralogy and Petrology Group of the British Geological Survey has been involved in a number of waste processing investigations over the last seven years. Four of which are described in this paper. In the first, ceramic-grade feldspar was produced by the use of air classification to upgrade the fines resulting from the hand sorting of a pegmatitic-feldspar in Thailand. This is followed by two studies in which combined magnetic separation and froth flotation was used to produce glass- and ceramic-grade feldspar from quarry and mine waste. In the final case, gravity separation was used to remove a significant proportion of the heavy metal bearing minerals from tailings of the former Pb-Zn mining area of Leadhills in Southern Scotland. The aim of this study was to determine the potential for traditional mineral processing technology to recover metal from waste for environmental remediation.

Introduction

Over the last seven years, the British Geological Survey (BGS) has been involved in a number of waste processing investigations. The main driving force behind this work has been the need to alleviate the environmental impact of the generation, storage or disposal of mineral wastes, although processing of mineral wastes can also produce saleable mineral products.

The benefits of recovering valuable minerals from waste, plus four case study waste processing investigations are detailed in the following sections. Much of the work concerns the recovery of industrial minerals, although latterly attention has been focused on the treatment of metalliferous waste.

Benefits of processing waste

Known reserves of some industrial minerals in many countries are scarce or are becoming depleted. Some deposits are expensive to process because of the necessity to exploit reserves that are fine-grained or have complex mineralogical associations. This has encouraged the search for alternative sources of industrial minerals, including investigations of the potential for reclamation of industrial minerals from mine or quarry wastes.

Benefits from processing of mine tailings or quarry fines include the following:

- Lower operational costs. The extraction and crushing has already been carried out. These processes may account for up to 20 to 25% of production costs.

- Lower disposal costs. Processing the tailings of an active operation would reduce the total amount for disposal. Tailings may represent up to 30% of the head feed and consume between 5 to 10% of production costs.

- Increased revenue. The sale of reclaimed mineral products would increase the revenue realised per tonne of material extracted.

- Reduced environmental impact. A reduction in the amount of waste material would reduce the amount of land required for its disposal.

- Reduced mineral extraction. Competition from reclaimed industrial minerals may ultimately reduce the market share of primary minerals produced by mining or quarrying. This may lead to a reduction in the total amount of mineral extraction.

Case studies

Production of ceramic-grade feldspar from Thailand

Granitic pegmatite veins occurring at Takua Pit Thong mine, Rajburi, Thailand, near the border with Myanmar, contain a high proportion of K-feldspar (microcline and microcline perthite) and are currently worked as a source of ceramic-grade feldspar. The pegmatite is blasted and the coarse feldspar is removed by hand sorting. Finer grained feldspar (-20 mm), which represents approximately 70% of the worked material, is currently stockpiled as it is too small to hand sort. The stockpiled fines contain up to 4% muscovite mica, which if present in a ceramic raw material would impart a poor colour to the fired product. In 1990 the BGS investigated the possibility of processing this stockpiled waste material to remove impurities such as mica and to produce a ceramic-grade feldspar (Fig. 1).

