Importance of Microscopic Studies in Mineral Dressing

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The importance of microscopic studies in mineral dressing is emphasised with illustrations based mostly on the studies conducted by the authors on Indian samples The information obtainable includes (i) identity of minerals, (ii) grain size, nature and degree of intergrowth of minerals, (iii) quantitative data on the mineralogical constituents, and (iv) genesis and other data of special significance.

MINERAL dressing is primarily a process of separation of minerals by physical methods, involving little or no chemical change. A thorough understanding of the identity and texture of minerals present in an ore is, therefore, a pre-requisite to any attempt to separate one mineral from the other. Mineralogical examination of an ore often provides a useful clue to the plausible methods for its beneficiation and thus dispenses with a large amount of avoidable experimentation. Such examination of the various products of concentration will also be helpful in effecting improved efficiency in treatment. Microscope is an indispensable tool for mineralogical studies and the techniques employed are too well known[1-5] to need repetition. Its practical applications in the field of ore-dressing are outlined below with illustrations mostly on the basis of studies conducted by the authors on various samples from India at the National Metallurgical Laboratory.

The information available to the ore-dressing engineer as a result of microscopic studies comprises: (i) identity of minerals, (ii) grain size, nature and degree of intergrowth, (iii) quantitative data on the mineralogical constituents, and (iv) genesis and other data of special significance.

IDENTITY OF MINERALS

The exact identification of the valuable minerals as well as gangue, is necessary to assess their properties and hence their metallurgical behaviour. Chemical analyses, useful though they are, provide no information about the minerals present in an ore. The ore dressing engineer is primarily concerned with the minerals.

Valuable minerals.—A value may be carried by different minerals in different ores. The metal copper for example may be present in the form of chalcopyrite, chalcocite, covellite, cubanite, bornite, malachite, azurite etc. the concentration of each of which may vary, according to its specific nature. A value may also be carried by several minerals in the same sample. For instance, Figure 1 shows three manganese minerals viz. sitaparite, braunite and hollandite in one sample. Identification of each of the minerals is important for complete recovery of the value.

The grade of concentrate obtainable is limited by the actual composition of the valuable minerals in a sample. Identification of the minerals under a microscope will generally throw light on their composition and thus indicate the maximum grade of a particular concentrate that can be obtained by ore-dressing methods. Bementite (8 MnO $5H_2O$. $7SiO_2$) for example, was identified[6] as the principal mineral in a manganese ore, and the manganese concentrate obtained was low grade and high in silica. Some minerals are variable in their composition and should be checked for their purity under a microscope and assayed. This assay value of the pure mineral will determine the grade of concentrate obtainable for that ore. Chromite for instance, has a variable composition of (Fe, Mg)O. (Fe, Al, $Cr)_2O_3$. Microscopic examination of a chrome ore will determine whether its undesirable elements Fe, Al and Mg are present in the chromite mineral itself or as separate gangue. Ore dressing will be of help only in the latter case. An ore from Byrapur Chromite Mines, Mysore, gave on analysis, a Cr/Fe ratio of 1.41. Under microscope no iron-bearing mineral other than chromite was noticed and hence the entire iron content was attributed to the composition of chromite itself. The impossibility of effecting any improvement in Cr/Fe ratio by ore-dressing methods was thus suggested and these findings were confirmed by concentration tests yielding concentrates with a Cr/Fe ratio of only 1.44. In contrast to this sample, a chrome ore

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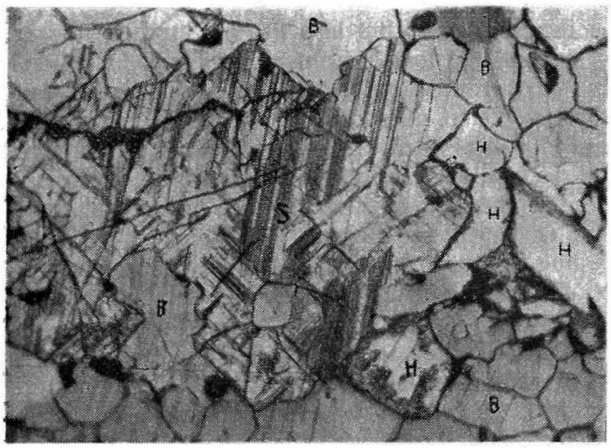

