

A Survey of the Methods Available for the Mineralogical Examination of Material in Connection with Mineral Dressing

K. F. G. Hosking, M.Sc., A.M.I.M.M.

Introduction

IN this paper the author has aimed at bringing to the notice of the reader those methods of mineralogical examination which have been found to be of use in connection with mineral dressing problems. Clearly, in the limited space available, it has been impossible to give complete descriptions of the many methods, but the end will have been achieved if the major advantages and disadvantages of each method are apparent, for then, he who has had his interest whetted will be able to seek further information from the authoritative literature compiled in a bibliography at the end.

At the outset it must be stressed that although some of the methods possess somewhat awe-inspiring names, yet on the whole, the techniques involved are easily acquired and a considerable proportion of the necessary apparatus is inexpensive.

It must also be stated that this paper does not deal with mineral dressing tests such as the amenability of the ore to flotation, gravity treatment, cyanidation, electro-static separation, etc.

The value of mineralogical examination in connection with mineral dressing.

Efficient mineral dressing requires information gained by mineralogical examination during the four following stages :—

1. The stage immediately following the discovery of the ore-body.
2. The laboratory stage of flow-sheet development.
3. The pilot-mill stage.
4. The stage of operation of the mill proper.

As will be apparent later, whilst some of the methods described are applicable to mineralogical examination at all stages, others are pre-eminently suited to the examination of material encountered at a particular stage.

STAGE I

When what appears to be a potentially valuable mineral deposit has been discovered, it is immediately necessary to take true samples of it and to discover the following :—

1. The elements present.
2. The minerals present.
3. The percentages of economically valuable elements (e.g. gold, lead).
4. The percentages of economically valuable compounds (e.g. baryte, fluorite).
5. The spatial relationships of the various elements present.
6. The spatial relationships of the various minerals present.
7. The "size" of the mineral components, and degree of unlocking.

1. The elements present.

Economically it is a sane policy to discover at the outset the elements present in an ore for the following reasons :—

(i) Their presence may immediately indicate certain precautions to be taken in the dressing of the ore. For example, the presence of tellurium in a gold ore immediately suggests that gold tellurides may be present which will require a special cyanidation treatment.

(ii) Although the prime interest in a deposit might be centred about one element, if the percentage of that element in the deposit is not particularly high, the mining venture might still be assured of success by the presence of a second valuable element. Thus the presence of silver in galena might considerably enhance the value of a predominantly lead ore-body. The presence of scheelite in a gold mine might greatly increase the fortunes of the mine, and the presence of gold in pyrite might make, what at first sight appears to be a valueless deposit, a highly valuable one.

2. The minerals present.

(i) Sometimes only certain naturally occurring compounds of a given element are of economic value. Thus celsian, which contains barium, is of no value, whilst baryte is of considerable value.

(ii) The problems of making a concentrate of a given element vary with the mineral in which it occurs and also with the associated minerals. The problems involved in making a copper concentrate in the form of chalcopyrite are very different from those involved in making a copper concentrate in the form of malachite.

3. & 4. The percentages of economically valuable elements and minerals.

Having decided which elements or compounds are of economic value in the deposit it is necessary at the outset to establish whether or not they are present in sufficient quantity to warrant further expenditure in development of the mine, mill, etc.

5. The spatial relationships of the various elements present.

To know which elements are intimately associated in a given ore, i.e. to know which elements occur in a given mineral, may greatly facilitate the mineral dressing problems involved in the production of a concentrate. Thus, if in an argentiferous complex sulphide ore it could be shown that the silver was entirely confined to the jamesonite, then, in order to make a silver concentrate, it would simply be necessary to make a jamesonite concentrate.

6. & 7. The spatial relationships of the various minerals present ; the "sizes" of the various components and degree of unlocking.

How minerals are related to each other in a given ore is very important from a mineral dresser's point of view. If, for example, a given ore was known to consist of discrete crystals of cassiterite and chalcopyrite set in a quartz matrix, and if the size ranges of the crystals were known, then the problems of dressing the ore would be, in essence, fairly simple, as the amount of crushing necessary to liberate the heavy minerals could be easily determined, the quartz could be removed by gravitational methods and the chalcopyrite separated from the cassiterite by flotation. If, on the other hand, the cassiterite had been deposited before the chalcopyrite, and furthermore, if it had been shattered and then cemented by the chalcopyrite, then anything like a clean separation of the chalcopyrite from the cassiterite by ordinary mineral dressing methods might well be economically, if not practically impossible.