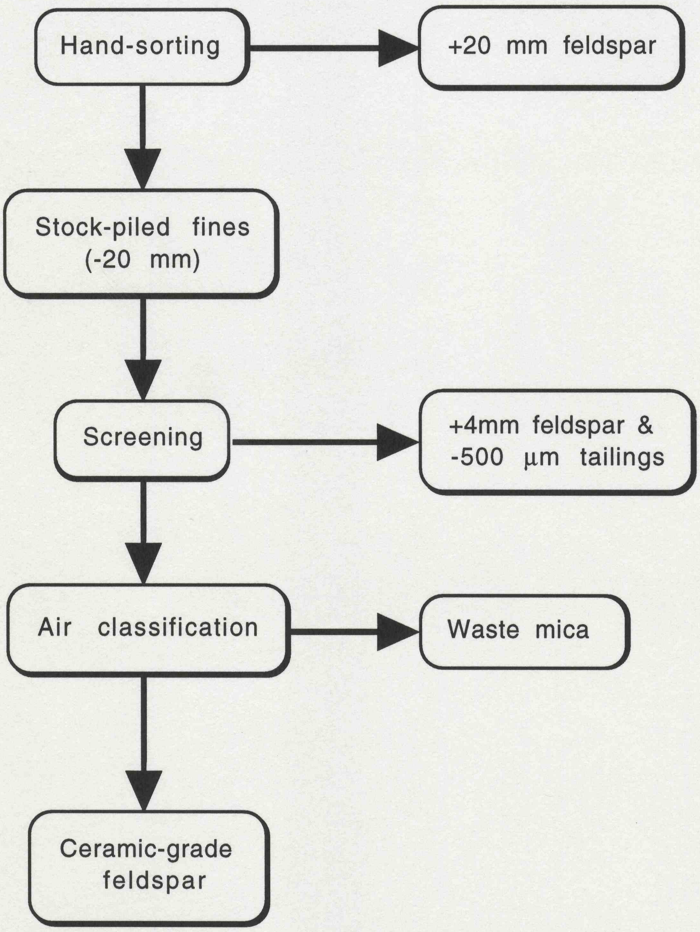

Figure 1. Processing flowsheet for air classification of feldspar from Thailand

The feldspathic fines consisted mainly of white microcline feldspar (70%) and quartz (25%), with a minor amount of muscovite mica (4%) and tourmaline (dravite). Some of the feldspar and quartz grains were iron-stained. The mica content was found to increase with decreasing particle-size. The +4 mm material contained virtually no mica (<1%), with the exception of a trace amount of book mica and inclusions within the feldspar. Below 4 mm the mica content gradually increased from 2 to 3% in the +2 mm material, 10 to 15% in the +500 µm material to over 20% in the -500 µm material.

The laboratory methodology chosen for effective processing therefore used a combination of screening (to exploit the preferential concentration with size) and air classification. The fines were screened at 4 mm and 500 µm, the +4 mm material was retained as a feldspar concentrate and the -500 µm rejected as a mica tailing. The feldspar was further screened to produce four size fractions: -4+2.8 mm, -2.8+2 mm, -2+1 mm and -1 mm +500 µm. Each size fraction was processed by air classification to selectively winnow out the platy mica from the granular feldspar and quartz.

The air classifier used was a Hosokawa Micron Multi-plex laboratory classifier type 1-40 MZM, which is capable of processing up to 100 kg/hr of material in the size range 100 µm to 6 mm and is comparable in performance to pilot- and industrial-scale classifiers. The classifier consists of a zig-zag column through which passes an upward moving air current. Material fed into the column is separated into a coarse, granular, higher density fraction that falls through the column and a finer-grained, flakier, less-dense fraction that is entrained in the upward moving air current. Initially designed to separate chiefly on particle-size it can be used to separate pre-sized material on the basis of particle-shape. Hence its use in the separation of mica from feldspar and quartz in this study. The separation conditions varied with particle-size. A higher airflow rate was required to remove mica from coarser grained material. For example, a rate of 32 m^3 per hour was required for the -4+2.8 mm size fraction whereas only 17 m^3 per hour was required for the -1 mm +500 µm size fraction.

The processing trials were successful in removing a significant proportion of the micaceous impurities resulting in a high-grade feldspar-quartz product. This product contained a combined feldspar-quartz content of 99%, with a feldspar recovery of over 90%, with less than 1% mica and thus a significantly reduced iron content (Table 1). It had a similar composition to commercial ceramic-grade feldspar.

Table 1. Mineralogy and chemistry of feldspar, Takua Pit Thong, Rajburi, Thailand

	Feldspar-quartz content (wt %)	**Feldspar-quartz recovery** (wt %)	**SiO_2 content** (wt %)	**Fe_2O_3 content** (wt %)
Stock-piled fines	96	100.0	79.1	0.45
Feldspar product	99	91.1	81.6	0.25
Commercial ceramic-grade feldspar *	99	na	75.0	0.30

* = Felquar Feldspar, Unizel Minerais Lda, Portugal [1], na = not available

Production of feldspar from granite fines

Mineral processing trials have been carried out by BGS to determine the potential for the production of glass-grade feldspar from granitic fines produced by a major European aggregate quarry.