FIG. 1—*Braunite (B), hollandite (H) and sitaparite (S, with lamellar twinning).*

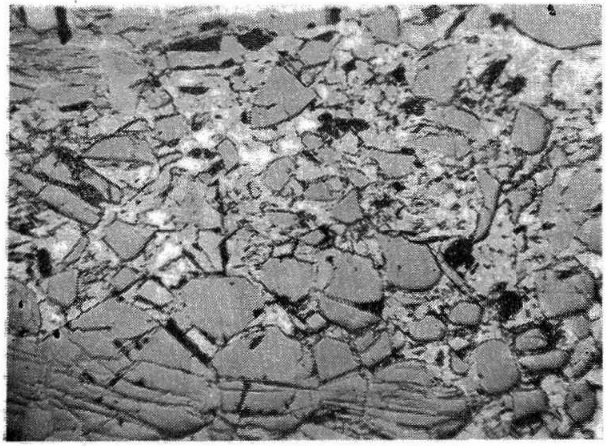

FIG. 2—*Grains of chromite (dark grey) with interstitial haematite (white). Cuttack, Orissa.*

from Orissa which had a Cr/Fe ratio of 0.99 was found to contain a large proportion of free iron oxides (Fig. 2) as the principal gangue. The possibility of eliminating the ferruginous gangue and thus improving the Cr/Fe ratio by mechanical methods was indicated. The beneficiated concentrate had a Cr/Fe ratio about 3:1. Another typical example, is a manganese ore from Kodur Mines, Andhra, which contained 8.65% Ba as received. No barium-bearing mineral was noticed under microscope and hence the barium content was attributed to psilomelane, a mineral of varying composition. The concentrate, which was free from gangue, assayed 9.67% Ba.

Mineralogical studies may also indicate whether any useful by-product of sufficient purity can be obtained from an ore. For instance, examination of a manganese ore from Tirodi Mines, Madhya Pradesh indicated that in addition to the manganese mineral, braunite, it contained magnetic vredenburgite. While the latter is to be considered as a contaminant in manganese concentrate by lowering its grade, it could be utilised in iron smelting, if separated in sufficient purity. From certain ferruginous manganese ores also an iron rich by-product could be obtained, apart from a manganese rich concentrate. Minerals like pyrite, pyrrhotite, barite, flourspar, siderite etc. may also form useful by-products, under certain condition and their presence and purity obtainable, may be indicated by the microscope.

Gangue.—The nature of impurities in an ore needs to be well understood in order to effect their elimination. For example to reduce the silica content in a manganese ore, it is essential to know whether it is present as quartz, garnet or other silicates, because each of these requires a separate method for its elimination. In a manganese ore from Kachidana Mines, Madhya Pradesh, the silica was present mostly as quartz which could be easily removed by gravity methods, while the ore from Tirodi Mines, Madhya Pradesh, contained a part of the silica as garnet which required electrostatic separation for its elimination. Silica was present as amphiboles and pyroxenes in an ore from Balaghat, Madhya Pradesh and it could be removed by controlled magnetic separation. Thus microscopic identification of the gangue minerals present in an ore may indicate the probable methods or at least the impracticability of certain methods, and thus save considerable amount of futile experimentation.

Some gangue minerals in an ore may contain small amounts of values in chemical combination. Identification of such minerals will be of help in their separation and improvement in the grade of concentrate though it will be at the sacrifice of recovery. For example, microscopic examination of a manganese ore from Miragpur Mines, Balaghat showed that it contained a large percentage of manganiferous garnet, as gangue, whose elimination therefore would involve considerable loss in manganese recovery in concentrates. Actual tests indicated that about 24% of the total Mn. was lost with garnets in the tailing. Similarly, the presence of jacobsite and rhodonite (observed in some Indian manganese ores) may indicate that their elimination will entail loss in recovery of manganese.