4. Methods of mineralogical examination suitable for Stage I material.

Bearing in mind the fact that large specimens of ore as well as crushed samples are available during this stage, the following methods are believed to be amongst the most valuable :—

1. Examination of representative portions of the ore and of picked minerals by methods of qualitative and quantitative chemical analysis.
2. Spectrograph analysis of representative fractions of the ore and of picked minerals.
3. X-ray analysis of complex minerals or of minerals only occurring in comparatively small amounts.
4. Differential thermal analysis of certain complex minerals, especially members of the clay group.
5. Fluorescent tests.
6. Tests for radio-active minerals by means of the Geiger counter, etc.
7. Microscopic examination of thin sections of the ore and of crushed portions of it by transmitted light in order to determine the characteristics of the transparent minerals.
8. Examination of polished sections of the ore, largely to determine the characteristics of the opaque minerals, by a combination of some of the following methods :—
 - (a) Examination under an ore-microscope by reflected light.
 - (b) Partial determination of minerals by measuring their reflectivity.
 - (c) Partial determination of minerals by measuring their hardness.
 - (d) Partial determination of minerals by etch reactions.
 - (e) Partial determination of minerals by micro-chemical methods.
 - (f) Partial determination of minerals by chromographic contact printing.

Clearly, which of the methods above are adopted, will depend upon the nature of the ore, the apparatus available and the skill (and to some extent preferences) of the investigators.

1. Chemical analysis.

At the outset it must be stated that regardless of the methods used to establish the identities of the various elements and minerals present in an ore-body it will always be desirable and usually necessary to establish the percentages of the important elements present by the classical methods of quantitative chemical analysis. Only comparatively rarely are other methods superior. The determination of the normally very small quantities of such elements as gallium, indium and scandium which are found in some ores is best carried out by means of the spectrograph, whilst small quantities of zinc are best determined in many instances by means of the polarigraph.

A straight-forward qualitative analysis carried out on a macro or semi-micro scale on a sample of the ore and/or each of the major components, will often establish many of the important elements present, but the procedure is likely to occupy a considerable length of time. Equivalent information is generally obtained much more rapidly if blow-pipe tests, spot, drop and micro-chemical tests are carried out on the various components whose identities have previously been at least partially established or hinted at by consideration of such characteristics as colour, hardness, streak and specific gravity.

If only about 40 mg. of a given component are at hand, it is possible to obtain its specific gravity reasonably accurately by any one of several simple pieces of apparatus now available. Once the specific gravity of a mineral has been determined, this, combined with the hardness and streak characteristics, enable the identity of the mineral, with the help of tables, either to be established absolutely, or to be limited to a small number of possibilities. In the latter event, one or two spot tests will frequently establish which of the possibilities is the correct one.

That this method of attack is much quicker and simpler than the conventional methods of analysis is further substantiated by the fact that many of the elements commonly encountered in ores, e.g. titanium, vanadium, tungsten and uranium, do not fit into any simple scheme of analysis.

It might also be added that ore analyses carried out by chemists without some knowledge of mineralogy can sometimes be

misleading. Thus, the author once had occasion to examine a sample of Malayan tin ore which, according to the accompanying analysis, contained a certain amount of lead. On examination, the lead was found to be duck shot. On another occasion, an examination of a parcel of ore which was accompanied by a partial analysis purporting to give the percentages of the important constituents, he was struck by the numerous flakes of molybdenite present, but the analyst, having clearly no knowledge of mineralogy, had made no mention of molybdenum.

Spot tests are conveniently carried out by bringing a small portion of the substance under examination into solution by warming it with a drop or two of attacking reagent on a microscopic slide over a microflame. Having obtained a solution, several methods of testing it are available. Small fragments of solid reagent may be added to it or a drop of liquid reagent merged with it, and any resulting crystals examined under the microscope. Alternatively, the liquid may be transferred by means of a capillary tube to a depression on a spot plate or to a piece of spot-reaction paper and there mixed with suitable reagents and any colour development noted. Crystal characteristics seen in the first method and colours developed in the other two methods, enable deductions of a quantitative nature to be drawn.

When the mineral requires a preliminary fusion, this is best carried out in a wire loop (usually platinum or silver), from whence the fused product may be transferred to a slide or spot plate depression for attack and addition of "identification" reagents.

2. Spectrographic analysis.

In the hands of an experienced operator the spectrograph permits of rapid identification of the majority of elements present in a sample of ore, and the apparatus will also enable rapid estimations of the quantities of various elements present in minor amounts. However, such an instrument is very expensive and not available on many mining camps. A much simpler apparatus capable of giving very rapidly a great deal of valuable qualitative information can be set up by utilising an arc in connection with a simple bunsen spectroscope such as is found in most centres of higher information. The setting up of this apparatus is not expensive and the technique

required for using it efficiently is rapidly attained. Several prominent workers have emphasised the marked superiority of this method of visual arc spectroscopic detection of elements over the usual blow-pipe and wet reagent tests. It is, in the opinion of the author, a piece of apparatus that could be highly recommended to any progressive mining body.