The granitic fines consist mainly of K-feldspar, Na-feldspar (plagioclase) and quartz, with minor amounts of biotite mica and pyroxene, and trace amounts of magnetite and apatite. The K-feldspar occurs mainly as laths up to 3 mm in diameter, the larger grains with inclusions of quartz, apatite and plagioclase. The plagioclase feldspar occurs as small laths, up to 1 mm in diameter, which are commonly sericitised. The particle-size distribution of the fines is typically 30% gravel (+2 mm), 60% sand (2 mm to 63 µm) and 10% silt / clay (-63 µm) grade material. The feldspar is well liberated in those size fractions finer than 1 mm.

Mineral processing trials involved use of magnetic separation to produce combined quartz-feldspar concentrates, and combined magnetic separation and froth flotation to produce feldspar concentrates. The samples were processed in the size range 710 to 106 µm (Fig. 2).

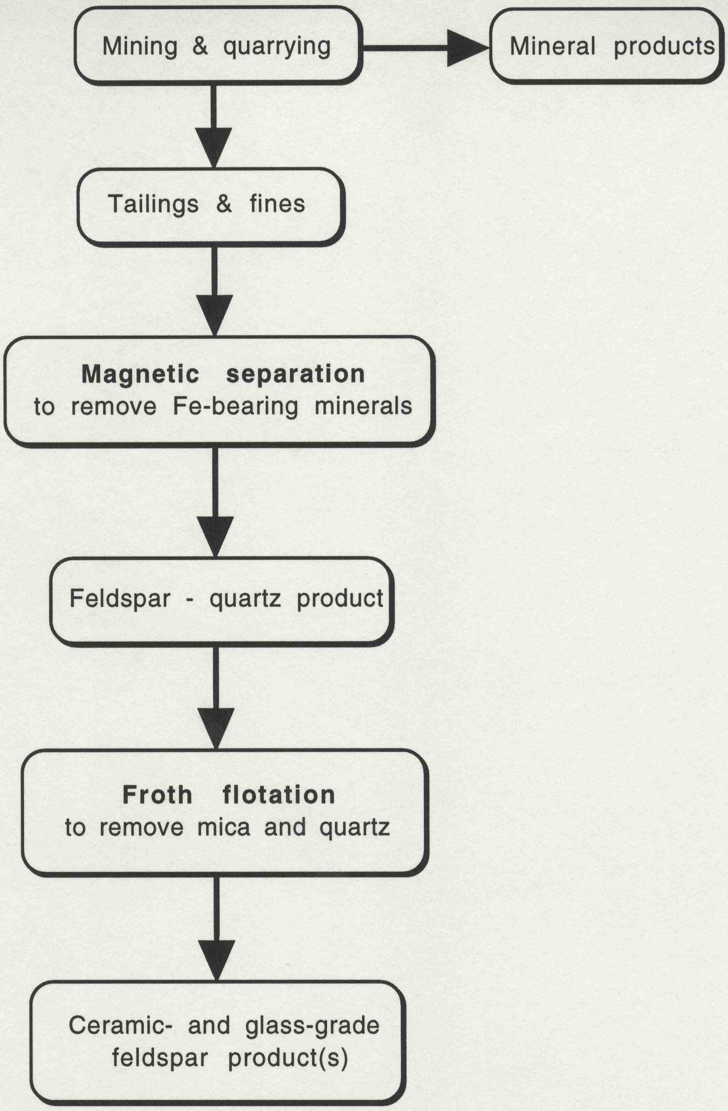

Figure 2. Processing flowsheet for magnetic separation and froth flotation of mine and quarry waste

Magnetic separation was carried out primarily to remove iron-bearing minerals using either one of two types of magnetic separators. The Frantz isodynamic magnetic separator consists of an inclined channel, tilted to one side, which splits into two at the downslope end. The channel is encased in an electromagnet which exerts a magnetic attraction along its raised length. Minerals with a high magnetic susceptibility passing along the channel are attracted to the raised part and are thus separated from non-magnetic minerals. The Carpco high-intensity induced-roll magnetic separator consists of a laminated roll, composed of alternating layers of phosphored steel of different diameters giving the roll a serrated surface. A magnetic field, generated over the roll, concentrates on the raised parts of the serrated surface producing a high magnetic intensity. Mineral grains are fed onto the rotating roll via a vibratory hopper. Minerals with a magnetic susceptibility higher than a particular value will be attracted to the roll surface, whereas those with a lower susceptibility are thrown from the roll by its rotational momentum.

