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THE APPLICATION OF ELECTRONIC SORTING TO MINERALS BENEFICIATION

R. A. WYMAN

MINERAL PROCESSING DIVISION

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THE APPLICATION OF ELECTRONIC SORTING TO MINERALS BENEFICIATION

by

R. A. Wyman*

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ABSTRACT

Developments during the past twenty years have made electronic sorting techniques potentially valuable for solving many mineral beneficiation problems. Pertinent information on the subject is presented, available equipment is described, further development possibilities are indicated, and examples of separations are given.

RÉSUMÉ

Les progrès réalisés au cours des 20 dernières années dans les techniques de triage électronique pourraient maintenant permettre de résoudre plusieurs difficultés relatives à l'enrichissement des minéraux. L'auteur présente des données utiles à ce sujet, décrit le matériel disponible, indique les possibilités de perfectionnement et donne des exemples de séparations.

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INTRODUCTION

The 20 years which have elapsed since the end of World War II have seen the gradual evolution of a new approach to minerals beneficiation. This is an adaptation to mechanical operation of the oldest of all concentration methods, hand sorting. Since mechanical operation has been made possible through the development of electronic systems, the term "electronic sorting" is commonly applied. Electronic sorting has now become an important method of mineral concentration, and a review of pertinent information on the subject is appropriate.

At some point in unrecorded history the bright colour of gold in a stream bed must have caught the eye of a primitive man. Pieces of gold were thereafter sought for use as ornaments. Later, man discovered that the pieces could be roughly shaped by hammering them between stones. In searching the streams for gold someone eventually noticed darker-coloured pieces which somewhat resembled gold. These, too, could be beaten and shaped. So the copper age was born. The act of selecting pieces of metal from stream beds by eye and hand is a sorting operation, a means of concentration.

Copper extraction from rock is thought to have begun in the Sinai Peninsula about 4000 BC. The most extensive primitive copper smelter operations have been found in this region. The first evidence that metals were used for purposes other than adornment appears at about 5000 BC. Over the ages, knowledge of metals and minerals gradually increased. Men learned to recognize a large variety of minerals by sight, and continued to separate one from the other by hand. Agricola referred to hand sorting in "De Re Metallica".

Sorting by machine simply substitutes some form of sensing device for the eye and some form of mechanical action for the hand. It would be virtually impossible to devise a sensing device more efficient than the eye, or a mechanical device more precise than the hand. However, man's ingenuity has devised sensing devices which will select minerals not only in much the same way as does the eye, but also in ways other than optical; and he will undoubtedly devise many more ways in the future. Similarly, he has devised methods of removing the selected mineral pieces -- methods that do not yet achieve the precision of the hand, but are satisfactory substitutes.

THE COMPONENTS OF MECHANICAL SORTING SYSTEMS FOR MINERALS

The elements necessary for a successful mechanical sorting device are: 1) a means of presenting the mineral pieces for examination; 2) a sensing device for selecting the pieces to be removed; 3) an electronic system to act upon the information provided by the sensing device; and 4) a means of removing the selected pieces.

The usual method of presenting pieces for examination is to cause them to fall freely through the sensing area. Examination of pieces on a moving conveyor has also been employed.

Sensing is the most important element in, and the real key to, mechanical sorting. The broadest view of sensing is that any significant difference between minerals may be utilized to select one from the other and that devices may be designed and constructed to do so. Undoubtedly there are practical considerations to limit this broad range, but equipment now in service has already utilized a half dozen different methods of sensing.

The function of the sensing device is simply to detect the mineral and indicate that it has done so. It is designed to detect significant relative differences between the mineral to be collected and the other minerals present. When the sensing device locates a piece of mineral exhibiting the characteristic it is designed to detect, it produces an electrical signal. This signal need not be strong since the faintest signals may be amplified.

Once a signal has been produced, the electronic circuit to which it has been directed amplifies it to sufficient strength to trigger whatever mechanical apparatus is used for removing the piece of mineral. The most common removal mechanism is a jet of air, although pushing devices and gates have also been used.

PRESENT LIMITS OF APPLICATION OF SORTING SYSTEMS

Theoretically it should be possible to separate any mineral from an assemblage of minerals, provided it exhibits one or more characteristics which distinguish it from the other minerals present and which may be detected by a sensing device. At present this has been only partly achieved, but equipment is being devised at a rapid rate and sensing devices to exploit different

mineral characteristics are appearing frequently.

It is not practical at present to sort material of small size, because small pieces severely limit capacity and in many cases make it difficult for a machine to detect the distinguishing characteristic. Moreover, as the particle size is reduced it becomes increasingly difficult to remove a selected piece. For practical purposes this limiting size is probably 8 to 10 mesh (2.4 to 1.7 mm), although some manufacturers prefer a lower limit of 3/8 or 1/4 in. (9.5 or 6.4 mm). Experiments by the author with material as small as 14 mesh (1.2 mm) have met with partial success. Eventually it should be possible to process very small pieces at a high rate of speed.

The maximum size of pieces which can be sorted is defined more by the nature of the material than by the physical dimensions. The processing of pieces larger than 12 in. (30.5 cm) may never be required, but equipment is available to do so should the occasion arise.

The object of all sorting is, of course, concentration of one or more valuable minerals. The amount of concentration will depend on the individual circumstances. A typical application may be partial concentration only, with the object of reducing the bulk in a later processing stage. For such an application the pieces to be sorted might be comparatively large and not necessarily composed of a single mineral. On the other hand, the object in many circumstances may be a final concentration of the valuable mineral, in which case the valuable mineral must be liberated from other minerals. In this sort of application the pieces to be sorted would usually be comparatively small. Each application presents a particular set of circumstances, and the most advantageous method of sorting must be worked out to obtain the best results.

SENSING

It is not proposed to enter into a definitive study of sensing in this bulletin, but a number of ideas are put forward to stimulate thinking in that direction. Equipment already in use and sensing methods under development make it clear that there is a wide range of possibilities for sorting systems. It is also clear that an extensive study of mineral properties will be necessary to reveal many of these possibilities. It would appear that every future beneficiation study should include an examination of the valuable material to determine whether it has one or more distinct physical properties to which some sensing system might be applied.

It is expected that such properties will generally not be the common

ones of specific gravity, magnetism, electrostatic characteristics, and shape, although none of these should be entirely ruled out. For example, one of the machines to be described later employs electrical conductance, usually associated with electrostatics.

The best way to visualize the wide range of possibilities for sensing is to examine the electromagnetic spectrum (Figure 1), beginning at the long wave length end. Although it may be difficult to visualize the development of a sensing device employing Hertzian waves (radar, radio, television), this is a broad range and should certainly not be overlooked. Scanning systems similar to that of television are already in use, and radar techniques may prove fruitful.

The infrared range has more definite possibilities. A novel system, developed by the Minerals Beneficiation Division of the Battelle Memorial Institute, has been in operation at the Detroit mine of the International Salt Company since 1957. In this case it is specific for separating halite from dolomite and anhydrite, but the principle might readily be adapted to sensing in the sorting of other minerals. This system utilizes the low radiant heat absorption of halite compared with that of dolomite and anhydrite. The heated impurities adhere to a belt coated with heat-sensitive resin, while the salt does not. A significant fact in this system is that the wave length required to give selective heating is in the low infrared range. Longer wave lengths were not effective in this case, but might well be in other mineral combinations.

Computing Devices of Canada Limited recently announced the development of an infrared scanning device highly sensitive to minute heat differences. Although this is visualized at present as serving to spot minor, localized forest fires from the air, and possibly to outline geological formations, it offers good sensing prospects for mechanical sorting.

The phenomenon of wave length shift, occurring in the low infrared range, offers definite sensing possibilities. Infrared rays of specific wave length, when reflected from a surface, show a shift in wave length which is characteristic of that particular surface. Infrared aerial photography is based on this principle. Minerals could be classified according to the shift they produced, and sensing devices developed to detect the differences.

The fluorescence produced by the ultraviolet radiation of many minerals is well known and is also an obvious prospect for sensing. This is being tested and practical equipment may be developed soon. It is also possible that other changes may occur in minerals during or after exposure to ultraviolet radiation. A search for such phenomena for sensing seems justifiable.

Of even shorter wave length are X-rays and gamma rays. These are very much the same thing -- small quanta of energy. X-ray systems for identifying minerals are well developed and with some ingenuity these might be adapted to selective separation.

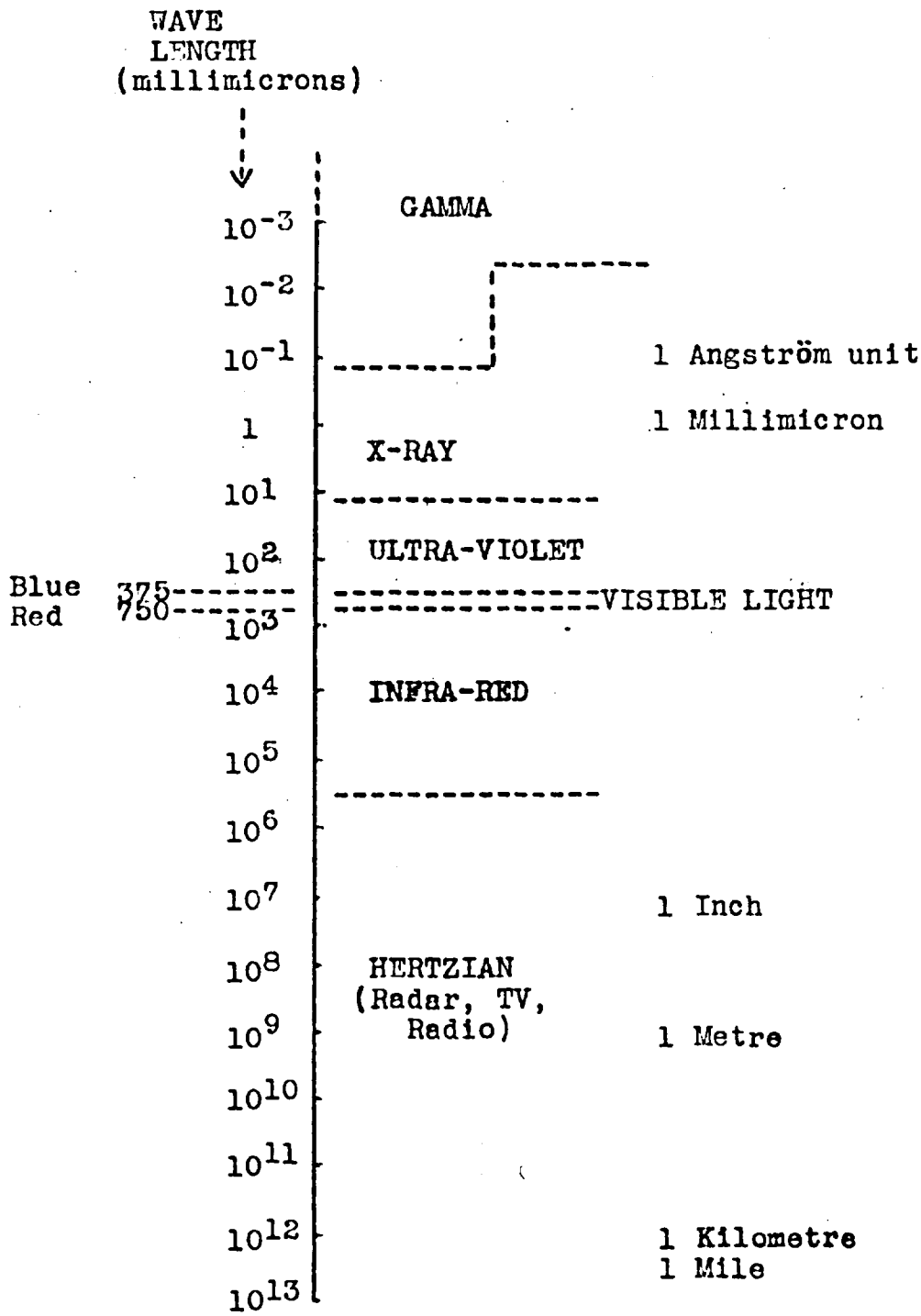


Figure 1. The electromagnetic spectrum.