3. X-ray analysis.

X-ray analysis is the best method that exists for confirming the identity of a given mineral, especially when the mineral in question is either highly complex and/or available in small quantity. The apparatus, however, is very expensive and a highly skilled person is necessary to maintain and operate it.

The method depends on the fact that when a narrow beam of monochromatic X-rays impinge upon a small sample of a powdered mineral, diffraction takes place in a manner which is absolutely characteristic of the mineral species. If the diffracted beams are permitted to impinge upon a photographic film and the film is subsequently developed, a particular pattern termed a powder pattern will be seen.

In practice, the powder pattern of the unknown mineral is compared with powder patterns of known minerals, and the identity of the mineral under examination becomes known when its powder pattern exactly resembles that of a known mineral.

4. Differential thermal analysis.

This method depends on the fact that when many minerals are heated under carefully controlled conditions they exhibit exothermic or endothermic characteristics at certain definite temperatures. Curves indicating these peculiarities are prepared automatically and mineral identification simply depends on the finding of a curve of a known mineral which corresponds exactly with that of the unknown.

The method is of special value in the identification of members of the clay group of minerals, but the procedure is laborious and the apparatus fairly expensive to construct.

5. Fluorescent tests.

Examination of the ore under both short and long wave ultra-

violet light is quite likely to produce valuable information. In more than one gold mine the presence of valuable quantities of scheelite has passed unnoticed for a considerable period of time, a state of affairs which could not have happened had an examination of the ore under short wave ultra-violet light been carried out, as the mineral, depending upon its state of purity, fluoresces blue, white or yellow. Many of the secondary uranium minerals, e.g. autunite, zippaieite, and rutherfordine fluoresce under both long and short wave ultra-violet light, whilst the presence of uranium in any non-fluorescing mineral may be indicated by the following fluorescence test :—Place in a flat-bottomed nickel dish, about three inches in diameter, sufficient of a mixture, composed by weight of 2% sodium bisulphate, 5% sodium fluoride and 93% fusion mixture, to cover the bottom when melted. Heat the mixture until it has melted, then tip the dish to remove all but a thin film of the flux. Allow the flux to cool, then place the fragments under test on it and reheat until the flux melts, then continue heating for about 30 seconds and cool. On examination in the dark, under long and short wave ultra-violet light, fragments containing uranium will be surrounded by an intense yellow halo. Under similar conditions Nigerian columbite is surrounded by a very pale yellow halo.

The presence of mercury in an ore may be shown by heating a sample between a radiating ultra-violet lamp and a willemite screen. If mercury is present, black "smoke" appears on the green fluorescing screen.

Locally, a given mineral which does not normally fluoresce, may exhibit fluorescent properties and this enables it to be easily identified during any stage of mineral dressing. Furthermore, if a fluorescent mineral is sufficiently massive, a concentrate of it may be made in a mill by hand-picking it from a belt irradiated by ultra-violet light.

6. Tests for radio-active minerals.

Whenever there is a likelihood of radio-active minerals being present in an ore, then a Geiger-Muller, or allied type of counter, is indispensable at all stages of work associated with the mining of the ore and the development and running of the mill, as this piece of electronic apparatus will not only rapidly and easily detect the

presence of radio-active material, but it may also be used for obtaining rapid, but fairly accurate, quantitative data.

Photographic techniques are of considerable value, not only because they afford a cheap but somewhat prolonged method of detecting radio-active minerals in ores, but also because they afford a means of locating the exact site of radio-active components within a given specimen of ore and of providing a permanent record of this information.

The method generally adopted is to grind a flat surface on the specimen, then to place it on a thin piece of paper laid on top of a photographic plate. The assembly is left undisturbed in a dark room for several days and on developing the radio-active areas will appear dark on the negative.

By comparing the intensity of the image produced by the specimen under examination with that due to a specimen of known uranium content which has undergone identical treatment, some idea of the radio-activity of the former may be arrived at. It is well to note that both the Ilford and Kodak companies now produce special plates for this purpose which produce less diffuse images than do ordinary plates.

The spintharoscope and gold leaf electroscope will both detect radio-active substances and the latter may be used for quantitative estimations, but both these have been superseded by the Geiger counter.

The best chemical test for small quantities of uranium is carried out as follows :—A drop or two of a nitric acid solution of the ore is placed about one inch from the top of a piece of Whatman No. 1 filter paper two inches wide and about fourteen inches long. The spot is allowed to dry and then the top end of the paper is placed in a "tank" containing ethyl acetate to which has been added a little nitric acid. The strip is arranged to hang vertically in a covered gas jar. The solvent diffuses over the spot and carries uranyl ions with it, leaving the other ions in the spot area. After the solvent has moved two or three inches beyond the spot, the strip is removed and allowed to dry. After drying it is sprayed with an aqueous solution of potassium ferrocyanide, when the presence of uranium is indicated by the development of a brown band just behind the solvent front.