Both magnetic separators were used at a low electromagnet current (0.1A), which generates a low intensity magnetic field (1400 Gauss using the Carpco separator), to remove strongly magnetic minerals such as magnetite. Subsequent passes were carried out using higher magnetic fields (up to 15,700 Gauss using the Carpco separator) to remove moderately and weakly magnetic minerals, such as ilmenite and mica respectively. The non-magnetic product either forms a quartz-feldspar product or the feed for froth flotation trials.

Froth flotation was carried out in two stages, the first to remove mica and the second to separate quartz and feldspar. Flotation was performed using a standard Denver D12 laboratory flotation machine with Pyrex cell. Suspensions were made with de-ionised water, pH was regulated with sulphuric acid and caustic soda, and any excessive frothing was moderated with heavy distillate. Mica removal was carried out using alkylamine acetate (Armoflote 64) as collector and methyl isobutyl carbinol (MIBC) as frother. Conditioning was for 4 minutes at a pH of 2.5 to 2.7 and a pulp density of 50 to 60 wt % solids. Flotation was carried out at a pH of 3 to 3.3 and a pulp density of 20 to 30 wt % solids. Quartz-feldspar separation was effected using a fatty acid derivative as collector (Armoflote 543) and MIBC as frother. Prior conditioning was for four minutes at a pH of 1.8 to 2.0 and a pulp density of 50 to 60 wt % solids. Flotation was carried out at the same pH and a pulp density of 20 to 30 wt % solids.

All products were scrubbed with caustic soda to remove reagent residues. A final magnetic separation, using the Frantz magnetic separator, was carried out to remove any remaining iron-bearing minerals prior to chemical assay.

Both magnetic separation and froth flotation trials were successful in producing concentrates of quartz and feldspar, and feldspar respectively. The combined quartz-feldspar products typically contained 62% feldspar, with a recovery of 60%. They compare favourably with ceramic-grade feldspar, such as that produced by Unizel Minerais Lda (Portugal) (Table 2).

Table 2. Chemistry of quartz-feldspar and feldspar produced from quarry fines

	Feldspar content (wt %)	**Feldspar recovery** (wt %)	**SiO_2** (wt %)	**Fe_2O_3** (wt %)	**Na_2O** (wt %)	**K_2O** (wt %)
Typical quartz-feldspar product	62.0	90.5	74.5	0.31	4.6	3.4
Commercial ceramic-grade feldspar *	63.0	na	75.0	0.30	4.5	3.3
Typical feldspar product	95+	81.0	67.8	0.19	6.2	4.6
Commercial glass-grade feldspar **	na	na	68.9	0.07	7.2	3.9

* = Felquar Feldspar, Unizel Minerais Lda, Portugal[1], ** = C-20 Feldspar, Feldspar Corporation, USA[2]
na = not available

The pure feldspar products typically contain over 95% feldspar, with a recovery of 80%. They have a similar composition to glass-grade feldspar, such as that produced by the Feldspar Corporation (USA). However the iron content of the products was generally between 0.2% and 0.3% Fe_2O_3. This is significantly higher than the maximum iron content (0.08% Fe_2O_3) generally demanded by the glass industry. The high iron content of the feldspar, produced from the granitic fines, is due to the presence of inclusions (or middling grains) of biotite and magnetite. Processing material finer than 180 µm did not result in products with an iron content lower than 0.2%. It seems likely, however, that these inclusions would be liberated below 100 µm, but at this size an effective separation would not be achieved by flotation.

In conclusion the quartz-feldspar concentrates produced from the granitic fines by magnetic separation alone have a similar composition to commercial ceramic-grade feldspar products. However the feldspar concentrates contained significantly more iron than commercial glass-grade feldspar products.