Of more immediate practical interest is the gamma-neutron interaction. Professor Gaudin of MIT first pointed out the possibilities of this in 1952, in the Sir Julius Wernher Memorial Lecture to the Institution of Mining and Metallurgy; then, in collaboration with Senftle and Freyberger, he published the results of bombarding 150 specimens representing 51 different minerals in the atomic reactor at Brookhaven National Laboratory, and measuring the induced beta and gamma activity of each. More recently, Dr. H. P. Dibbs of the Department of Mines and Technical Surveys, Canada, determined the sensitivity of detection of 66 elements.

Materials bombarded with neutrons produce heavier isotopes through neutron absorption. These are usually unstable and break down rapidly with the emission of beta and/or gamma rays. The isotopes of each element have specific half-lives, and the rays produced have characteristic energy levels. This information has been developed into a system of "neutron activation analysis" by various workers, and provides a sensitive method for the determination of a large number of elements. It should be quite feasible to adapt this method of sensing for sorting purposes.

An example of how this would work can be taken from iron oxide and quartz. Following neutron bombardment, the half-life for oxygen is less than one minute, for silicon a little over two minutes, and for iron 2 1/2 hours. Thus, between one and two minutes after exposure there is little detectable radiation from oxygen, and the number of disintegrations from iron per second are few in comparison with the number per second from silicon with its 2 plus minute half-life. In a stream of exposed particles, therefore, a high disintegration count between one and two minutes after exposure would signify the presence of a quartz particle.

The mobile P. I. F. Analyser incorporates this system. A small radioisotope source (about 1 cm in diameter and wafer-thin) in a safety housing provides the energy. The exposed material is viewed by a photomultiplier tube through two balanced, "absorption edge" filters bracketing the X-ray line of the element being detected.

Nuclear methods may be applied to measure hydrogen density in relation to bulk density. This is in effect a measurement of the water of hydration, and it might be applied in such separations as gypsum from anhydrite, provided the surfaces of the particles are substantially dry.

Another useful nuclear technique is the production of neutrons from beryllium by gamma-ray bombardment. These neutrons may be detected with a material having a high neutron-to-gamma-ray ratio. This is the principle of the Berylometer, a patented device for the detection and analysis of beryllium. Experiments applying this principle to the sorting of beryl from associated minerals have been successfully carried out. The method relies on the fact that one of the beryllium isotopes will produce neutrons from

lower-energy gamma rays than other materials. Thus if the ore is bombarded with low-energy gamma radiation, only the beryl produces neutrons. A neutron counter senses the beryl-bearing piece and activates an ejector. Although this system is based largely on a beryllium characteristic and should apply to all beryllium minerals including gems, it could possibly be adapted to allow the sensing of other elements.

So far nothing has been said about the narrow band of visible light. This is the most obvious area to exploit and many of the devices presently in operation employ visible light. Photometric sorting should therefore be explained in a little more detail.

HOW PHOTOMETRIC SORTING WORKS

Photometric sorting is based on an electronic device which converts a change in the intensity of light striking it into electrical current. This is the photoelectric cell, or phototube (Figure 2).

The cathode of a photoelectric cell is coated with a light-sensitive material. A small potential is established to cause electrons to pass steadily from cathode to anode. This current will remain steady as long as the light falling on the cathode remains the same. If the amount of light is increased, the cathode will emit more electrons, increasing the output of the tube. If the amount of light is reduced, such as by an object between the light source and the cathode, fewer electrons will be emitted, decreasing the output of the tube.

If a phototube is placed at the open end of a box (Figure 3) the inside of which is white and under steady illumination, light reflected from the end of the box to the phototube will produce a constant output. Placing a white object near the end of the box will cause very little change in the light being reflected to the phototube and also little change in its output. Placing a dark object in the same position will decrease the amount of light reflected and cause a drop in output from the phototube. A change in output from the phototube can be amplified, controlled, and used as desired.

This comparatively simple system is elaborated and combined with other techniques to produce practical methods of separation. Usually, several phototubes are arranged to receive light from the same small area but from different angles. The tubes are "focused" on this area by placing a slit, or a small hole, in front of them. In this way most of a mineral's surface may be examined simultaneously. In line with the "view" of each phototube is placed a removable background. Light intensity is kept as constant as possible

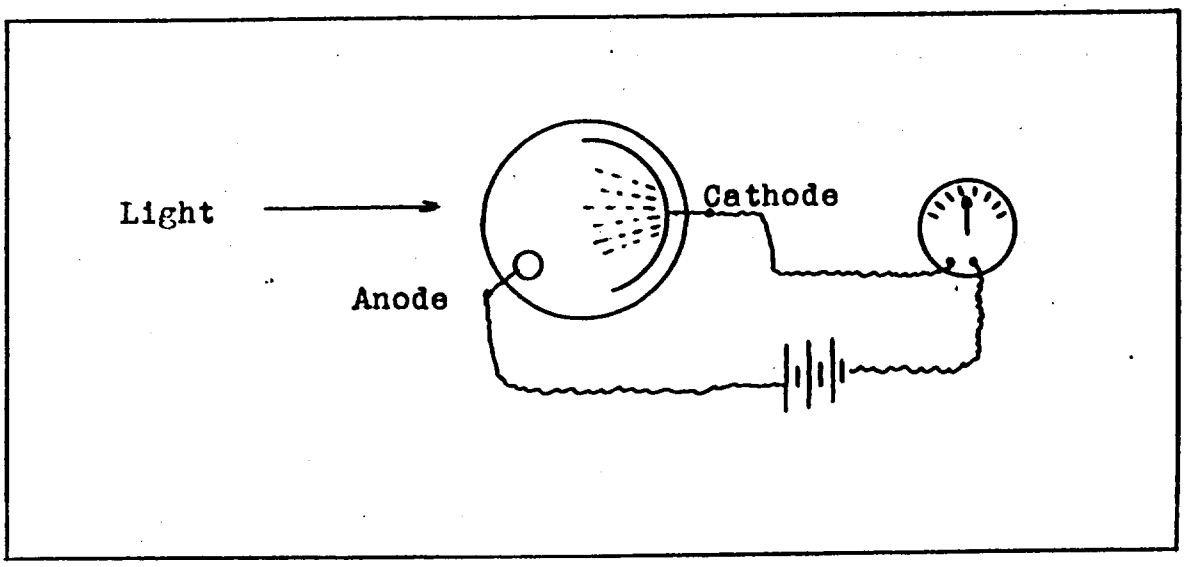


Figure 2. Phototube.

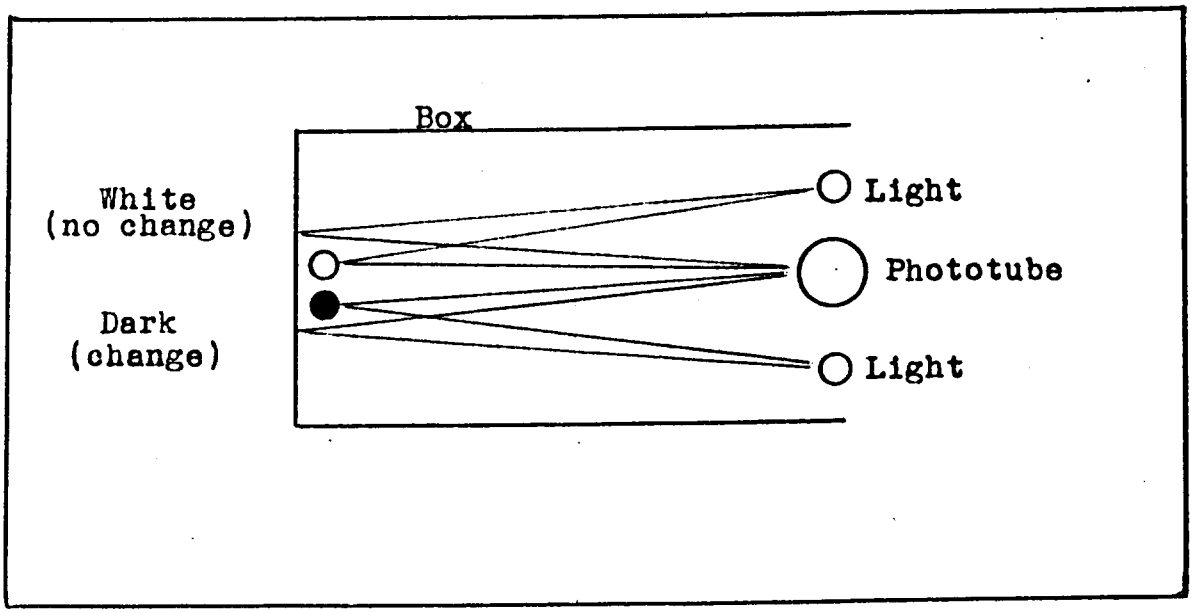


Figure 3. Object detection.

by enclosing the scanning area within white walls illuminated by bright lamps. In this way a similar constant output is established in all phototubes. (By changing to backgrounds of higher or lower reflectivity, this constant output may be increased or decreased.) In any mineral sorting operation, the background is chosen to match as closely as possible in reflectivity with the major constituent of the minerals to be sorted.