7. Microscopic examination of thin sections and of crushed samples.

When the ore in question contains a fair amount of transparent material a great deal of important information regarding the nature, abundance, size and spatial relationships of the various components may be obtained by examining a thin section of it in transmitted light under a petrological microscope. It is, however, often useful from a diagnostic point of view, to crush a representative portion of the ore, and by one or more of the methods noted below, to isolate the various mineral components, and then to determine the identity of the more obscure transparent species by determining under the microscope their refractive indices by means of refractive index liquids, together with such optical data as the nature and sign of any interference figures that may be apparent. Given this data, diagnosis, with the aid of such excellent tables as those due to Larsen and Berman, is comparatively easy.

This last method is highly valuable for the determination of transparent mineral grains encountered during any stage of mineral dressing and especially when those grains are of a complex nature and not readily identified by the combination of simpler optical and chemical tests.

In order to carry out refractive index determinations adequately, it is necessary to have available a refractometer (the Bellingham and Stanley model is one of the best), in order to check the refractive indices of the liquids used, but unfortunately this apparatus is somewhat expensive. It must be added, however, that even when a set of refractive index liquids and a refractometer are not available, and when no easy method of preparing a thin section is at hand, a great deal of useful information may be obtained about the type of ore under consideration by crushing some of it by means of a steel pestle and mortar, or even with a hammer, and examining some of the product under any kind of microscope, having first immersed the grains in any colourless liquid at hand.

8. Examination of a polished section of the ore.

If the ore consists of opaque minerals, or if the opaque minerals present are likely to be of economic importance, a polished surface should be prepared and examined under an ore microscope in

ordinary and polarised reflected light. By this method a considerable number of minerals can be determined, inclusions and other spatial relationships of the components noted, and sizes of crystals arrived at.

However, recognition by the above method is not always conclusive and therefore several other techniques have been devised to help the investigator.

Reflectivity, defined as the ratio of the intensity of light reflected from a given surface to the intensity of light vertically incident on that surface, is approximately constant for any given opaque mineral and is therefore of some diagnostic value. The reflectivity "constant" is obtained by examination of a carefully polished surface by means of an ore microscope fitted with special reflectivity measuring devices. Considerable experience is necessary to obtain good results and the method suffers from a further drawback in that the reflectivity values for two given minerals may be very nearly the same, and therefore a given reflectivity value is not of itself sufficient to permit of absolute mineral identification.

The approximate hardness obtained by observing the groove formed when relative movement takes place between a hard point and the polished surface of a mineral under carefully controlled conditions is an aid to identification. To obtain this observation, either a hand-held needle of standard hardness, weight and shape can be used, or a more elaborate, diamond-pointed apparatus such as the Talmage hardness machine.

The process of etching, long employed successfully by the metallographic investigator, has been employed by the mineralographic investigator with equal success. In this method a drop of one of a small number of etch reagents (aqua regia, nitric acid, ferric chloride, etc.) is applied to the polished section under the microscope and after a given time the reagent is washed off and the results of etching noted. Etching is a considerable aid to mineral identification, but unfortunately a given mineral species does not always react to a given reagent in a constant manner and furthermore, misleading results are frequently obtained when the etch reagent covers more than one mineral.

By means of a hard needle, a small amount of powder may be

removed from a mineral appearing in a polished section under the microscope and this powder may be transferred to a microscope slide and examined by the micro-chemical methods described earlier. This method is very useful, but has the disadvantage in that a new surface must be prepared before further optical work can be carried out.

Probably one of the most useful techniques in connection with the examination of opaque and transparent minerals in a polished section is that of chromographic contact printing. The method, however, is only suitable for the examination of those minerals which can be attacked by liquid reagents at room temperature, with, in some instances, the help of an electric current. In essence the method consists of pressing onto the polished section a piece of gelatine-coated paper impregnated with a reagent capable of bringing a given element into solution. The liberated element migrates into the gelatine layer and is trapped there. On removing the paper and treating it with a suitable developing reagent a fairly accurate distribution pattern of the element in the polished section is obtained. By varying the attacking and developing reagents a series of distribution patterns of many of the elements in a given section can be obtained and by comparing these with each other and with the section itself or a photomicrograph of it, it is frequently possible to obtain most of the information necessary for the development of a flow-sheet.

If the section under examination is largely composed of conducting material then by passing a current through the system during printing either cations or anions, depending on the current direction, will migrate more rapidly and easily into the gelatine film. This method, known as electrographic contact printing, is of value in that certain minerals which do not yield prints of their ions by the simple pressure method, do so with this method. Furthermore, electrographic contact prints are sharper than those obtained by the simple pressure method. However, the simple pressure method is of wider application as many minerals are, for the purposes of this method, non-conducting.