Microscopic examination of an ore may also reveal the presence of any soluble gangue, that may give rise to unexpected metallurgical difficulties. Dissolved salts may introduce complications, especially in flotation and cyanidation. Hence by detection of these minerals, the trouble may be foreseen and avoided. Carbonates like calcite or magnesite render the pulp highly alkaline. In a pyrite sample from Amjor, Bihar, the presence of a soluble mineral melanterite (Fe SO_4. $7H_2O$) rendered the flotation pulp highly acidic. Magnesium sulphate dissolved in water has a harmful effect on cyanidation as has been experienced at the Sons of Gwalia mine in Western Australia.[7]

Identification of reactive gangue which adversely affect process of concentration is an essential prerequisite so that steps may be taken to nullify their effects. This is of utmost importance in beneficiation of gold ores, where some gangue like pyrrhotite, marcasite, copper sulphides, stibnite—particularly the oxides of copper, antimony, or arsenic, are very objectionable as they inhibit the dissolution of gold on cyanidation. Certain gangue sickens the mercury in amalgamation. Hence due attention must be focussed on the nature of the gangue in gold ore, before its recovery by cyanidation or amalgamation is contemplated.

Ores sometimes contain minerals whose elimination is necessary, not with a view to effect any improvement in grade, but because their presence, even in minute amounts in the concentrates is highly objectionable and will seriously affect their sale value. Phosphorus and sulphur in manganese and iron ores, arsenic in pyrite, arsenic and tungsten in zinc ores, bismuth in lead ores, lead in fluorspar etc. are considered highly harmful. Particular care has to be taken to detect the minerals carrying these objectionable elements, often present in very small quantities. Failure to detect such minerals may render the problem of their elimination difficult, which may mean considerable loss in revenue by way of penalties payable for such concentrates. In a manganese ore from Mansar Mines, Madhya Pradesh, apatite was identified, and hence the possibility of reduction in phosphorus content was suggested. Actual tests indicated that the phosphorus content could be brought down from 0.46% phosphorus in the original ore to traces in the concentrate by suitable methods. However, in most of the manganese ores studied, it was not possible to determine the phosphorus bearing mineral and hence reduction in their phosphorus content could not be effected. Sulphur, for example, if present as barytes, or gypsum in manganese ores can be brought down. Microscopic examination of a fluorspar sample from Chandidongri Mines, Drug, Madhya Pradesh indicated that lead was present mostly as cerussite and a little galena whose identification assisted in devising suitable methods for their elimination.

GRAIN SIZE, NATURE AND DEGREE OF INTERGROWTH

Microscopic examination often provides valuable information about the grain size, nature and degree of intergrowth between the ore minerals and gangue, and hence about the liberation size of the minerals, a knowledge of which is of utmost importance to decide the amount of grinding necessary for obtaining the maximum efficiency in separation. The liberation size will also dictate the selection of method of separation. Over-grinding will result not only in increased costs but also in higher production of slime and the loss of valuable minerals in it. Incomplete grinding on the otherhand, will lead to bad separation and poor products. Microscopic examination will also reveal, whether the intergrowth of ore and gangue is too intimate to effect any separation at the size ranges employed in ore dressing, and thus will avoid considerable amount of futile testing. Studies of mill products are often helpful to determine whether the loss in grade or recovery, if ever it happens, is due to intergrowth of the minerals or inefficient operation. They will also throw light on any unusual metallurgical behaviour of minerals. Innumerable examples can be cited, where textural relationship revealed by microscope has had direct bearing on ore-dressing. A few are given below.

Figure 3 shows a chrome ore from Boula Mine, Nausahi, Keonjhar. Microscopic examination indicated, and subsequent ore dressing tests confirmed, that the best size for separation of minerals would be 35 mesh.

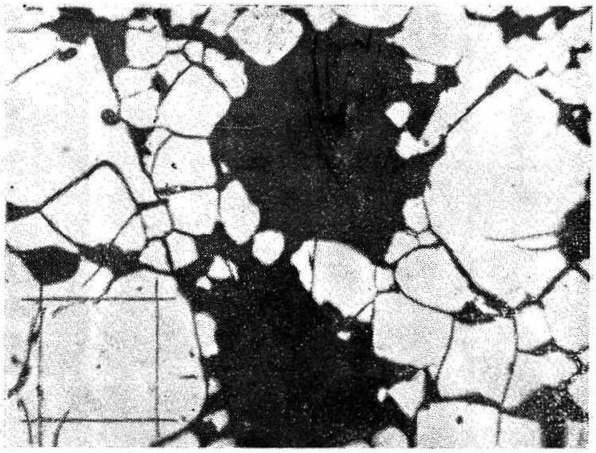

FIG. 3—*Coarse grained chromite (white) and gangue (black). The square represents 35 mesh aperture. Keonjhar, Orissa.*

An example of intimate intergrowth between valuable mineral and gangue is provided by a ferruginous manganese ore from Sandur, Mysore, in which magnetite (highly martitized) was found to be finely disseminated in psilomelane. Figure 4 shows that even at 200 mesh complete liberation will not take place. The manganese concentrates were, therefore, contaminated with iron to some extent.