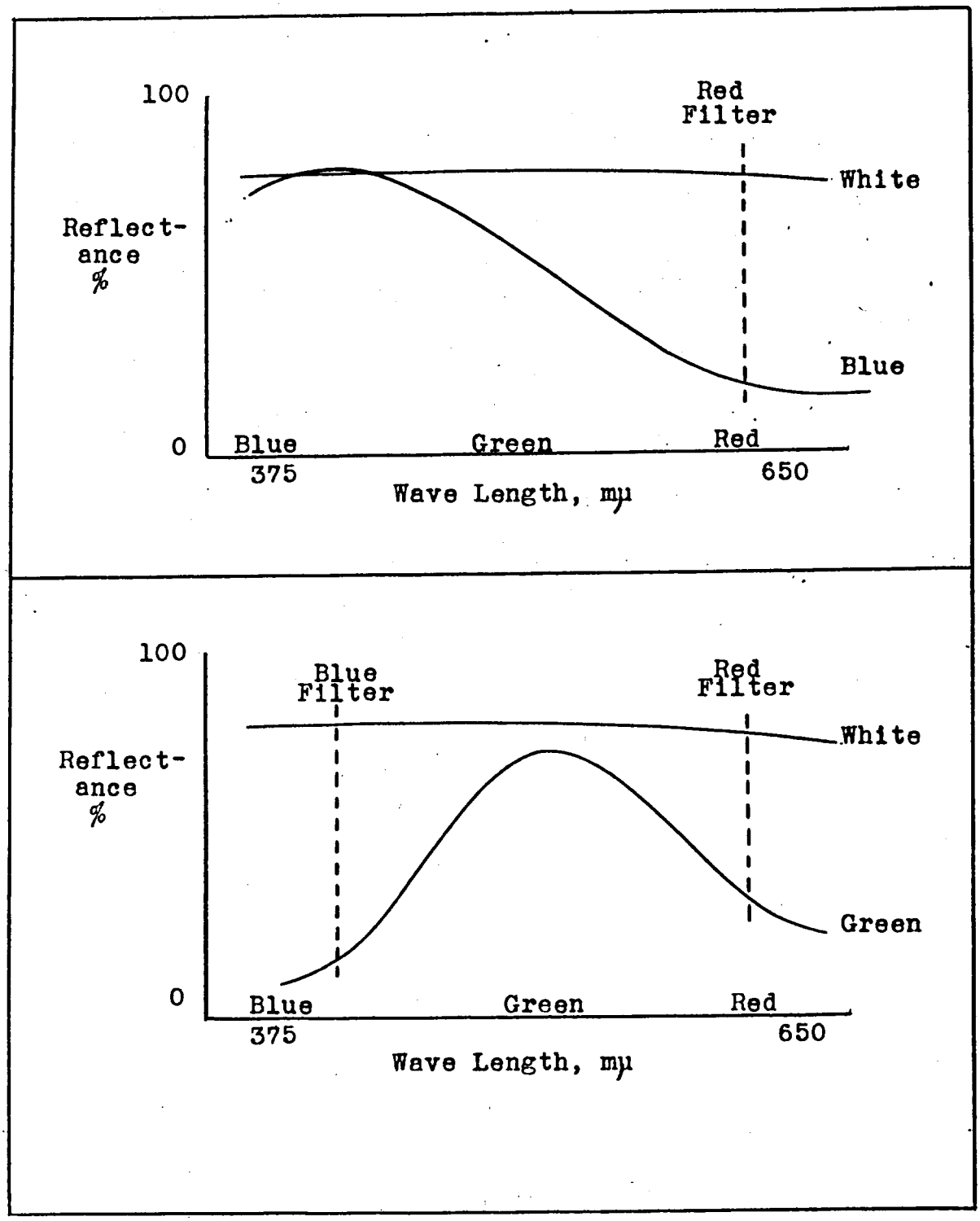
The mineral particles to be examined are introduced into the viewing position one after the other as quickly as possible, usually by a slide or a conveyor belt. Those that match the background fairly closely in intensity of light reflected cause little or no change in output of the phototubes, but those that differ from the background cause a change in output from the tubes which are used to activate some form of mechanical device to remove them.

Minerals may be transparent or opaque. Transparent minerals usually receive some form of special treatment in order to capitalize on this characteristic. With opaque minerals, reflected light is used. The colour, shade and lustre of minerals are not distinguished by a phototube as they are by the eye, because a phototube can only detect a difference in the intensity of the light reaching it. It usually becomes necessary, therefore, to enhance intensity differences by narrowing the range of light reaching the phototube from the mineral. To do this, filters are employed. The average phototube requires a difference of 7 to 8% in the intensity of light striking it to cause sufficient change in output for a usable signal. A method of developing the required difference is, first, to examine the light being reflected from the surfaces of representative specimens of the minerals to be sorted, at various wave lengths across the visible spectrum, and, next, to select a filter that will enhance the maximum difference.

Figure 4 shows a plot of the light reflected from a white mineral compared with that from a bluish mineral. There is very little difference in their reflectivity at the blue end of the spectrum, but a considerable divergence at the red end. To capitalize on this difference, a red filter would be used, effectively isolating the light being received by the phototube to the red end.

Figure 5 shows a plot of the light reflected from a white mineral in comparison with that from a green mineral. Here the reflectivities of the two match closely in the green area of the spectrum, but diverge in both the blue and red areas. Either a blue or a red filter could be used to enhance the differences between these minerals.

Lustre is a highly troublesome characteristic of minerals because it can cause bright flashes, or highlights, to reflect from the mineral surface to the phototube. This constitutes an increase in light intensity which will trigger a signal from the tube, whether it be from an acceptable mineral or from one to be rejected. The use of diffused light reduces highlight misreadings to a minimum.



Figures 4 and 5. Reflectance curves.

An interesting example of the use of lustre as the activating agent exists. The National Coal Board in Britain employed it as a means for distinguishing between bright and dull coal. Unpolarized light reflected from both bright and dull lumps was found to be similar, but light reflected from the lumps through a rotating polarizing disc onto a phototube was found to produce different voltage outputs, 12.5 volts for the bright coal and 2.3 volts for the dull. This difference enabled a separation to be made. It was further found that the shale, which reported with the dull coal in the first sortings, could be removed in a second operation after dampening with water. The coal absorbed the moisture quickly and remained substantially the same, but the shale glistened, producing a response similar to that of the bright coal.

Chemical staining of minerals should be borne in mind in connection with photometric sorting. Many identifying stains are known and used by mineralogists and geochemists and may also provide the means for differentiating minerals. Cases arise, particularly in the separation of near-white shades, in which there is insufficient difference to allow a distinction by the machine, but if the shade of one mineral is altered even slightly, or changed to another colour in whole or in part, a distinction can usually be made. A drawback to the use of straining techniques may be cost, but the use of comparatively cheap dyes is promising. Simply exposing some minerals to dye will alter their shade slightly, probably because of roughness or porosity. Whether staining or shade altering would be profitable would depend on the overall value of the mineral commodity to be sorted.

EQUIPMENT ALREADY DEVELOPED

A number of manufacturers are producing sorting equipment for mineral applications, and others are becoming interested. Types of sensing devices available include those based on light reflectance or transmittance, those employing X-rays, those utilizing radioactivity, and one based on electrical conductance. A device to sense fluorescent minerals is under development, and neutron bombardment techniques are being studied.

1. The Lapointe Picker

This is probably the first true mineral sorting machine to be developed. The uranium boom which followed the Second World War brought about an intensive search for uranium concentration methods. A group of scientists at the Canadian Mines Branch, led by Dr. C.M. Lapointe*, worked out a method for selecting uranium-bearing pieces of rock. The system was invented in 1946 and field tested in 1947 and 1948 at Port Radium, Northwest Territories, and Port Hope, Ontario, first on 2 1/2 in. (6.4 cm) and then on 12 in. (30.5 cm) pieces.

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*In 1950, Dr. Lapointe received the McCharles Prize, awarded by the University of Toronto, for his work on this device.

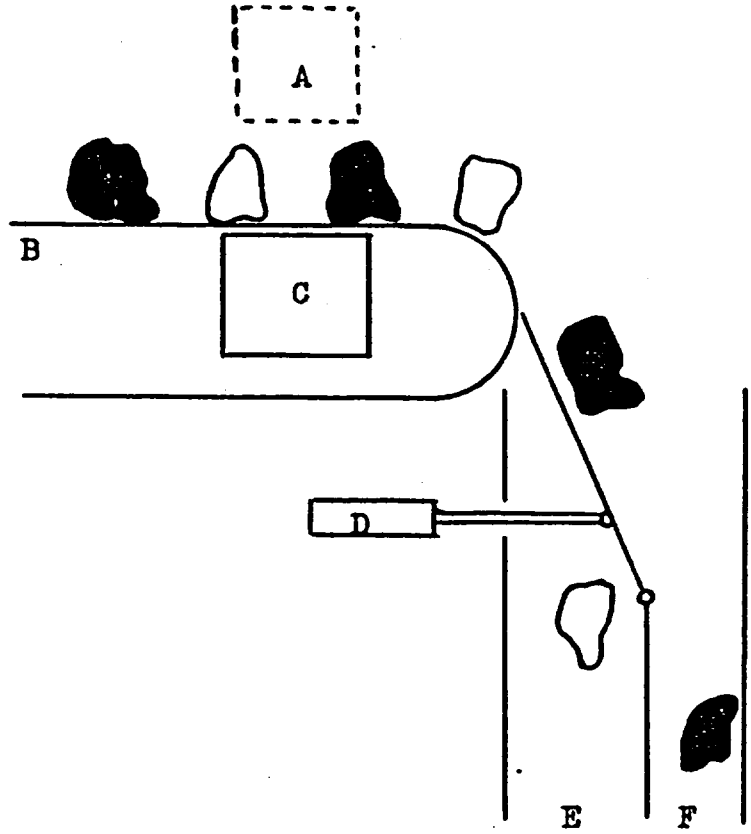
The basic equipment consists of a conveyor belt upon which the pieces are lined up with a few inches of space between each piece (Figure 6). In the original system the pieces passed under a shielded, beta-sensitive Geiger tube. Radioactive pieces were shoved over the side of the belt by a plunger located to one side and beneath the Geiger tube. The ejection system was later improved by using a gate at the end of the belt. This was opened by an air piston on a signal from the Geiger tube, but otherwise remained closed to divert waste pieces. A capacity of about 5 tons/hr could be obtained on -6 +4 in. (-15.3 +10.2 cm) feed.

The sensitivity of the system was improved in 1954 by placing a scintillation detector under the belt instead of the Geiger tube over the belt. This method detected gamma radiation from the pieces that passed close to the detector. Tests on disseminated low-grade ores were successful.

2. The Newman and Whelan Separator

Work on the separation of bright from dull coal for the National Coal Board in Britain resulted in the development of a photometric separation system which was described in 1952. The success with coal led to tests on non-metallic minerals with good overall results. The early work revealed that, although in many cases there was little difference in the intensity of direct reflection alone from bright and dull surfaces, there was frequently a distinct difference in the intensity of direct and diffused reflection from the same surfaces.

An optical system designed to take advantage of this difference was gradually evolved and refined. Light reflected from a mineral surface was passed through a convex lens from which the centre had been removed and replaced with a prismatic convex segment. Thus a direct reflection from a smooth surface would pass through this centre portion and be diverted away from the main lens axis. Diffused reflection, on the other hand, would pass through the main lens and be focused at the axis. By placing a rotating disc (2900 rpm) with two sets of alternating concentric slots at this point, diffused or direct reflected light from mineral surfaces could be flashed in rapid succession onto a single phototube. A change in the output of the phototube, in response to differences in light intensity produced in this way, could be used to operate a correctly timed deflection system. A line drawing of this device is presented in Figure 7.



A Geiger Tube (if used)

B Conveyor

C Scintillation Detector

D Air Piston

E Ore

F Waste

Figure 6. The Lapointe picker.