It is convenient to mention here that ore fragments may be mounted in bakelite, polished and printed by means of the simple pressure method and if it is desired to print conducting grains by

means of the electrographic method then they may be mounted in a conducting medium consisting of bakelite and carbon. The use of bakelite has a disadvantage in that a press is necessary, but several of the easily manipulated thermo-setting plastics can be used in its stead and further work will doubtless show that suitable conducting plastics of this nature can be prepared. The most valuable paper to date on this subject is by Williams and Nakhla (1951).

STAGES 2, 3 and 4.

During the laboratory stage, pilot mill stage and full scale mill operating stage the problems of mineral examination are very similar in that they largely involve the examination of ore fragments ranging in size from those obtained from jigs down to the extremely small particles such as are encountered during flotation and in tailings. Generally, then, a method of mineral examination suited for stage 2, will be equally suitable for stages 3 and 4. However, during the operation of a full-scale mill the minerals occurring in any intermediate product or final product will be largely or entirely known, and rapid methods of determining the relative amount of each of these minerals present at any given stage in concentration assume overwhelming importance.

During the stages of laboratory experimentation and of the pilot-mill changes in operation may frequently be made so that a variety of different mineral combinations may be produced, and this, combined with the fact that the ore will still be somewhat unfamiliar, calls for a considerable amount of rapid identification as well as rapid quantitative estimation.

During the early stages mineralogical investigation in connection with such topics as the degree of liberation of the ore-minerals from the gangue by grinding and the relative efficiencies of different methods of flotation will be constantly in demand.

The laboratory separation of mineral grains in connection with mineralogical examination

For various reasons it may be desirable or necessary to make a complete, or reasonably complete, separation of the various species of mineral grain in a product prior to mineralogical, chemical or beneficiation tests. It may also sometimes be necessary to separate the components into size groups.

Many of the methods of separating components on a laboratory scale are similar to those used in the mill on a much larger scale and therefore the processes utilised in making laboratory separations often serve the added purpose of supplying data which may be of considerable value in the dressing of the ore.

To bring about the required degree of separation, either one or more of the methods mentioned below may have to be used. The choice of method, or methods, will depend initially on how much mineralogical information about the ore is available.

The methods generally used can be divided into the following six groups and the major methods falling within each classes, together with their advantages and disadvantages, are discussed below.

- Class 1. Methods depending on specific gravity differences of the minerals.
- Class 2. Methods depending on magnetic and conducting properties of minerals.
- Class 3. Electro-static separation methods.
- Class 4. Chemical methods.
- Class 5. Hand sorting.
- Class 6. Sieving.

Class 1.

(a) Hydraulic methods.

Both panning and vanning are methods so well known and so well tried for separating heavy fractions from light that little more need be mentioned about them. It is worth while noting, however, that a vanning assay often gives a far better idea of the recovery to be expected in practice by gravitational methods, than does a chemical assay and is an accurate method as long as the purity of the vanning concentrate is also determined. This is specially true in connection with most tin ores.

Far superior to either the pan or the vanning shovel is the mechanical device known as the Haultain Superpanner which is capable of making excellent gravity separations from closely sized fractions over the range 65 mesh to 14 microns. It has been used considerably for determining the quantity of free gold in tailings, but has, of course, very much wider application.

(b) Vibration methods.

If a small sample of particles in the range $-60 + 90$ mesh is placed on a glazed paper which is slowly rotated with one hand and tapped by a pencil held in the other, it is possible, with a little practice, to make a reasonably good separation of "heavy" from "light" grains.

A rather more elaborate method, which works quite well, is to clamp a metal plate at one corner and to place on it about 10g. of the sample under examination. If then, a vibrating tuning fork, whose frequency is equivalent to the period of vibration of the plate, is so placed that it can strike the plate, the vibrations set up cause a separation of components according to their differences in specific gravity.

(c) Heavy media methods.

These well known methods are based on the fact that if a mineral fragment is placed in a liquid or melt it will either sink or float, depending on whether or not its specific gravity is greater, or less than that of the medium in which it has been placed.

Suitable liquids have been known for a considerable time with specific gravities as high as 3.3 and therefore they could be used for separating an aggregate of mineral grains into a "heavy" and "light" fraction. They could also be used for separating minerals with specific gravities less than 3.3 into numerous groups. For making cuts at higher specific gravity levels, melts were used, but recently high specific gravity suspensions of metals (and alloys?) in liquids have been made generally available in America which are likely to render the use of melts obsolete.

Class 2.

The bar magnet is very useful for extracting magnetite and pyrrhotite grains and also magnetic iron compounds produced during the roasting of certain ores. It is also of use in removing fragments of tramp iron.