Production of feldspar from a former tin mine in Namibia

An investigation is currently being carried out by BGS on feldspathic-tailings, from a former tin mine at Uis in Namibia in an attempt to produce ceramic-grade feldspar (Fig. 2). Tin has been produced from the Uis pegmatite swarm since the 1920s. The major producer closed its mine in 1990, due to a collapse in the price of tin, and left behind an estimated 75 million tonnes of sand-grade feldspathic tailings. The tailings from Uis consist mainly of alkali feldspar (K- and Na-feldspar) and quartz, with a minor amount of muscovite and trace amounts of magnetite and chlorite. The alkali feldspar occurs as laths, with the coarser grains often having a surface iron staining. The feldspar present in both samples is well liberated.

Several samples were processed at BGS using a combination of magnetic separation and froth flotation (similar to the laboratory methodology detailed in the previous section). The feldspar was screened to produce two size fractions: -500 +250 µm and -250 +125 µm. A Carpco high-intensity magnetic separator was used to remove magnetite and other minerals. A two-stage froth flotation process was used to remove mica and quartz from the feldspar. A final magnetic separation, using the Frantz isodynamic magnetic separator, was carried out to remove any remaining iron-bearing minerals prior to chemical assay.

The processing trials were successful in producing concentrates of feldspar. The feldspar products contained 99% feldspar, with a recovery of approximately 45% and an exceptionally low iron content (this could be attributed to the low iron content of the untreated tailings, 0.5% to 0.6% Fe_20_3). Table 3 gives the chemical composition of the feldspar concentrates and several industrial-grade products for comparison. The feldspar products have a similar composition to commercial mixed alkali ceramic-grade and glass-grade feldspar products. However in this case the main local market for ceramic-grade feldspar, which is in South Africa, demands a potassium feldspar. The feldspar produced from the tailings was a mixed sodium / potassium feldspar and therefore does not meet the local market requirements.

Table 3. Chemistry of feldspar produced from mine tailings, Uis, Namibia

	Feldspar content (wt %0	**Feldspar recovery** (wt %)	**SiO_2 content** (wt %)	**Fe_2O_3 content** (wt %)	**Na_2O content** (wt %)	**K_2O content** (wt %)
Typical feldspar product	99.0	45.8+	69.7	0.05	5.3	5.4
Commercial glass-grade feldspar *	na	na	68.9	0.07	7.2	3.9
Commercial ceramic-grade feldspar **	na	na	68.3	0.06	7.0	4.1

* = C-20 Feldspar [2], & ** = F-20 Feldspar [3], Feldspar Corporation, USA
na = not available, + = inclusion of the high grade middling would increase this to 60%

Further work being considered includes :

(i) Dry processing using air classification to remove muscovite. This would minimise the amount of process water required and may also produce a pure mica product.

(ii) Froth flotation to separate sodium and potassium feldspar. This would satisfy the local demand for a pure potassium feldspar.

Processing of historic Pb-Zn tailings from Scotland

The metalliferous tailings dumps found in the Leadhills-Wanlockhead area of Strathclyde are all that visibly remain of this former Pb-Zn mining area. The Pb-Zn mineralisation (mainly galena, sphalerite, pyrite and chalcopyrite) is contained within banded veins hosted by Ordovician greywackes. Mining activity reached a peak between 1850 and 1915, ceasing in the 1930s, by which time over 70 Pb-Zn veins had been worked in an area of approximately 8km^2. The mineral waste produced from these mining operations contains residues of heavy metal sulphides and could represent a potential source of environmental contamination.

An investigation was carried out to determine the potential for conventional mineral processing technology to recover the heavy metal-bearing minerals from the metalliferous mine wastes (Fig. 3). This could then be used to assess the feasibility of environmental remediation of this waste using physical separation methodologies.