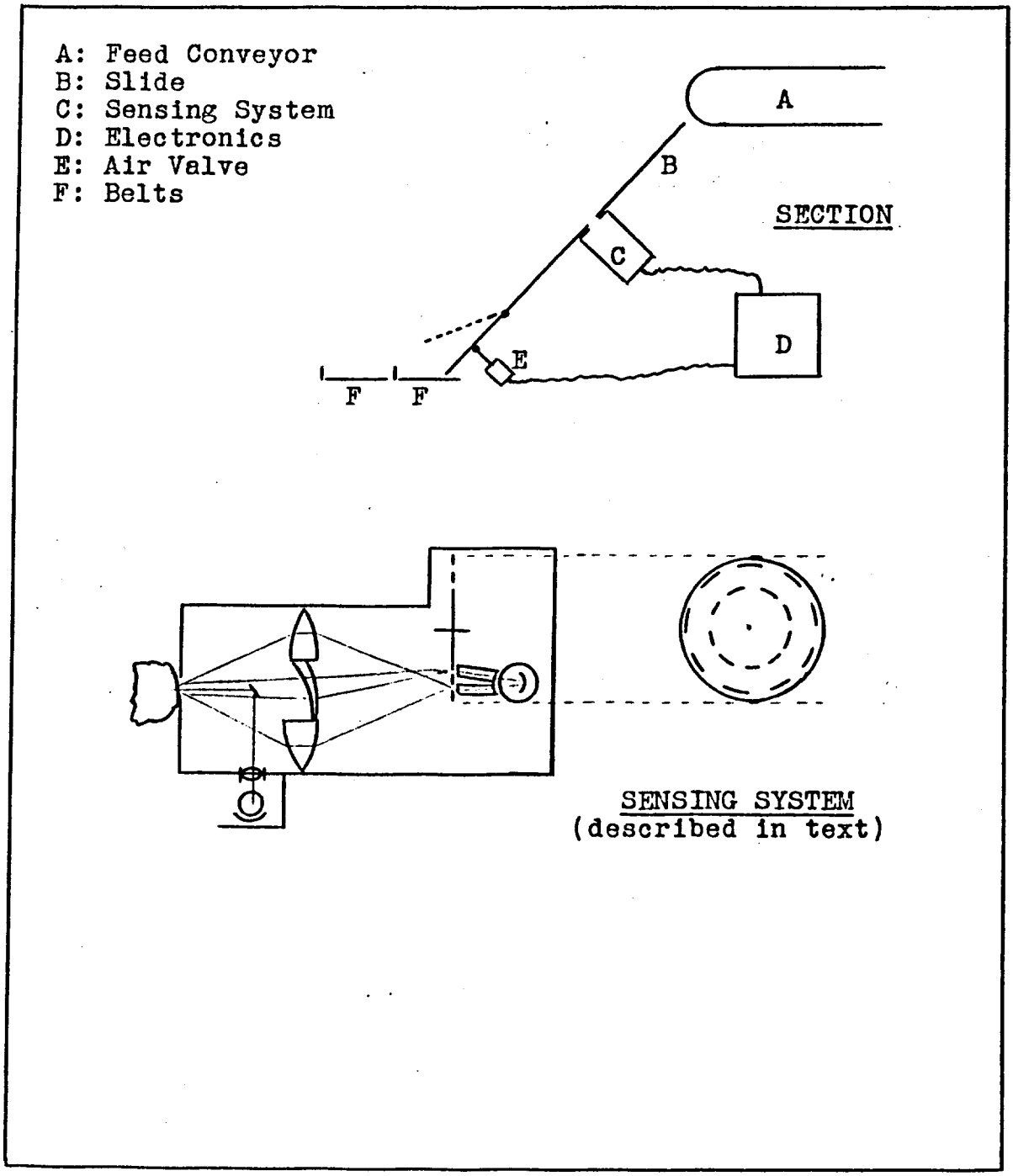


Figure 7. Newman and Whelan separator.

A pilot plant built and operated on this ingenious system was used to test 12 additional non-metallic minerals. Individual minerals, rather than mixtures, were tested. The diffuse-direct reflection comparison, with the electronic system set to react to a 10-unit difference, caused 100% acceptance of 7 minerals and 100% rejection of 3. It was found that the two other minerals could be completely rejected by altering the optical and electronic conditions. It is interesting to note that at that time the cost per feed ton for sorting was calculated to range from 0.2 penny for 3 in. lump to 2.5 pence for 3/4 in. pieces. These figures seem remarkably low, particularly in comparison with current cost estimates.

3. The Goodman Sorter

A new sorting system was recently announced, and commercial development may be expected shortly. It was designed, and a prototype was built to demonstrate its feasibility, by a Canadian Mines Branch team under Dr. R. H. Goodman. This system depends upon recognition of specific X-rays emitted by heavy-element-containing minerals exposed to beta radiation.

The Mines Branch prototype is arranged to sort material about 2 in. (5.1 cm) or greater in size, although commercial units will possibly allow the sorting of smaller pieces. The pieces, arranged in single file on a conveyor (Figure 8), are bombarded with radiation from a shielded strontium-90 source. The exposure causes a heavy element to emit X-rays which are characteristic of that particular element, and a sensing device is employed which recognizes the X-rays involved. The signal is amplified and triggers a gate which is timed to eject the identified piece.

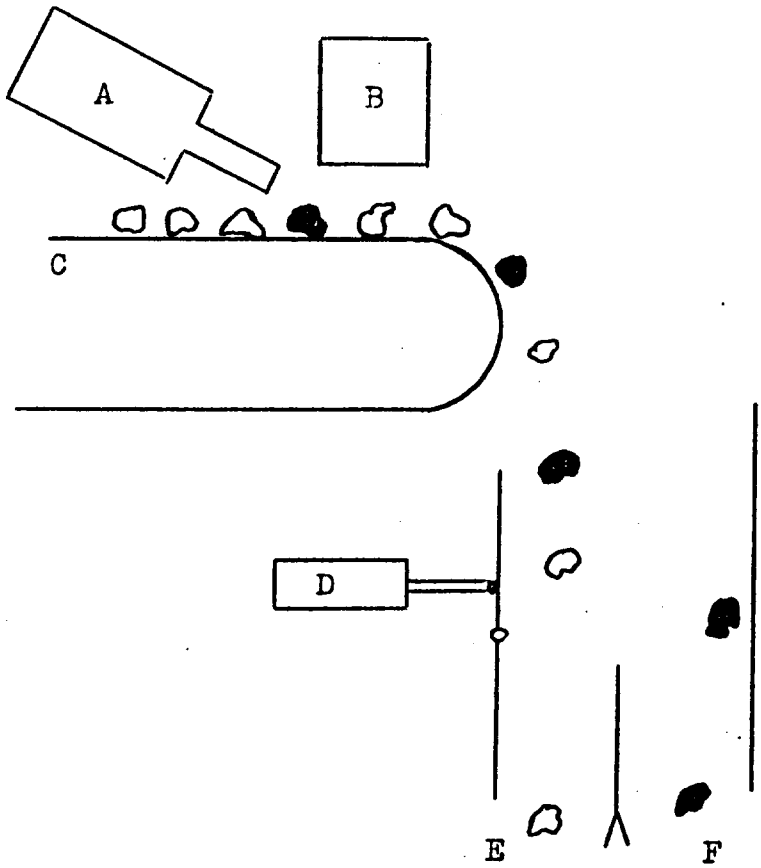
The system works very well on minerals containing elements above atomic number 36, and has been tested on molybdenite and cassiterite ores. The detection of some elements below atomic number 36 may eventually be possible, but at present is not practical because of the air absorption of X-rays.

This system will probably find its best field in partial concentration of low-grade ores, but it might eventually be adopted to concentrate liberated mineral pieces of small size into high-grade concentrates.

4. Sortex Equipment

Several manufacturers have developed good mineral sorters based on the reflectance or transmittance of light. Gunson's Sortex Limited, of London, England (represented in North America by Sortex Company of North America, Inc., Lowell, Michigan), has been in the forefront of this development.

Sortex equipment was originally developed for the removal of undesirable material from agricultural products. Early work on minerals was done with this equipment, and the success achieved led to the design and production of a machine specific for mineral sorting.



A X-ray Detector

B Strontium 90 (in fail-safe shielding)

C Conveyor

D Air Ram

E Ore

F Waste

Figure 8. The Goodman sorter.

The Sortex mineral machine incorporates two "channels" operating simultaneously in a totally enclosed housing of standard size. This permits several machines to stand side by side when capacity above that of a single machine is required. It also provides good appearance, ease of dust or wet proofing, ease of cleaning by "hosing down", minimum space requirements, and ease of access for inspection.

The pieces to be sorted are lined up on a short conveyor running at constant speed (Figure 9). They fall from the end of this conveyor through the scanning area, where they are examined under bright, diffused light from three directions, simultaneously, by photomultiplier tubes focussed on preselected backgrounds. Any piece showing a deviation from the background causes any one of the photomultiplier tubes to produce a signal which, via the electronic system, activates an air jet timed to deflect that piece from its normal path into a reject hopper. Accepted pieces are collected in a separate hopper. Filters of any desired colour may be used to provide a variety of monochromatic light. Provision is made to keep dust out of the scanning area by controlled air movement and by placing the ejection jet below this area. Feed may be damp or dry. Dampness sharpens colour contrast in many minerals.

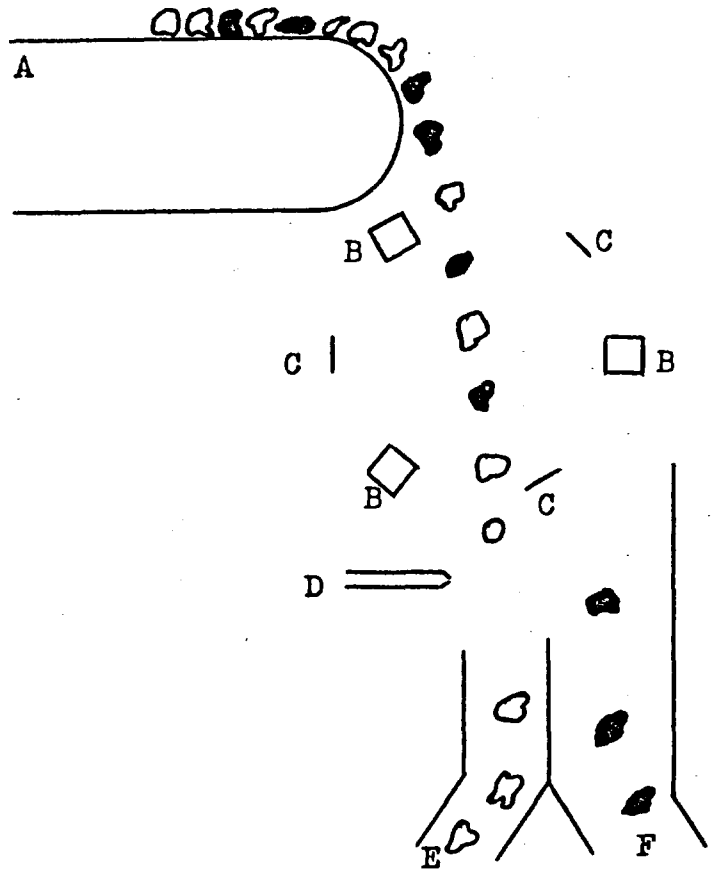
Material from about 3/4 in. (1.9 cm) to 10 mesh (0.17 cm) can be processed, although for reasons of capacity and accuracy the manufacturer prefers to specify a 1/4 in. (0.63 cm) minimum. The feed should be closely sized for best results. If a high-grade concentrate is the objective, the valuable mineral should be liberated.

On -3/4 +1/2 in. (-1.9 +1.3 cm) pieces this equipment will handle up to 2 tons per hour of material having a sp gr of about 2.7. If no more than 20% of the feed is to be rejected, the separation is usually good. If more than 20% is to be rejected, it will probably be necessary to rerun in order to obtain a clean product.

The Sortex Company produces equipment capable of handling material up to 6 in. (15.3 cm) and is also experimenting with other forms of sensing.