A good electro-magnet fitted with adjustable pole-pieces and having incorporated in its circuit a variable resistance is an exceedingly useful piece of apparatus for mineral examination in connection with mineral dressing problems and it also possesses a further advantage in that it can be readily made in almost any workshop.

A considerable number of minerals are to some extent magnetic and because of variations in this property, the electro-magnet can often be utilised to make good separations. Thus, the following useful fractions were made by the author from a mill product obtained during examination of a sample of ore from Malaya, and after the magnetite present had been extracted by a bar magnet.

1. Moderately magnetic fraction :—Ilmenite.

Magnetic cassiterite.

-
2. Weakly magnetic fraction :—Monazite.

-
3. Non-magnetic fraction :—Non-magnetic cassiterite.

Zircon.

Quartz.

Comparatively recently an interesting electro-chemical magnetic method of separating certain - 100 mesh mineral grains has been described by Vincent. The apparatus consists of a small iron container of circular cross-section which is about 7 cm. in height and which has an internal diameter of 7 to 10 cm. The interior of the vertical walls are varnished. About 10 g. of the grains under examination are placed in the container which is then partially filled with a solution of ferrous chloride and calcium chloride. An iron disc-shaped anode is inserted into the liquid and a current of density .05A per square cm. is passed through the anode, liquid and the iron container (the cathode) for three to four minutes. On completion of the passage of current the sample is removed, washed and dried, then subjected to a magnet which removes the conducting grains because they, during the above treatment are coated with a thin layer of metallic iron. The iron-coated grains are treated with dilute hydrochloric acid in order to remove the iron, then washed and dried. It is claimed that this method yields quantitative results. Clearly the method is an ingenuous one, but considerable work still remains to be done before its full possibilities can be appreciated.

Examples of conducting and non-conducting minerals, as far as the method above is concerned, are listed below.

Conductors		Non-Conductors
Pyrite	Quartz	Zircon
Galena	Silicates	Haematite
Copper sulphides	Baryte	Ilmenite
Native metals	Wolfram	Cinnabar
Arsenopyrite	Apatite	Sphalerite
Graphite	Rutile	Manganese ores.

Class 3.

Several small pieces of laboratory apparatus have been devised for the separation of certain minerals by electro-static methods but as far as the experience of the author goes, they are not very satisfactory because it is extremely difficult to ensure that both apparatus and sample ore are absolutely dry, and unless this is so, good results cannot be obtained.

Class 4.

Grains of a given mineral can sometimes be separated from others by the simple expedient of dissolving the unwanted grains in a chemical reagent. As a simple example, baryte could be separated from witherite by dissolving the latter in hydrochloric acid.

As an interesting example of the partial use of a chemical method to effect a separation it may be stated that cassiterite grains can be readily separated from grains of such minerals as ilmenite, monazite, and zircon by placing the sample in a small flat bath made by bending thin sheet zinc and covering the sample with 5N hydrochloric acid. After five or ten minutes the cassiterite will be coated with metallic tin and if now the acid is diluted somewhat and the bath carefully shaken the cassiterite grains, possibly buoyed up by hydrogen emanating from zinc entrapped in the tin coating, can easily be induced to congregate in a corner. If now the walls of this corner are broken down, the cassiterite can be washed out of the bath by means of a few drops of water.

Class 5.

Preliminary examination of mill products under the microscope often reveal a few grains upon which it is desirable to carry out certain chemical tests. With a little practice a given grain can be easily isolated from the rest by means of a sharp needle whose

movements are controlled by observing through the microscope. If then the needle is damped the isolated grain may be picked up by it and transferred to another slide.

Class 6.

Sieving, sedimentation and elutriation are methods utilised for dividing the components of a sample into size groups and are of value in mineralogical examination in connection with mineral dressing in that they help to show whether or not a given mineral is concentrated largely within one size group or is distributed fairly regularly throughout the various size groups.

Methods suitable for the examination of mineral grains

The following methods are suitable for the examination of mineral grains :—

1. Specific gravity determinations.
2. Determination of optical properties in transmitted and reflected light.
3. Etch reactions.
4. Staining and allied methods.
5. Microchemical and allied methods.
6. Contact printing and allied methods.
7. Methods involving the use of ultra-violet light.
8. Methods involving the use of the Geiger counter.
9. Spectrographic methods.
10. X-ray analysis.

Those methods noted above which have already been discussed have not been referred to below unless some special modification, specially suited to mineral grain examination exists.

Specific gravity determinations.

The specific gravity of a grain of about 40 mg. weight may be determined with considerable accuracy by means of apparatus now available. If, however, several grams of grains of a given mineral are at hand, then several classical methods depending on displacement of liquid can be used with advantage.