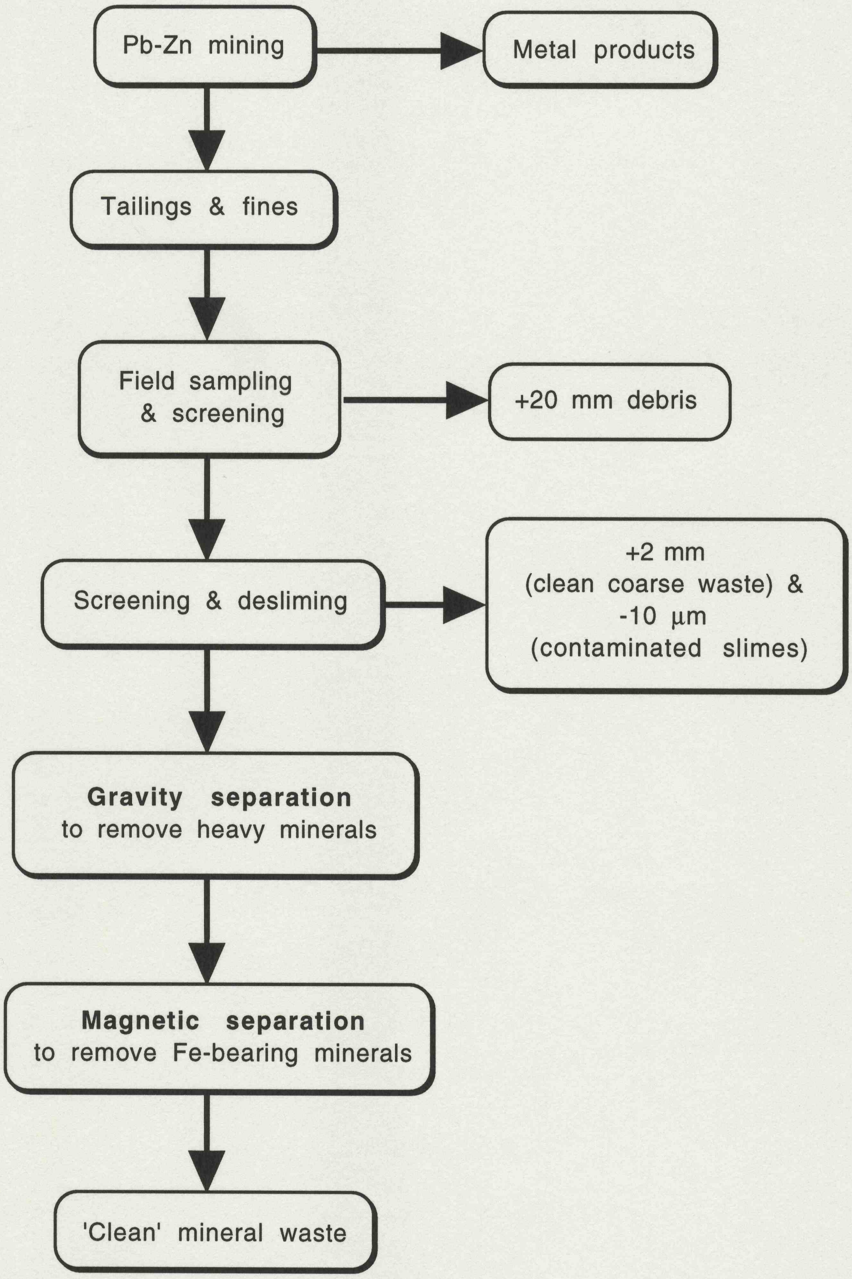

Figure 3. Processing flowsheet for the treatment of Pb-Zn mine tailings

A sample from a tailings dump close to Glencrieff mine was screened on site to remove +20 mm debris. A sub-sample was further screened and deslimed (using a hydrocyclone to remove the -10 μm material). Material between 2 mm and 10 μm was processed using a Mozley laboratory mineral separator. This is a shaking table type of gravity separator, which uses a flowing film of water over a flat inclined surface to separate less dense and heavy minerals. Heavy minerals migrate to the table surface and become entrained in a slower moving stream. Less dense minerals remain on top and are removed downslope by a faster moving stream. The table is oscillated, with an additional 'knock' at the upslope end, which enhances the displacement between heavy and less dense minerals. The heavy products were further processed using a Frantz Magnetic separator.