5. Gromax Electronic Sorters

The mineral sorter of Gromax Inc., 855 West Ave. 135, San Leandro, California, differs from the Sortex in design features, but is essentially the same in operating principle. The machine is a two-channel device with the channels mounted on frames to either side of the control housing. Pieces as small as 1/8 in. (3.1 mm) but preferably above 1/4 in. (0.63 cm), or as large as 1 in. (2.5 cm), may be handled. Capacity and selectivity are approximately the same as for Sortex equipment.



A Conveyor
B Photocells
C Backgrounds
D Air Jet
E Ore
F Waste

Figure 9. Sortex mineral separator.

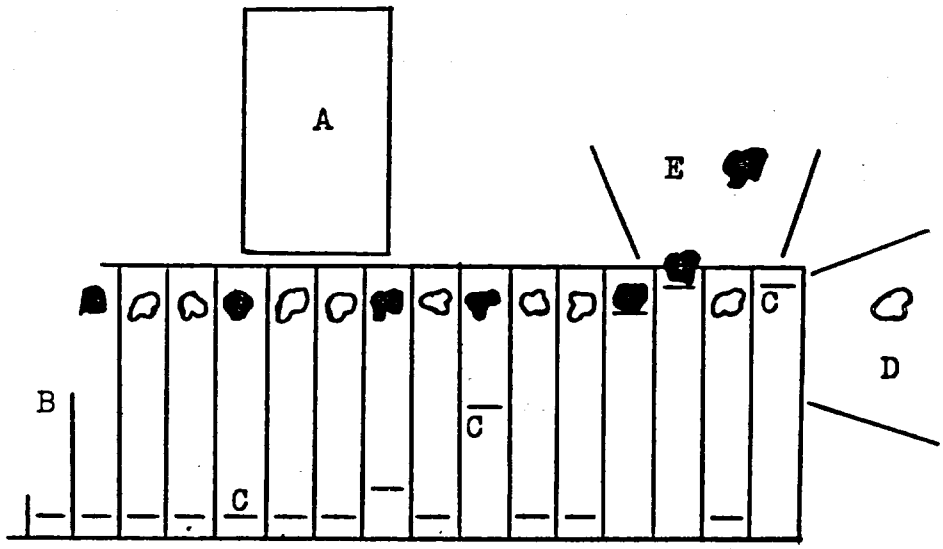
A larger unit, called the Gromax Selector, was developed for a specific requirement, but it may have a wide range of applications in the future. The chief mechanical component is a device composed of two parallel chains, roughly 2 ft (61 cm) apart, connected by a series of parallel 4 in. wide (10.2 cm) steel plates (Figure 10). The chains form an endless conveying system by travelling over toothed wheels. Fastened to each plate is a "deflecting boot", arranged to slide along it. Each "boot" is held in place by a cam along one side of the conveyor. The cam may be tripped by a solenoid switch on a signal from the electronic system. When tripped, the cam engages a rail so placed that it gradually moves the boot across the plate to the opposite side. The boot remains in this position until the conveyor has turned over at the end of the system and is moved back into its original position on the under (or return) side of the conveyor. This conveying system travels at a rate of 150 ft (46 m) per minute. Pieces to be sorted are arranged in line along the opposite side of the conveyor from the boots and may be from somewhat less than 4 in. (9.2 cm) to about 12 in. (30.5 cm) in size.

The sensing component for this equipment differs considerably from that of the smaller sorter. A 1/8 in. (3.1 mm) beam of light is reflected from the lumps being scanned as they pass on the conveyor. The reflected beam is focused on a photocell via a wheel-type shutter set to allow seven exposures per inch (2.54 cm) of conveyor travel. The photocell detects changes in the intensity of the reflected light and produces a signal on any variation from the established norm. A cover protects the scanning area from outside light.

The electronic system includes a computing circuit which may be set to reject on any sequence of signals. In the specific case for which the equipment was developed, it was found that the desired result could be obtained by rejecting on the basis of 15 consecutive signals, representing approximately 2 in. (5.1 cm) of rock differing in colour from the desirable material. With less than 15 consecutive signals the counting system immediately returns to zero and begins a new count. Thus a "rock bruise", which might trigger a signal from the sensing device, will not result in an acceptable piece's being rejected. The electronic system also computes the length of each piece scanned, so that more than one deflecting boot may be activated according to the size of the particular piece to be removed.

Field testing of this equipment in connection with the original problem was successful. An accuracy of 93% to 96% was achieved in rejecting undesirable material. A feed rate of 50 tons/hr was maintained, although theoretically a feed rate of above 200 tons/hr should be possible.

Gromax Inc. reports development of a metallic ore detector for sorting copper minerals from waste. Unfortunately this company has decided to withdraw from active development in the minerals field, but its knowledge and experience are available and special machines will be constructed on request.



A Scanner

B Conveyor

C "Boots"

D Ore

E Waste

Figure 10. The Gromax selector.

6. Ore Sorters (Canada) Limited

Two Canadian engineers have played a notable part in the emergence of sorting equipment. Messrs. L. Kelly and J. F. Hutter collaborated with Bicroft Uranium Mines at Bancroft, Ontario, in the development of the K & H Radiometric Sorter, which functioned extremely well. Units were installed in Australia and at Beaverlodge, Saskatchewan, in addition to Bancroft.

The inventors then proceeded to develop high-capacity sorting equipment utilizing reflected or transmitted light, and differences in electrical conductivity. The rights to these inventions were taken up by Ore Sorters (Canada) Limited, 839 Erskine Avenue, Peterborough, Ontario, and Messrs. Kelly and Hutter joined this firm.

The methods employed can be better described in terms of an overall system rather than individual units. Conductance and optical sensing encompass a very broad spectrum of application. At present, Ore Sorters (Canada) Limited has standardized on basic equipment for conductance and optical sorting, including the presentation of pieces, the electronics, and the ejection system. The company is currently concentrating on the conductance method (electrical conductivity of minerals) because it has the most important range of application. Optical sensing may be employed with the same basic equipment.

As the system is the only multiple sorting method currently used, and provides a remarkable combination of versatility and capacity, it could very well attain a dominant position in the mineral sorting field.

For conductance sorting, feed above 3/4 in. (1.9 cm) is preferred, except in exceptional cases; for optical sorting, feed above 1/4 in. (0.61 cm) is preferred. This is because capacity drops rapidly with feed size. A throughput of 80 to 100 tons/hr is obtained on 2 to 4 in. (5.1 to 10.2 cm) feed. This drops to 30 tons/hr on 3/4 to 2 in. (1.9 to 5.1 cm), and to 20 tons/hr on 1/4 to 3/4 in. (0.61 to 1.9 cm) feed. The upper limit of size for either method is dictated by the material, but may go to any size that can be sorted practically. As an example, in separating shale from hematite, the product of an 84 by 60 in. (213.5 by 155.5 cm) crusher may be sorted by conductance because the two materials are in separate pieces.

The system is generally used for upgrading feed for later processing (i.e., discarding waste with a minimum loss of valuable mineral), but may be used to produce a final concentrate if the valuable material is in discrete pieces.

Because of the broad scope of the Ore Sorters' system, a wide variety of materials can be processed. The company has found it necessary to proceed with some care in order to remain within its present, but expanding, capabilities. Those sorting problems which offer the best economic prospects

are currently being handled, but a more complete coverage can be expected shortly.

When dealing with a problem that initially offers good prospects, the company prefers to pay a visit to the site for an on-the-spot survey. Considerations such as size range, approximate tonnage, approximate bulk elimination, simple test procedures and general economic possibilities are dealt with. The chief requirements for conductance sorting are sufficient differences in conductivity to allow sorting and a sufficient degree of beneficiation to make the installation worthwhile. If the prospects are promising, a representative bulk sample of several tons is collected for process testing in the laboratory. If the testing proves to be satisfactory, a complete proposal is submitted to the customer. A pilot installation can be operating 3 to 4 months after receipt of a firm order.

The Ore Sorters organization has so far preferred to withhold particulars of how its equipment works. However, the firm of Material Separators, Inc., 7185 North Center Street, Mentor, Ohio, as licencee for the equipment in the United States, has issued a brochure describing the conductance equipment, under the registered trademark of CONSEP, in the following terms:

"The CONSEP is an electro-pneumatic device capable of separating, concentrating, or sorting particulate matter on a basis of electrical conductivity. It is a high capacity unit that will positively distinguish and separate a more conductive particle from a less conductive particle. It is a practical commercial machine that can be operated and maintained with an absolute minimum of expense and labour.

"Material containing particulate matter to be separated, concentrated or sorted, is fed as a random, single layered stream onto the full width of a slide plate on the CONSEP. Here, the particles, within the material being treated, accelerate under the force of gravity in such a manner that they tend to space themselves and pass individually under high voltage electrodes, in place, and perpendicular to the flow of solids. These electrodes each control high speed air blast valves located immediately down stream and in line with the flow of material passing beneath them.

"A conducting particle, while momentarily beneath the electrode, allows the passage of a few milliamps of current and produces a voltage pulse across a series resistor. The intensity of this pulse is measured and, if in excess of a desired control value, is amplified electronically to activate a solenoid-operated air blast valve. This valve is timed to release a directed air blast at the exact time the conducting particle passes by it. Such a conductive particle is thus forced out of the main body of the falling stream of material being treated.

"Non-conductive, or lesser conductive, particles which do not activate an air blast mechanism remain with the main body of the falling stream.

"The operation of the CONSEP may be visualized from the accompanying illustration which denotes the sequence of flow (Figure 11).

"The CONSEP will apply to any separating, concentrating or sorting process in which two criteria exist. These are:

(1) The material to be treated must contain particulates of measurable difference in electrical conductance.

(2) The measured differences in conductance must relate to grade, quality or nature of a desired product or products.

"The total installation costs of a CONSEP circuit will parallel those of other conventional separating or concentrating equipment.

"The operating costs of a CONSEP circuit will be appreciably less than other conventional processes.

"The maintenance costs of a CONSEP circuit will be extremely low."

Although this description does not provide full particulars of the system, and does not include the photometric method, it serves as a general indication of the principles involved.

Ore Sorters (Canada) Limited also produced the original Kelly & Hutter Radiometric Sorter. This machine operates on pieces from about 2 in. (5.1 cm) in size to about 12 in. (30.5 cm). The pieces are lined up on a conveyor belt, from the end of which they fall through the scanning area (Figure 12). In this area the radioactive level of each piece is measured by a scintillometer, and at the same time the physical size of the piece is determined by measuring the reduction of light falling on a photoelectric cell. Both signals are instantaneously processed by the electronic system, the uranium content being evaluated by a computing circuit. If the U content of a piece is below a predetermined level, the system activates an air jet and the piece is diverted from its normal path into a waste hopper. Accepted pieces fall into a product hopper and proceed by conveyor to further processing.

The level of upgrading is decided on the basis of economics and on the particular circumstances existing for each installation. The machines will process up to 40 tons/hr of feed.