A diffusion column prepared by carefully pouring a suitable "light" liquid on a "heavy" and allowing diffusion to take place is sometimes of considerable value in determining the specific

gravity of individual grains. After a suitable period the specific gravity of the column will be found to increase reasonably regularly from the surface to the bottom and the column can then be indexed by carefully dropping into it known mineral fragments whose specific gravities are within the range of the column. The specific gravity of an unknown fragment may then be judged by noting what position it takes up when introduced into the column.

A small scale separation of heavy grains from light may be made by stirring them with a few drops of a suitable specific gravity liquid on a microscope slide and then removing the lighter fraction by bringing the surface of the liquid into temporary contact with a cover slip.

Determination of optical properties.

Refractive index determinations are of great value for the determination of the identity of transparent **grains**.

Transparent grains may also be embedded in dental cement and a thin section made of the synthetic rock and examined in the normal manner. Similarly, opaque grains may be embedded in bakelite and after polishing they may be treated in just the same manner as larger fragments.

Staining and allied methods.

The differential staining of mineral grains without mounting in a medium such as bakelite can often be of considerable use in the solution of mineral dressing problems, in that, when applicable, the method is quick and is capable of supplying not only qualitative information but also semi-quantitative information. Thus, the presence and approximate amount of cerussite and anglesite in an essentially quartz-baryte product can be arrived at by placing a small sample on a slide and treating it with a drop of 8% acetic acid and then a drop of 8% potassium iodide. After leaving for about one minute and draining off most of the solution examination under the microscope will reveal the lead minerals because they will be of a dense yellow colour. Slight staining of fragments should be ignored as this is due to "transported" lead iodide.

The presence and approximate amount of wolfram in, say, a wolfram-cassiterite-quartz product can, with a little experience, be

arrived at by sprinkling a little of the sample on to a piece of mica on which some sodium peroxide has been heated just to melting. The development of green manganate around the wolfram fragments indirectly indicates wolfram, whilst the amount of green compound developed gives some indication of the quantity of the wolfram present.

Contact printing and allied methods.

When the grains are not too small they may be embedded in bakelite prior to printing, but when finer sizes are to be examined it is better to utilise the ingenious apparatus devised by Williams and Nakhla. This apparatus blows a true sample on to gelatine-coated paper suitably impregnated with reagents chosen to stain one or more of the components. By this means the designers were able to differentiate readily between descloizite and vanadinite and to arrive at the relative amounts of these minerals that were present.

A somewhat allied method has been used by the author for the approximate determination of fluorite in certain products, and is based upon tests described by Feigl. A piece of spot-reaction paper is covered with zirconium-alizarin solution and dried. The paper is then placed on the top of a small beaker half filled with water and this is brought to the boil. The sample is sprinkled over the paper and after two or three minutes the paper is removed and the fragments brushed off. Where a fluorite grain originally rested will be a yellowish-white area easily seen against the pink reagent paper and the number of such areas gives some idea of the amount of fluorite present in the ore.

Conclusion.

In this survey, all the known methods of mineralogical examination have not been discussed, but it is hoped that the majority of the most useful techniques have, at least, been "touched upon."

Certain pieces of apparatus used for the magnetic separation of minerals, together with the Haultain Infrsizer, have been ignored, because it is felt that these fall more nearly within the category of apparatus for mineral dressing tests proper.

The electron microscope has not been discussed because of its

limited application and great cost, and the various methods of chromatographic analysis have been largely ignored, because they have yet to be proved to be of general use in the field of work under consideration.

Finally, the author would be pleased to receive information of any method of mineralogical examination which, in the experience of any reader of this article, has proved of value in connection with mineral dressing.

The Assay Office, School of Mines, Camborne.

SELECTED REFERENCES

1. Technical Methods of Ore Analysis. Low, Weinig and Schoder. John Wiley & Sons, Inc., New York : 1945.
An excellent manual of wet assaying of the commoner elements which also contains a useful series of carefully described spot tests.
2. The Sampling and Assay of the Precious Metals. Smith, E. A. Griffin & Co., Ltd., London : 1947.
3. The Analysis of Minerals and Ores of the Rarer Elements. Schoeller, W. R., and Powell, A.R. Griffin & Co., Ltd., London : 1940.
4. Qualitative Analysis by Spot Tests. F. Feigl. Elsevier Pub. Co., Inc., New York : 1947.
5. A Rapid Polarographic Method for the Determination of Copper, Zinc and Lead in Flotation Tailings. Crowe, G. A., and Bishop W. T. T.P.2010 Min. Tech. : March, 1946.
6. Petrographic Methods and Calculations. Holmes, A. Murley & Co., London : 1930.
Contains a great deal of material which may be applied to mineralogical problems connected with mineral dressing.
7. Elements of Optical Mineralogy. A. N. Winchell. John Wiley & Sons, Inc., New York : 1931.
3 vols. Part I Principles and Methods.
Part II Descriptions of Minerals.
Part III Determinative Tables.
One of a large number of excellent publications on the determination essentially of the non-opaque minerals. Very valuable if the various techniques are to be acquired without the help of an instructor.
8. The Microscopic Determination of the Non-opaque Minerals. Larsen, E. S., and Berman, H. Bulletin 848 of the United States Geological Survey. United States Government Printing Office : 1934.