A sample of maganese ore from Kamji Mines, Banswara, Rajasthan, showed very intimate association of calcite with pyrolusite (Fig. 5) and hence liberation could not be achieved even after very fine grinding.

In a fluorspar sample from Chandidongri Mines, Drug, Madhya Pradesh, a portion of gangue was intimately associated with fluorspar (Fig. 6) and

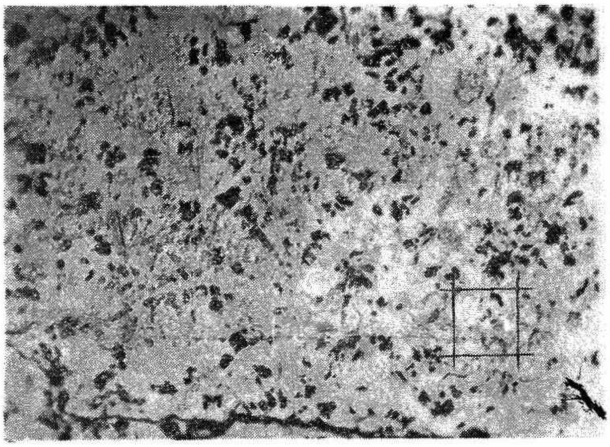

FIG. 4—*Grains of martitised magnetite (M) in psilomelane. The square represents 200 mesh aperture. Sandur, Mysore.*

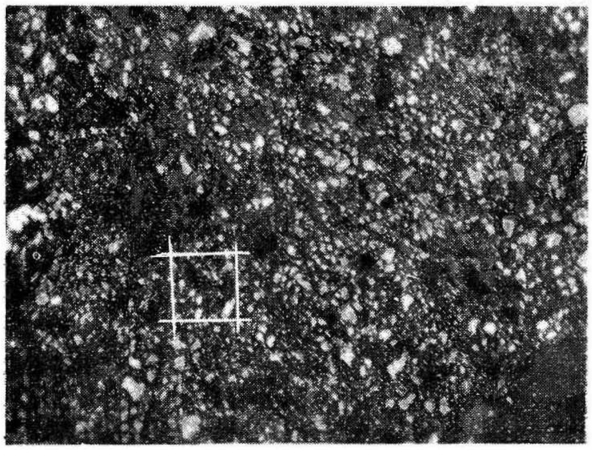

FIG. 5—*Finely disseminated pyrolusite (white) in calcite (dark grey). The square represents 200 mesh aperture. Banswara, Rajasthan.*

hence even the best concentrate by flotation contained 3.6% SiO_2.

A jig concentrate from a manganese ore from Balaghat showed that the gangue which was finely interlocked with braunite, was responsible for its low grade (Fig. 7).

A manganese ore from Banswara, Rajasthan, contained a few grains, strongly magnetic in character and assaying high percent of manganese. Microscopic examination revealed that the grains were mostly pyrolusite containing fine dissemination of magnetite, which was responsible for the unusual behaviour.

A manganese ore sample from Tirodi Mines, Madhya Pradesh yielded on magnetic separation at 20 mesh 43.4% by weight of highly magnetic manganese concentrate, assaying 21.02% Fe. Microscopic examination indicated that this product contained the mineral vredenburgite which was responsible for its magnetic character. It was therefore ground to 100 mesh and subjected to wet magnetic separation. The resultant nonmagnetic manganese concentrate free of vredenburgite assayed only 1.6% Fe.