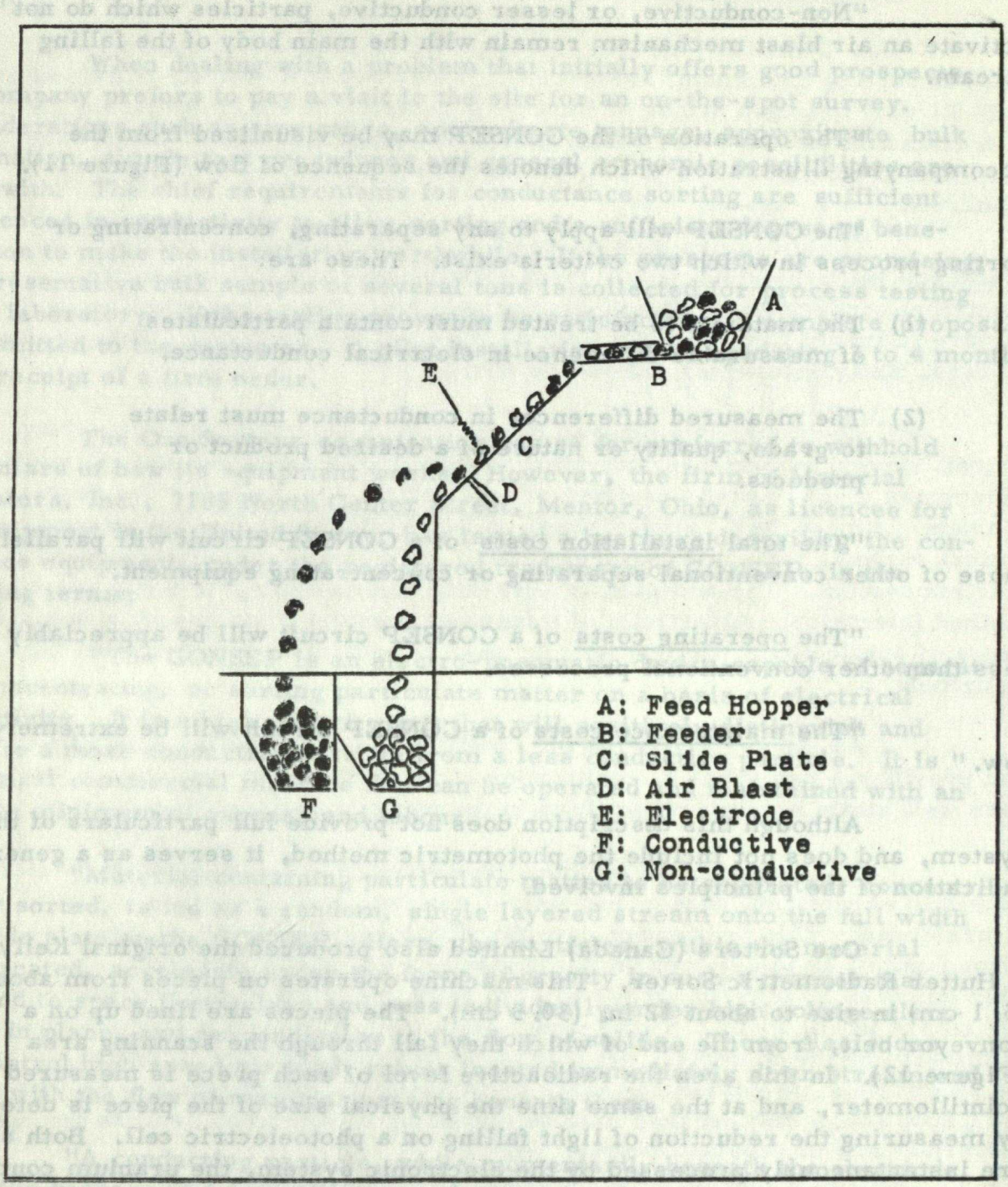


Figure 11. Sequence of flow in the CONSEP.

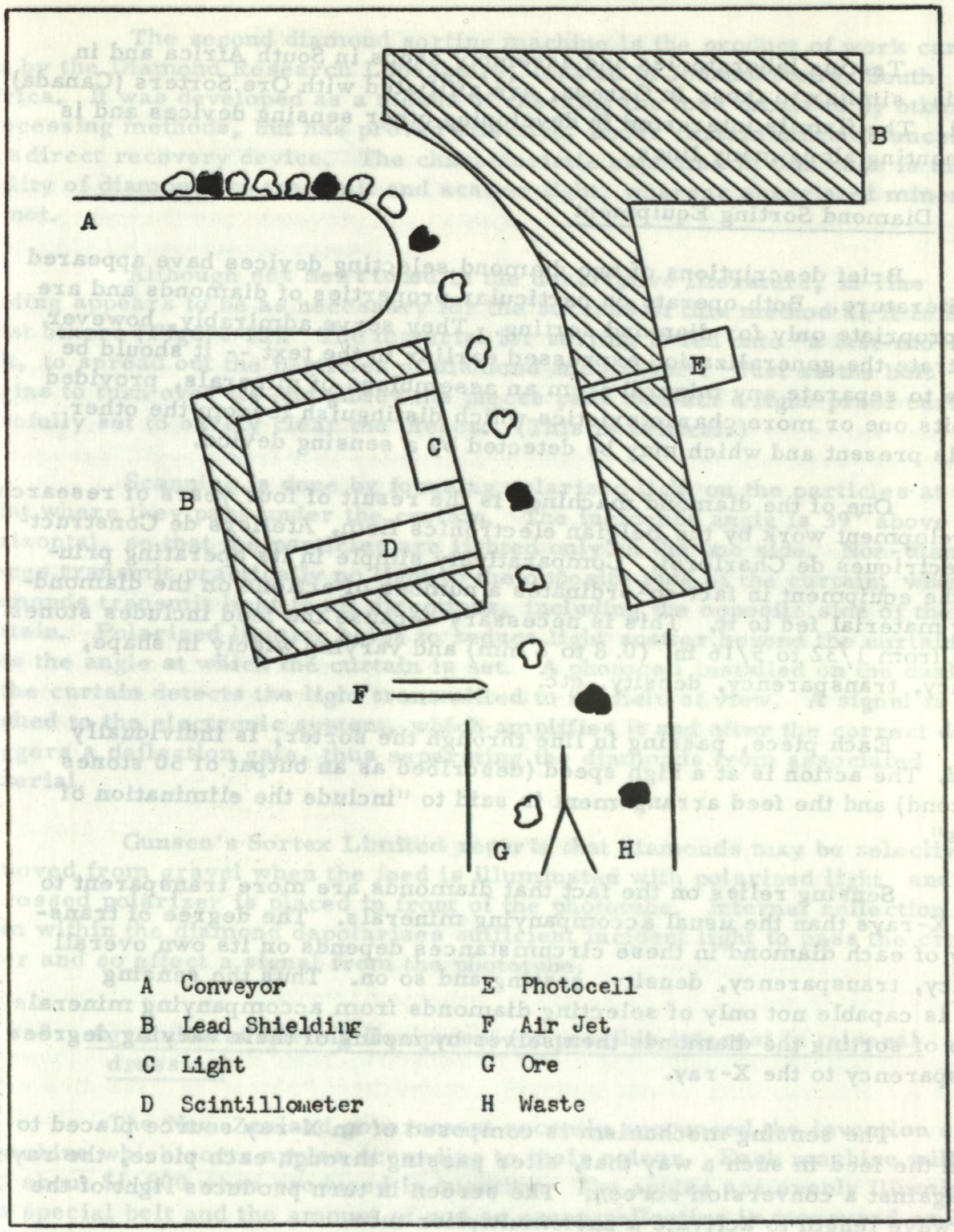


Figure 12. The K and H radiometric sorter.

Testing laboratories and assembly shops in South Africa and in Australia, similar to those in Canada, are affiliated with Ore Sorters (Canada) Limited. The firm is interested in developing other sensing devices and is experimenting along many lines.

7. Diamond Sorting Equipment

Brief descriptions of two diamond selecting devices have appeared in the literature. Both operate on particular properties of diamonds and are thus appropriate only for diamond sorting. They serve admirably, however, to illustrate the generalization expressed earlier in the text -- it should be possible to separate any mineral from an assemblage of minerals, provided it exhibits one or more characteristics which distinguish it from the other minerals present and which may be detected by a sensing device.

One of the diamond machines is the result of four years of research and development work by the Belgian electronics firm, Ateliers de Constructions Electriques de Charleroi. Comparatively simple in its operating principle, the equipment in fact co-ordinates a number of actions on the diamond-bearing material fed to it. This is necessary because the feed includes stones ranging from 1/32 to 5/16 in. (0.8 to 8 mm) and varying widely in shape, brilliancy, transparency, density, etc.

Each piece, passing in line through the sorter, is individually scanned. The action is at a high speed (described as an output of 50 stones per second) and the feed arrangement is said to "include the elimination of doublets".

Sensing relies on the fact that diamonds are more transparent to certain X-rays than the usual accompanying minerals. The degree of transparency of each diamond in these circumstances depends on its own overall brilliancy, transparency, density, coating, and so on. Thus the sensing system is capable not only of selecting diamonds from accompanying minerals but also of sorting the diamonds themselves by means of their varying degrees of transparency to the X-ray.

The sensing mechanism is composed of an X-ray source placed to focus on the feed in such a way that, after passing through each piece, the rays strike against a conversion screen. The screen in turn produces light of the proper wave length to activate a photomultiplier tube.

The intensity of the signal from the photomultiplier tube is used by the electronic computing circuit to determine the nature of the scanned piece. Each signal is then amplified sufficiently to activate a mechanism which removes the non-diamond pieces and sends each diamond to join others of similar category. The electronic system also includes circuits for complete surveillance of all operating areas of the equipment, so that any working defect may be detected and immediately corrected.

The second diamond sorting machine is the product of work carried out by the Diamond Research Laboratory, located in Johannesburg, South Africa. It was developed as a means of checking the loss incurred by other processing methods, but has proved effective, under certain circumstances, as a direct recovery device. The characteristic exploited in this case is the ability of diamonds to transmit and scatter light, whereas associated minerals do not.

Although not mentioned in the descriptive literature, in-line feeding appears to be as necessary for the success of this method as it is for most others (Figure 13). The material for sorting is fed onto "a fast-moving belt, to spread out the particles of diamond and gravel". Just as the belt begins to turn over its end pulley the pieces pass beneath a light-proof curtain, carefully set to barely clear the pieces. (This is critical.)

Scanning is done by focusing polarized light on the particles at the point where they pass under the curtain. The incidence angle is 39° above the horizontal, so that the particles are lighted only on the one side. Non-diamond pieces transmit practically no light to the opposite side of the curtain, whereas diamonds transmit light in all directions, including the opposite side of the curtain. Polarized lighting helps to reduce light scatter beyond the curtain, as does the angle at which the curtain is set. A photocell installed on the dark side of the curtain detects the light transmitted to its field of view. A signal is flashed to the electronic system, which amplifies it and after the correct delay triggers a deflection gate, thus separating the diamonds from associated material.

Gunsen's Sortex Limited reports that diamonds may be selectively removed from gravel when the feed is illuminated with polarized light and a crossed polarizer is placed in front of the phototube. Internal reflection from within the diamond depolarizes sufficient incident light to pass the crossed filter and so effect a signal from the phototube.

8. Agricultural Sorting Equipment (of possible interest in mineral dressing)

The New Zealand government recently announced the invention of a machine which sorts apples according to their colour. Each machine will cost about $1,500 when produced in quantity. The apples are evenly illuminated on a special belt and the amount of red or green reflection is measured on 23 apples per second.

Lemons are sorted in California, and there is one report of sorting tomatoes. Cherries and other fruits, as well as nuts, are handled by many commercial installations. Such equipment may be useful in mineral dressing.