The size fractions and process products were analysed to determine their heavy metal content (As, Cd, Cr, Cu, Ni, Pb and Zn). This was found to increase with decreasing particle-size. The slimes contained up to eight times the heavy metal content of the +2 mm material. The +2 mm material represented approximately 80% of the sample weight, but contained only approximately 40% of the total heavy metals. Simple size fractionation of the waste would therefore result in a significant decrease in the heavy metal content. This could be achieved by screening to remove the -2 mm material (Table 4). Processing of the -2 mm material using a Mozley shaking table did not result in a product with a heavy metal content as low as that of the +2 mm material.

A larger-scale laboratory processing trial was carried out. A sub-sample was crushed to -2 mm, screened and deslimed. The material between 2 mm and 10 μm was processed using a Wilfley laboratory shaking table. The Wilfley table is similar in principle to the Mozley table, however it is capable of continuous operation and produces a more distinct separation between less-dense and heavy minerals. The process products were chemically analysed to determine their heavy metal content.

The heavy metals were found to concentrate in the middling and concentrate products. The tailings products contained significantly lower heavy metal contents than the untreated waste (Table 4). The most effective result could be achieved by combining all of the tailings coarser than 63 μm (all products finer than 63 μm contained relatively high heavy metal contents) to produce a product that would only contain 40% of the heavy metals of the untreated tailings. The remainder of the heavy metals would occur in a relatively small product, representing only 16% of the untreated tailings but containing approximately 60% of the heavy metals.

Table 4. Heavy metal content of tailings from Glencrieff, Leadhills, Strathclyde

	As (mg/kg)	**Cd** (mg/kg)	**Cr** (mg/kg)	**Cu** (mg/kg)	**Ni** (mg/kg)	**Pb** (mg/kg)	**Zn** (mg/kg)	**Total heavy metal recovery** (wt %)
Unprocessed tailings	34	9	118	210	69	16,470	3052	100.0
+2 mm material	20	8	120	110	44	7121	2645	56.5
+63 μm tailings	18	6	116	128	44	6045	2376	40.7
Dutch 'C' guidelines [4]	50	20	800	500	500	600	3000	na

na = not available

The results given in Table 4 can be compared with the Dutch 'C' guidelines for the classification of contaminated land[4]. Land that exceeds the values given in this guideline requires 'clean-up'. Screening to remove -2 mm material and processing by gravity separation both produce similar results. All the heavy metal contents, with one exception, meet the guideline requirements. However the Pb values exceed the guideline and on this basis alone the treated land would still be considered contaminated.

Discussion

The term ‘mineral waste' conjures up a negative image. The perception is that mineral waste has no further use, is an active threat to the environment and its disposal poses an economic drain on company finances. However, the mineral wastes produced by current and former mining and quarrying operations could be a valuable source of industrial and metalliferous minerals. Technically mineral waste is no different from unprocessed ore (with the exception of the presence of chemical reagents added during processing such as flotation reagents, filtration / flocculation aides, etc...). Therefore traditional methods of mineral processing could be applied for the production of saleable mineral products.

The economic advantages that accompany the exploitation of mineral waste can be summarised as follows: the costs associated with extraction and size reduction have already been covered, certain valuable components have already been removed making subsequent processing simpler, and treatment and disposal costs of any remaining waste would be reduced. This makes the exploitation of mineral waste an attractive proposition. However, the success of a waste processing operation will, as with other mineral operations, depend to a large extent on the mineral produced and the availability of a readily accessible market. Most industrial minerals have a fairly low placement value and require close proximity to any potential market. Therefore despite the potentially high quality of industrial minerals produced from mineral waste if they are not close enough to any potential market they will remain of academic interest.

Conclusions

Mineral waste is a valuable potential source of industrial and metalliferous minerals. Technically mineral waste is identical to mineral ore in that traditional mineral processing techniques can be applied to extract mineral products. The quality of these products can equal, or even exceed, that produced from traditional sources. However despite the quality of any mineral product derived from waste if it is not situated close enough to its potential market it will remain of academic interest.

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