9. Microscopic Determination of the Ore Minerals. M. N. Short. Bulletin 914 of the Geological Survey. United States Government Printing Office, Washington : 1940.
Describes the preparation of polished sections, together with the examination of the opaque minerals by physical and chemical methods.
10. Staining Minerals for Easier Identification in Quantitative Mineralographic Problems. Gaudin, A. M. Econ. Geology, vol. 30, pp 552-562 : 1935.
11. Ultra-violet Light. Warren, T. S. Bulletin No. G3—B15. Decc. Trefoil pp.5-12 : March, 1944.
12. A Short-Wave Ultra-violet Prospecting Set for Fluorescent Minerals. Rabone, P. Inst. of Min. and Met. Bulletin No. 472. pp.1-15 : May, 1945.
13. The Detection of Columbite by Ultra-violet Light. Mackay, R.A. Inst. of Min. and Met. Vol. 60, pp.129-131 : 1950-51.
14. Chromographic Contact Print Method of Examining Metallic Minerals and its Applications. Williams, D., and Nakhla, F. M. Inst. Min. and Met. Vol. 60, pp.257-295 : 1951.
The best account of this most valuable method of examination yet published.
15. Spectroscopy in Science and Industry. Judd Lewis, S. Blackie & Son, Ltd. : 1944.
An excellent general account of the modern methods of spectroscopy which also contains references for the more advanced reader.
16. The Spectroscope in Determinative Mineralogy. Peterson, M. J., Kauffman, A. J., Jr., and Jaffe, H. W. Am. Mineralogist, 32, 322-335: 1947.
17. A Direct Reading Analytical Spectroscope. Vreeland, F. K. Am. Mineralogist, 33, 600-611 : 1948.
18. Visual Arc Spectroscopic Detection of Halogens, Rare Earths and Other Elements by Use of Molecular Spectra. Jaffe, H. J. Am. Mineralogist, 34, 667-674 : 1949.
The above three papers indicate how a simple spectroscope may be utilised for the rapid quantitative determination of a great number of the elements encountered in minerals.
19. Simple Determinative Mineralogy. Beringer, H. R. Mining Publications, Ltd., Salisbury House, London, E.C.2 : 1931.
20. The Microdetermination of Density. Wilson, C. L. Metallurgia, pp.157-160 : Jan., 1946.
The article incorporates a good account of apparatus suitable for determining the density of a mineral particle of weight 100 to 20 mg.
21. Handbook of Chemical Methods for the Determination of Uranium in Minerals and Ores. H.M. Stationery Office : 1950.

22. A Prospector's Handbook to Radioactive Mineral Deposits. H.M. Stationery Office. 1949
Contains excellent descriptions of tests suitable for radioactive substances.
23. Autoradiographic Techniques in Geological Research. Bowie, S. H. U. Bulletin of the Geol. Surv. of Gt. Brit. No. 3, pp.58-70 : 1951.
24. Clay Mineral Research. Heystek, H. Journal of the Chem. Met. and Min. Soc. of South Africa. Vol. 51, pp.360-373 : 1951.
Contains an excellent review of the methods available for the study of clay minerals, some of which are equally well suited to the study of other mineral groups.
25. Differential Thermal Curves for Certain Hydrous and Anhydrous Minerals, with a Description of the Apparatus Used. Kauffman, A. J., Jr., and Dilling, E. D. Econ. Geology, vol. 45, pp.222-244 : 1950.
One of the best of a great number of papers on differential thermal analysis.
26. Quantitative Mineral Analysis with a Recording X-ray Diffraction Spectrometer. Carl, H. F. Amer. Min., 32, 1947, 508
27. Microseparation of Minerals in Heavy Liquids. Rodda, J. L. Am Mineralogist, 36, 625-626 : 1951.
28. Mineral Separation by an Electrochemical-Magnetic Method. Vincent H. C. G. Nature, vol. 167, p.1,074 : 1951.
29. Elutriation in Ore-dressing. Mining Magazine, pp.49-52 : Jan., 1931
A digest of a publication by Gaudin and others.
30. Splitting the Minus 200 Mesh with the Superpanner and Infrascizer Haultain, H. E. Trans. Canadian Inst. of Min. and Met., vol. 40 pp.229-240 : 1937.
31. The Determination of Specific Surface and Shape Constants from Screen Analysis Data. Morgan, T. D., Blitz, J., and van Doornum, G. A. W. Journal of the Chemical, Met. and Min. Soc. of South Africa, vol. 51 pp.1-13 : July, 1950.