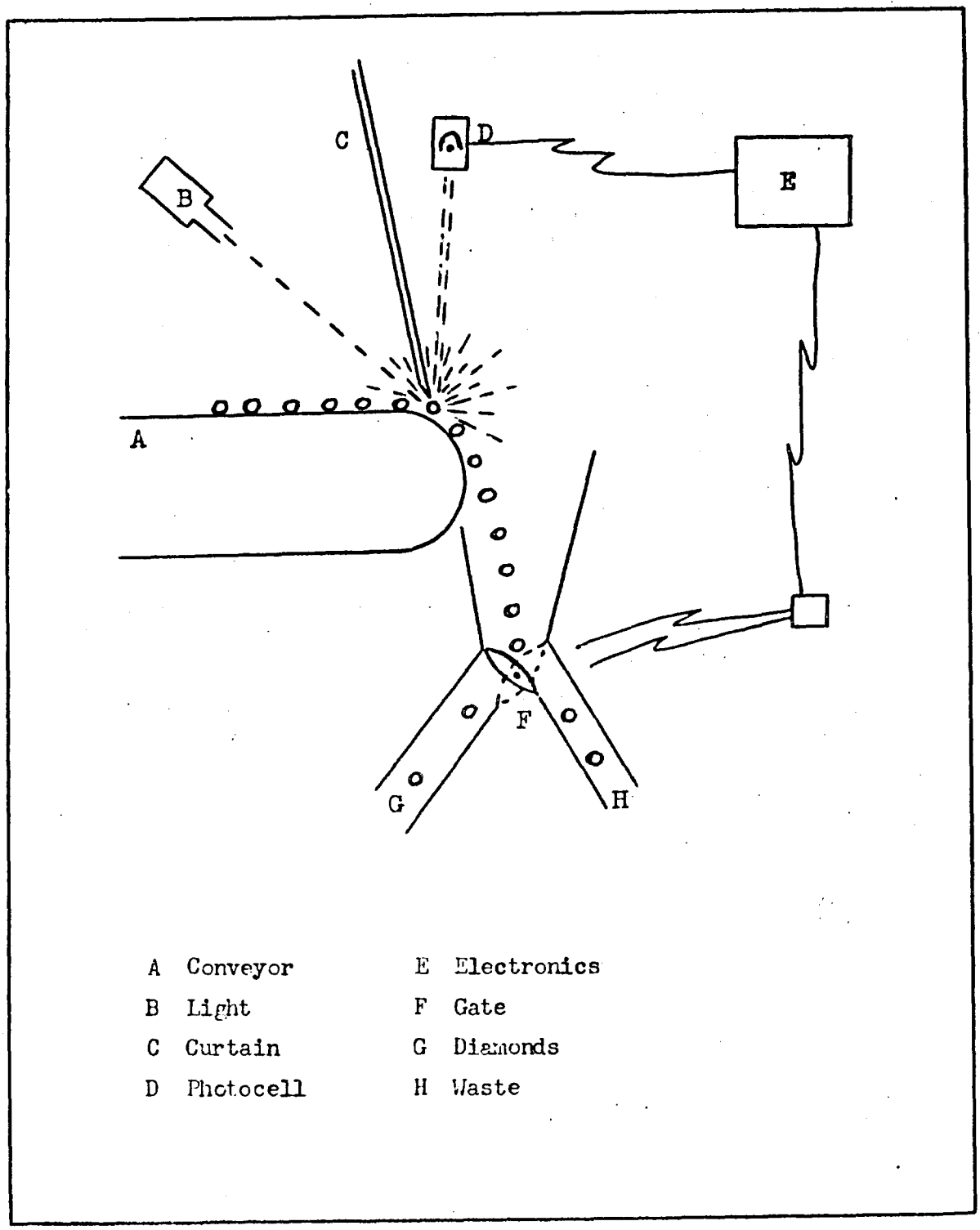


Figure 13. Optical diamond selector.

FORTHCOMING DEVELOPMENTS

Early correspondence with Gromax Inc. indicated that the firm was experimenting with X-ray, neutron bombardment, and other radiation devices. At the present time, however, the company advises that it will develop new equipment only by special arrangement.

The development of a device to detect and remove small diamonds from a slurry by X-ray scanning is reported to be under way at the Royal School of Mines in England. Also in the early stages of development is a laboratory photometric sorter for fine particles. Gunsen's Sortex Limited is working with the Royal School of Mines on this project. Particle size analysers such as the Dage, which will count 18,000 dust or droplet particles per minute and give a range of sizes, may be adaptable for this purpose.

Conductance in minerals has been employed in a special way by Eriez Magnetics, Erie, Penn. Eddy currents, induced in conducting minerals by changing, intense magnetic fields near their surface, cause deflection from a line of moving pieces to a greater or lesser degree, depending on their conductivity. Non-conducting particles are not deflected. Several minerals of differing conductivity may be separated from one assemblage, but minerals of low conductivity, or of equal conductivity, cannot be separated.

COST FACTORS

Information regarding installation and operating costs for electronic sorting equipment is difficult to obtain. There is as yet an insufficient background of experience to provide overall cost parameters. Variables such as commodity value, feed size, production rate, and number of sorting stages differ with each projected installation. Housing, power and labour costs vary from place to place.

At the present state of development, a manufacturer will usually offer to conduct test work in his own laboratory, and if the tests are successful, will present an overall installation proposal. Equipment may also be adapted or developed for a specific purpose, with a more indefinite cost involved.

A simple method for making an approximate estimate of the capital cost of an electronic sorting installation is to allow 1/3 of the overall cost of equipment it will replace. Thus if sorting will reduce the tonnage to be processed in later stages by 1/2, then the sorting installation will cost about 1/6

of the original projected cost of the plant, or the overall cost with sorting will be about 2/3 of the original projected cost. The actual cost will, of course, vary from this depending on the application, equipment purchased, and so on. Ore Sorters (Canada) Limited, with its high capacity machines, considers 1/5 of the cost of equipment replaced as reasonable for estimating installation costs. Lower-capacity devices on small-size feed might go as high as 1/2.

If a saleable product is the end point of a sorting operation, i.e., if the equipment is used to obtain a final concentration, the size of pieces sorted is usually small, and capacity would be low. The value of the commodity would play an important part in such an installation.

The figures in Table 1, provided by the Sortex Company of North America, give an indication of the costs involved in mineral sorting. A two-channel Sortex mineral machine has an initial cost of about $9,000.

As a comparison with the foregoing, the cost of operating Kelly and Hutter radiometric sorting equipment at the Eldorado Mining and Refining Company Beaverlodge operation is indicated to be 7 to 9 cents per ton mined, or 20 to 27 cents per ton of feed sorted.

EXAMPLES OF PHOTOMETRIC SORTING

Certain sorting equipment is specific, e.g. that for diamonds and radioactive materials. Some sensing systems, such as the Goodman X-ray, are just emerging in the practical sense. Other systems are still in the development stage, e.g. those using fluorescence and neutron bombardment. The methods based on visual light are usually designated as "optical" or "photometric", and are at present the most widely employed. The Sortex, Gromax, and Ore Sorters companies use both reflected and transmitted light in their photometric sorting equipment.

The Sortex and Ore Sorters companies have installations employing transmitted light which work satisfactorily on salt. Tests on a gold ore with the Ore Sorters equipment showed that a 90% reduction in bulk could be obtained with a recovery of 98% of the gold. The Gromax Selector, sorting dolomite from limestone, successfully eliminated 95% of the dolomite and reduced the magnesium oxide content from over 4.0% (well above the tolerance for portland cement) to 2.3% (well within the tolerance).

TABLE 1

Estimated Cost for 20 Sortex Machine Installation

DESIGNATION OF EXPENSES calculated on 3-shift operation, 300 days per year – 7,200 hours	Costs per Hour	Costs per Short Ton of product processed at hourly feeding rate of					
		1/4 TON	1/2 TON	1 TON	1½ TON	2 TONS	2½ TONS
	$	$	$	$	$	$	$
1. OPERATIONAL EXPENSES PER MACHINE (including Sortex Machine, Dust Collector, and Air Compressor)							
a) ELECTRICITY – based on cost of 3 cents per KWH	.060						
b) LAMPS – to be replaced every 200 working hours – each $0.29	.012						
c) SPARE PARTS – estimated at max. $60.00 yearly	.008						
TOTAL	.080	.320	.160	.080	.054	.040	.032
2. LABOR – Operator $2.50 per hour	.125	.500	.250	.125	.084	.063	.050
TOTAL	.205	.820	.410	.205	.138	.103	.082
3. DEPRECIATION OF MACHINE (including Sortex Machine, Dust Collector) – excluding costs of Conveying system, Construction, Building, and Insurance Approx. $9,000.00 per machine Over a 5-year period	.250	1.000	.500	.250	.167	.125	.100
TOTAL PER MACHINE	.455	1.820	.910	.455	.305	.228	.182

REMARKS:

1. OPERATIONAL EXPENSES. In case of operation of less than 7,200 hours per year, the increase of operational expenses is insignificant.

2. LABOR. In most cases, 1 man per shift can operate up to 50 Sortex Machines. Indicated costs for labor will therefore decrease accordingly. In case of an installation of less than 20 machines, only a short time per shift is required for supervision and maintenance.

3. DEPRECIATION. For an installation of less than twenty machines, initial purchase costs for machinery are slightly higher. If operation time is less than 7,200 hours per year, depreciation costs have to be increased accordingly. Depreciation calculated on write-off over five years only.

COST ESTIMATES ARE SUBJECT TO CHANGE WITHOUT NOTICE

AND, AS SUCH, CANNOT BE GUARANTEED

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TEST WORK AT THE MINES BRANCH

The Industrial Minerals Milling Section of the Canadian Department of Mines and Technical Surveys has been working since early in 1962 with a Sortex Model G3S machine. This model was designed for the sorting of foodstuffs such as coffee, peas, and nuts. It is a little more complex than the mineral machine described earlier and is limited to sorting pieces less than 5/8 in. (16 mm) in size. The operating principle is the same as that for the mineral machine. Considerable research has been done on the association of background reflectance with mineral reflectance, development of backgrounds for specific separations, statistics of the sorting obtained and other factors. At the same time, separations have been worked out and demonstrated on a variety of minerals. Several of these have been selected to illustrate the type of beneficiation to which photometric sorting may be applied.

1. Barite: The size of feed was -5/8 +3/8 in. (-16 +9.6 mm), ideal for colour sorting. The barite was white to buff; waste, consisting of quartz and siliceous material with some barite, varied from yellow to greenish blue to brown. Barite crumbles and becomes dusty with handling, but washing prior to making the separation was effective in removing dust.

One pass through the machine gave a rough separation of the lighter shades (barite) from the darker shades (waste). The lighter shades were then rerun to separate white from buff barite. Thus, in two passes through the machine, the feed was separated into white barite, buff barite, and waste.

Table 2 shows that 45% of the barite was recovered as a high-grade product, and an additional 31% as material suitable for use in oil-well drilling mud.

TABLE 2

Beneficiation of Barite

Fraction	Weight %	$BaSO_4$ %	Sp gr	Recov. %	Brightness *
Feed	100.0	64.9			
White barite	29.2	95.2	4.40	44.9	94.5%
Buff barite	21.1	91.1	4.26	31.0	
Waste	49.7	30.1	3.10	24.1	
Calc eed	100.0	61.9		100.0	

*Compared with magnesium carbonate as 100%.