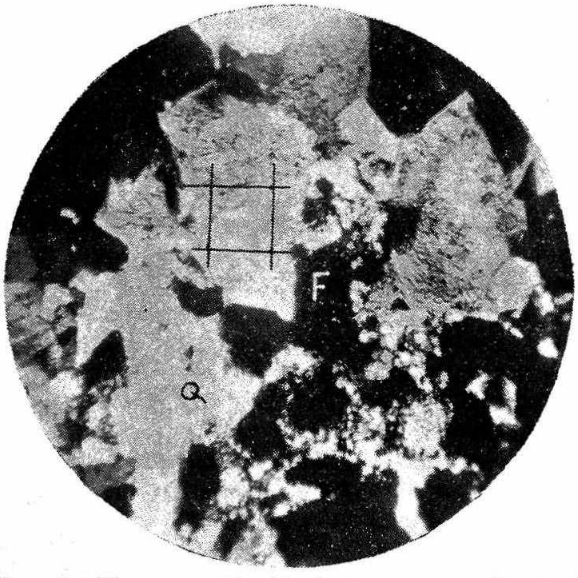

FIG. 6—*Fluorspar (F. black) in intimate interlocking with quartz (Q. white and light grey). The square represents 150 mesh aperture. Drug, Madhya Pradesh.*

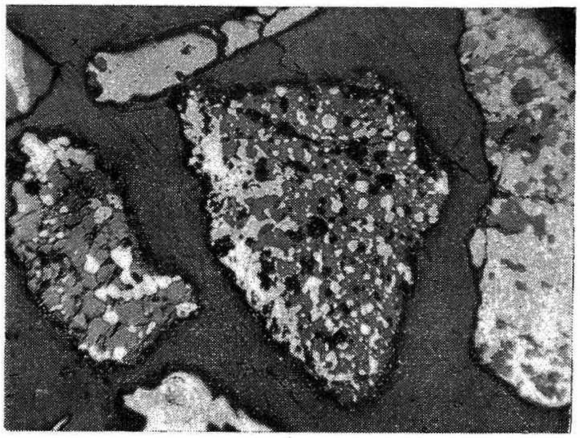

FIG. 7—*A Jig concentrate mounted in bakelite showing a few grains of brannite (light grey) interlocked with gangue (dark grey). Balaghat, Madhya Pradesh.*

Vredenburgite itself is composed of two minerals, jacobsite and hausmannite. It is obvious from Figure 8 that it is not possible to liberate the minerals even by fine grinding to the minimum size suitable for mechanical concentration. A similar example is provided by titaniferous magnetite. Figure 9 shows a sample of titaniferous magnetite (martitised) from Mayurbhanj, Orissa. Evidently, little or no separation between ilmenite and mag-

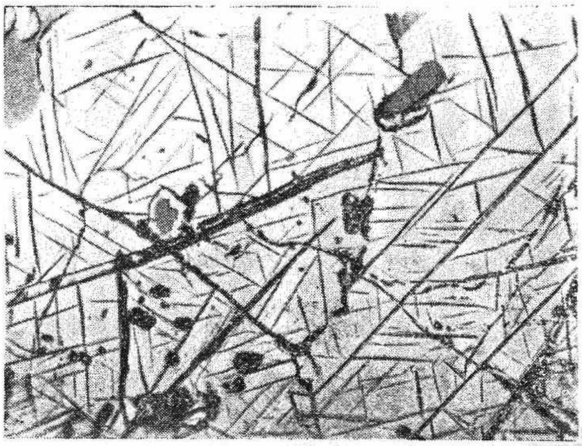

FIG. 8—*Vredenburgite—Orientated lamellae of hausmannite in a ground mass of Jacobsite. Balaghat, Madhya Pradesh.*

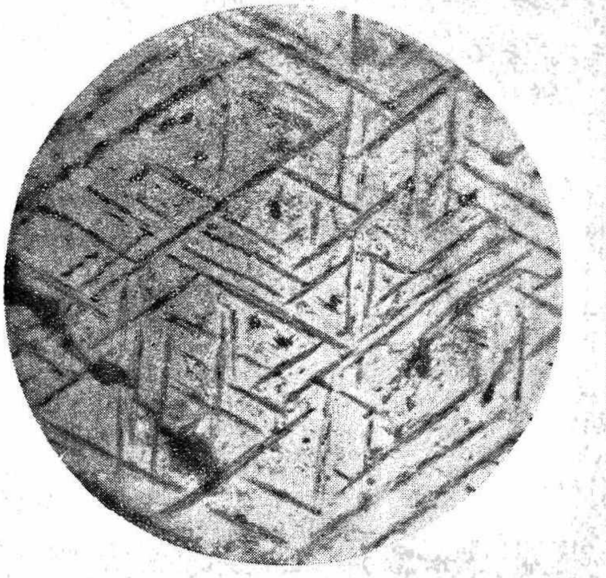

FIG. 9—*Exsolved ilmenite (dark grey) arranged along the octahedral planes of martitised magnetite (light grey). Mayurbhanj, Orissa.*

netite will be possible even with very fine grinding. A manganese ore from Balaghat contained areas of myrmekitic intergrowth of braunite and gangue (Figure 10). As is evident, the manganese mineral in such portions cannot be liberated for concentration.