2. Talc: The sample was dark green-grey and composed largely of chlorite or mixed pieces of chlorite and talc. It contained some pale green to white pieces of comparatively pure talc. Being soft, the feed required washing prior to testing. Although several sized fractions were processed, the example in Table 3 refers only to the results on -1/2 +1/4 in. (-12.7 +6.2 mm) material.

It was possible to isolate most of the lighter-coloured pieces with one pass through the machine. In a second pass, with this light-coloured fraction as feed, the purer talc was separated from mixed pieces.

TABLE 3

Beneficiation of Talc

Fraction	Weight %	Brightness*
Feed	100.0	79.0%
Waste	74.8	
Mixed	11.2	
Talc	14.0	89.5%

*Compared with magnesium carbonate as 100%.

3. Ilmenite: The bulk of the ilmenite was dark grey to black, although some was rust-stained. The contaminant was greenish-grey feldspar with some light-grey to white incrustrations and inclusions. It was present in small amounts, but in sufficient quantity to give the mixture a specific gravity of 4.4, whereas a minimum of 4.5 was desired. The testing of several sized fractions was necessary, but only the -3 +4 mesh (-6.7 +4.8 mm) results (Table 4) are given as an illustration.

It was found that most of the contaminant could be removed by one pass through the machine. As a matter of interest only, a second pass was made in which most of the stained particles were separated from black ilmenite.

TABLE 4

Beneficiation of Ilmenite

Fraction	Weight %	Sp gr
Feed	100.0	4.39
Waste	7.2	3.98
Rusted	5.5	4.42
Grey to black	87.3	4.56
Product	92.8	4.55

4. Feldspar: Two samples of material designated as "quarry waste" were tested. One contained approximately 90% feldspar and the other approximately 70%. The feldspar was nearly white, with a slight grey or bluish cast. The contaminants included white translucent quartz, smoky quartz, discoloured feldspar, and minor dark constituents. Various screen fractions were again processed separately; the -1/2 in. +3 mesh (-12.7 +6.7 mm) of the lower-grade material has been chosen as an example of the separation achieved (Table 5).

Because this separation involved shades of white with some smoky pieces, it presented a somewhat more difficult problem. Most of the dark and discoloured pieces were eliminated in one pass through the machine, but a second run with a new background and new control settings was needed to separate the quartz and feldspar. A product of good quality was obtained with a minor loss of feldspar. Table 6 gives analyses of feed and product for comparison.

TABLE 5

Beneficiation of Feldspar

Fraction	Weight %	Minerals
Feed	100.0	Feldspar, quartz, minor dark minerals.
First reject	26.0	Dark quartz, discoloured feldspar, dark minerals.
Second reject	8.0	Translucent quartz, some feldspar.
Product	66.0	Feldspar.

TABLE 6

Analyses of Feldspar Feed and Product
(%)

Determined	Feed	Product
SiO_2	68.8	66.0
Al_2O_3	16.9	18.9
Fe_2O_3	0.128	0.015
Na_2O	2.3	2.0
K_2O	11.4	12.6
CaO	0.2	0.2
MgO	Tr	Tr
LOI	0.2	0.2

5. Calcite: The sample was composed of material ranging in size from about 2 in. to dust. There appeared to be a sufficient number of pieces of relatively clean calcite in each size fraction to favour photometric separation. It was desired to eliminate a dark impurity described as serpentinic hornblende gneiss and retain a product suitable for use as a high-grade industrial filler.

To demonstrate the applicability of photometric sorting for this purpose, -1/2 +3/8 in. (-1.27 +0.95 cm) and -3/8 +4 mesh (-0.95 +0.48 cm) fractions were removed from the sample. With the larger fraction, most of the dark or blemished material was removed in one pass through the equipment, and material with small spots or flecks was removed in a second run. Similar results were obtained with the smaller size fraction, although the yield was less.

TABLE 7

Beneficiation of Calcite

Fraction	Weight %	Brightness %*	Remarks
Feed (-1/2 +3/8)	100.0		
1st reject	15.5		Dark material.
2nd reject	18.1		Spotted calcite.
Product	66.4	98.5	Calcite.
Feed (-3/8 +4 m)	100.0		
1st reject	21.2		Dark material.
2nd reject	31.4		Spotted calcite.
Product	47.4	98.7	Calcite.

*Compared with magnesium carbonate as 100%.

6. Silicon Carbide: This compound had physical properties which made sorting difficult, viz., 1) the small size and elongate shape of the particles of silicon carbide, 2) its crystalline nature with mirror-like facets, and 3) the close similarity in light reflectance between particles of different colour. All of these characteristics tend to reduce the possibility of a successful selective photometric sorting operation. Some elongate particles may pass through the scanning area with only the ends facing the sensing points, thus presenting very small surfaces for sensing. Highlights cause the photocells to "misread" -- in 4 out of 5 cases the equipment will give more accurate separations on dull material than on material with bright crystal faces. Finally, since the photocells detect the difference between light reflected from a mineral particle and from the background, some difference in the composition of the light reflected from contrasting mineral particles is necessary; in this case, the wave length vs reflectance curves for the three colours of mineral particle involved matched very closely.

The size of feed particles ranged from about 6 mesh (3.4 mm) to dust. Three colours were represented: green, blue-black, and straw. To the eye, the straw-coloured particles were much easier to distinguish from the black and green than were the green and the black from each other.

The feed was first separated into a series of closely sized fractions. Practically no straw-coloured particles were present in the +8 (2.4 mm) fraction. A good separation of black from green was made in one run, and a second run, or cleaning step, isolated the remaining black particles.

With the second, -8 +10 mesh (-2.4 +2.0 mm) fraction, it was found possible to isolate the straw-coloured particles in one run followed by a cleaning step. After changing background and control settings, black could also be separated from green in one run and one cleaning step.

The third fraction, -10 +14 mesh (-2.0 +1.4 mm), presented more difficulty. With such small particles, the air ejection system was found to remove more than one piece at a time, despite slow feeding and less than 1 psi air pressure. Nevertheless, one run and a cleaning step isolated most of the black, together with a small content of the straw-coloured. A second run followed by two cleaning steps, using a different background and control settings, isolated most of the straw-coloured (with a small content of black and green) from the green (with a small content of black and straw).

Work with the -14 +20 mesh (-1.4 +0.8 mm) fraction resulted in a general separation into three shades of mixed particles. The rate of separation with this feed was very low.

Capacity of the sorter decreases rapidly with feed size from approximately 200 lb/hr per channel on -6 +8 mesh (-3.4 +2.4 mm) to about 1 lb/hr per channel on -14 +20 mesh (-1.4 +0.8 mm).

7. Pollucite: The objective in this case was pre-concentration of the pollucite. The feed consisted of a mixture of greenish sericite, light-buff feldspar, light-grey siliceous material and several white minerals including pollucite (a caesium mineral). Isolation of the white material would at least double the concentration of pollucite.

The work was carried out on several screen fractions, of which the -1/2 in. +3 mesh (-12.7 +6.7 mm) portion was chosen as an example. Most of the greenish sericite and grey siliceous material was removed in one run. Removal of the light-buff feldspar and the lighter-grey siliceous particles proved more difficult, requiring two additional runs with different background and control settings.

TABLE 8

Beneficiation of Pollucite

Fraction	Weight %	Pollucite %
Feed	100.0	25
First reject	50.5	
Second reject	9.5	
Third reject	2.2	
Product	37.8	53

8. Multicoloured Chips: A segment of the minerals industry to which optical sorting may well make an important contribution is the growing trade in terrazzo and exposed aggregate. The size of pieces usually employed is convenient for optical sorting, and the objective is a blend of colours pleasing to the eye. Thus, sorting may be used to isolate pieces of a distinct colour for later blending with other suitably coloured pieces, or to separate pieces composed of mixed colours into a number of pleasing variations.

A separation of quartzite chips, ranging from red through brown, buff, cream, grey to white, and approximately 1/2 in. (12.7 mm) in size, has been chosen to illustrate sorting of such material. The chips were of mixed shades excepting the white, which were evenly coloured.

One run through the equipment separated the overall dark from the overall light shades. A second run with the light shades as feed produced a white product and a mixed light-shade product, and another run separated the dark shades into two products; thus a series of four distinct shades was produced. A more complicated approach, involving cleaning steps, separated the chips into a series of six shades.

EXISTING AND PROPOSED COMMERCIAL SORTING OPERATIONS

The following information was provided by Gunson's Sortex Limited, London, England.

1) Rock Salt: A well-established Canadian commercial operation removes anhydrite from salt in two stages. The feed ranges in size from 5/8 to 1/2 in. (15 to 12 mm) and is 60% salt. Feed rate to the first stage is 2 tons/hr through two channels, and to the second stage is 1.3 tons/hr through two channels. The second machine acts as a cleaner to remove undesirable pieces which were missed in the high-speed roughing. The final product is 99.98% soluble and represents a recovery of 70%.

2) Gypsum: An operation in England separates gypsum from red and green marl. The feed is divided into two sizes, each of which goes to a separate machine. One machine, receiving 3/4 to 3/8 in. (19 to 9.6 mm) feed, handles 1.2 tons/hr with two channels and the other, receiving 3/8 to 1/4 in. (9.6 to 6.2 mm) feed, handles 0.5 tons/hr.

3) Limestone: White limestone 3/4 to 1/2 in. (19 to 12.7 mm) in size can be sorted by passing it through two machines in series, both handling 1.6 tons/hr of feed through two channels. The feed contains 30.8% CaO, and 76% by weight is recovered at a grade of 43.8% CaO.

4) Talc: Biotite mica can be removed from bright tremolite-talc particles of 3/4 to 1/2 in. (20 to 13 mm) size, with a single two-channel machine operating at 1.5 tons/hr. A product representing 77% by weight of the feed is recovered. Fired tile made from this product has a reflectivity of 90.3% compared with magnesium carbonate.

5) Chalk: Dark flint can be separated from chalk in a particle size range of 3/4 to 1/2 in. (19 to 13 mm) with a single two-channel machine operating at 0.8 tons/hr. The feed contains 1.7% flint and the product 0.46%. The recovery of chalk is 97.5%.

6) Lepidolite: Dark-purple lepidolite of good quality can be isolated from lighter-coloured lower grades in 1/2 to 3/8 in. (12.7 to 9.6 mm) size material with one two-channel machine operating at 1.0 tons/hr. The feed contains 2.96% LiO_2, of which 76.2% is recoverable at a grade of 3.54% LiO_2.

7) Quartz: Iron-stained particles can be removed from quartz in 3/4 to 3/8 in. (20 to 9.6 mm) size feed with one two-channel machine handling 1.2 tons/hr. About 32% of the feed particles are stained. It is possible to recover 60.5% of the feed and lower the content of pieces with minor staining to 1.4%.

8) Gold Ore: A successful test run on South African gold ore in the size range 1/2 to 3/8 in. (12.6 to 9.6 mm) was made with two two-channel machines in series, the second recovering material not removed by the first. The first machine was fed at 0.6 tons/hr and concentrated 85.8% of the gold in 44% of the original weight; the product assayed 23.6 ppm gold. The second machine received feed at the rate of 0.3 tons/hr and recovered an additional 12.9% of the gold in 21.8% of the original weight; its product assayed 7.1 ppm gold. Thus, 34.2% of the original feed was discarded with a loss of 1.3% of the gold content.

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