Study of a few samples of beach sands from Orissa and Andhra showed that interlocked grains are not uncommon. Figure 11 shows a grain containing both haematite with exsolved ilmenite and ilmenite with exsolved haematite. Ilmenite magnetite intergrowths similar to Figure 9 are also seen.

QUANTITATIVE DATA ON MINERALOGICAL CONSTITUENTS

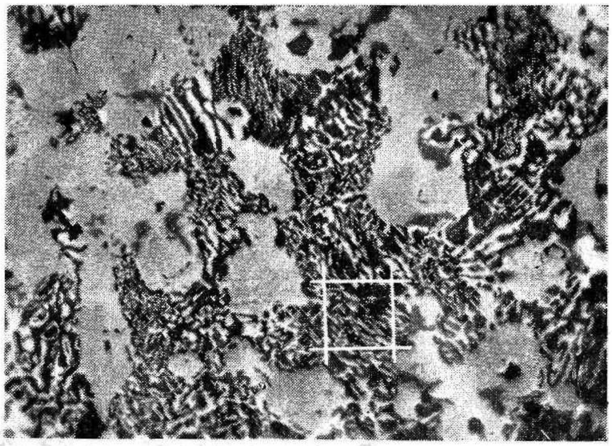

FIG. 10—*Myrmekitic intergrowth of braunite (light grey) and gangue (black). The square represents a 200 mesh aperture. Balaghat, Madhya Pradesh.*

FIG. 11—*A grain showing both exsolved haematite (white) in ilmenite (dark grey) and ilmenite in haematite. Beach sands of Orissa Coast.*

Correlation of chemical analysis with the mineralogical estimate is often very helpful. To assess the grade of beneficiated products, chemical analyses are usually resorted to, but there are instances where mineralogical analyses may be more easily carried out than chemical analyses. This is well exemplified in the case of beach sands. Zircon, monazite, rutile, and the like can be much more readily estimated quantitatively with the help of microscope than by analyses of the constituent elements. In the case of complex ores, where a variety of minerals, both valuable and gangue, are present, it is often necessary to estimate the various mineral constituents of the products of treatment in order to attain a clear picture of the changing distribution of values.

To effect an improvement in mill practice, it is necessary to know where and how the losses in grade and/or recovery occur during the course of treatment. An estimate of the nature and amount of the liberated and intergrown minerals in the different products of concentration will often provide such information. It will also reveal whether the separation process is operating satisfactorily or whether the treatment is inefficient due to defective grinding resulting in unliberated particles or excessive amount of slime. Edwards[8], Head[9-11] and others have vividly explained this aspect with detailed practical illustrations.

GENESIS AND OTHER DATA OF SPECIAL SIGNIFICANCE

Microscopic study may also throw light on the genesis of an ore which sometimes indicates mineralogical changes likely to occur in ore deposits at depths. The ore-dressing engineer should take this aspect into consideration in the design of the milling plant. Sulphide deposits, particularly of copper and silver may show significant changes in mineralogy. with depth. The minerals in the oxidation and enrichment zones may be entirely different from those of the hypogene. Microscopic study of the sample is an invaluable guide to foresee the likely changes. An estimate of the proportion of the hypogene mineral in the enrichment zone, may also in some cases provide a clue to the grade of primary ore likely to be available at depth. Recognition of martite under microscope may indicate that it may gradually be replaced by magnetite at depth. A sample from Sandur showed grains of magnetite in various stages of martitisation in psilomelane (Figure 12). If with depth, martite changes over to magnetite, the process of concentration may need modification and hence the ore dressing engineer should keep this point in view.

FIG. 12—*Martitisation of magnetite. Sandur, Mysore.*

Microscopic examination also reveals the tendency of any mineral confining itself solely in another. Such information can be profitably utilised during the concentration of these ores. A gold ore from Wynaad, Nilgris, showed that most of the gold was confined to a sulphide mineral (pyrite) in the sample and hence the sulphide was alone first floated and treated for gold recovery, thereby reducing the total bulk of the material to be handled.

A kyanite sample from Mysore yielded a low P.C.E. (Pyrometric cone equivalent) value. Careful study under microscope revealed that it was due to margarite, a low melting alteration product derived from and confined to corundum pieces only. Separation of the corundum lumps was possible by hand-picking, and the associated margarite was thus removed along with them. The residual kyanite, after jigging for removal of the free quartz gave the required P.C.E. value.

A manganese ore from Balaghat, Madhya Pradesh indicated under microscope that portion of the haematite was restricted only to jacobsite. Figure 13 shows that it ends abruptly at the border of braunite. Elimination of the magnetic mineral (jacobsite) will therefore carry the haematite associated with it and hence the iron content in the non-magnetic residue can be reduced.

FIG. 13—*Lamellae of haematite (H) in Jacobsite (J). The former ends abruptly at the border of braunite (B). Balaghat, Madhya Pradesh.*

SUMMARY

Microscopic examination of an ore as well as the products of concentration is of utmost importance in mineral dressing.

While chemical analyses provide data regarding the elements present in an ore, microscopic study furnishes information about the minerals carrying the element. The ore dressing engineer is primarily concerned only with the minerals.

A value may be carried by a variety of minerals, the method of concentration for each may vary according to its specific nature. Identification of each of them is necessary for complete recovery of the value.

Composition of the valuable mineral limits the grade of concentrate obtainable by ore-dressing methods. If the valuable mineral is of varying composition e.g. chromite, its isolation in a pure state and chemical analysis are necessary to know its composition.

An ore may contain more than one product of value. Microscopic examination in such cases can indicate the nature and purity of the various by-products that can be obtained from the ore.

Identification of the gangue minerals present in an ore is necessary to assess their properties and evolve suitable process for their elimination and production of high grade concentrate.

Soluble and reactive gangue in an ore sometimes affects the efficiency of ore-dressing operations like flotation, cyanidation etc. Their early identification will enable remedial measures to be adopted.

The presence of certain impurities even in minor amounts may be highly objectionable in concentrates. It is essential to determine in what form they are present in the sample in order that the possibility of their elimination may be studied in detail.

The determination of the size of liberation of the minerals valuable and gangue, is of utmost importance for optimum efficiency in separation in ore-dressing. The liberation size, dictates the selection of process of treatment. Microscope is an indispensable tool to determine the intergrowth relationship between minerals and this may yield a useful clue to the optimum grinding necessary for liberation of minerals.

Microscopic inclusions of foreign substances in metallurgical practice and a study of this phenomenon is thus warranted.

In some cases the impossibility of liberating minerals, even by fine grinding, to the minimum size suitable for mechanical concentration may be disclosed by microscopic studies.

Correlation of chemical analysis with mineralogical data is often highly desirable. Chemical analyses, valuable as they are, to determine the grades of products obtained by ore-dressing methods, instances are known where mineralogical analyses can be more easily carried out and are more useful. Beach sand is an instance.

Improvement in mill practice is often guided by the results of a quantitative estimate of the mineralogical constituents of various mill products.

Textural relationship may give a clue to the genesis of an ore, a knowledge of which is essential to foresee the mineralogical changes likely to occur at depth and their consequent effect on mill practice.

The tendency of a mineral to be particularly associated with another can be studied under microscope and may be taken advantage of in ore dressing.

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DISCUSSIONS

Dr. Krishnaswamy *(Atomic Energy Establishment, Bombay)*: Mr. Subramanian has rightly pointed out the importance of microscopy. However, in the case of uranium ores, we have found that microscopy alone is not as helpful as in other cases. As for example, once we observed under the microscope that a magnetite grain had considerable quantity of uranium in it and with X-rays, we observed that the magnetite was really haemetite and what was really magnetite was not carrying uranium. Therefore, we were able to separate the altered magnetite from the un-altered magnetite thereby increasing the uranium concentration which we were not able to do before. Similarly in a number of other cases I have found that microscope alone cannot be of much help.

Mr. N. N. Subramanian *(author)*: I thank Dr. Krishnaswamy for his comments. I agree that microscopy is not the only tool for determination of minerals and sometimes it can be profitably supplemented by X-ray studies, electron microscopy, and the like.