II. IMPORTANCE OF MINERALOGY IN MINERAL PROCESSING

Mineral processing technology is evolved to separate and recover ore minerals from gangue in a commercially viable method and is mainly based on the process of mineral liberation and the process of mineral separation. Though ore is mined with the highest efficiency of the technology, the excavated ore gets partly contaminated by the surrounding host rock (overburden) and the geological material closely associated with the ore during mining. Both the materials are undesirable and hence form the gangue. Thus, the contributors to gangue may be igneous rock, sedimentary rock (shale, quartzite, phyllite), hydrothermal vein material, quartz reef and their metamorphic equivalents. For example, chromite and magnetite may form in a magmatic crystallization process whereas iron ore may form in a sedimentary environment with the episodes of metamorphism, supergene enrichment and martitisation. So, the former is associated with ultramafics (dunite, peridotite, serpentinite), basalt, gabbro whereas the latter is associated with shale, jasper, quartzite, and their weathered equivalents (kaolinitic and gibbsitic shale, quartzite, laterite etc.). So, the expected gangue minerals are different in these two cases. Similarly, the sulphide mineralisation is associated with hydrothermal veins (quartz vein or quartz reef) intruded into various rock types (granites, basalt, meta-basalt, meta-sedimentary rocks). The Table-1 enlists the possible ore minerals and gangue minerals in the ores from wide range of deposits.

From mineral processing point of view, it is important to identify the ore and gangue minerals (mineralogical study), their textural relationship (grain size, grain boundary relationship etc.). The mineralogical study also helps in the modal distribution of ore and gangue minerals which decides the grade of ore. Grain size of the minerals and their textural relationship helps in deciding the size reduction and liberation in mineral processing. An effective liberation of gangue minerals and ore minerals influences the optimum separation efficiency.

Mineralogical study may be described under the following heads.

1. Mineral identification by optical microscopy, XRD, SEM, EPMA : For mineralogical characterization of the ores/rocks, optical microscopy is an invaluable tool. For this, polished sections of ores and thin sections of rocks are prepared. The ores/ore forming minerals are studied under reflected light microscopy while the rocks/ rock forming minerals are studied under transmitted light microscopy. The minerals are identified basically from their optical properties. The optical properties differ from mineral to mineral because their crystal structure is different and the chemical constituents of the mineral; also their relative positions in the crystal lattice sites differ. But mineral kingdom is so vast sometimes it becomes difficult to identify all the minerals using only the optical microscope because there are cases where the optical properties of one mineral very closely resemble another. In such cases the help of advanced characterization techniques such as X-ray diffraction (XRD), Scanning Electron Microscopy (SEM) with micro-chemical analysis by WDS or EDS, and Electron Probe Micro-analysis (EPMA) is taken. The latter techniques help in confirming the mineral phases which is very important. On the other hand, the textures and liberation characteristics are studied under optical microscopes.

Mineral identification by X-ray diffraction technique is based on the diffraction peaks at various 2-θ values corresponding to d-spacing characteristic to the mineral. As each mineral has a characteristic crystallographic identity, its d-spacings are characteristic and the set of diffraction peaks are characteristic based on Bragg's law. This technique is useful for identifying clay minerals. In the Figure-1, the phases in the iron ore sample are identified as goethite, kaolinite, hematite/ martite, magnetite and braunite. The limitation of the technique is for the minerals whose volume percentage is less than 3% in the sample.

Some of the trace phases of very small size can not be studied by optical microscopy or XRD. In that case, SEM and EPMA provide a high resolution image of very high magnification and the chemical analysis is done by Energy dispersive X-ray spectrometry (EDX) or by wavelength dispersive X-ray spectrometry (WDX). By chemical calculations, the empirical formula is computed out and the mineral is identified.

Knowledge of the sizes and intergrowth relationships of ore mineral grains is of great importance. Only through careful examination of the ores in polished section can the optimum grain size for effective liberation be determined. Insufficient grinding may result in loss of valuable minerals in the tailings; over grinding wastes energy and may produce slimes that are difficult to treat. The nature of the boundaries between intergrown particles will show whether or not the rupturing of larger particles during grinding is likely to occur at grain boundaries. Information regarding fractures and fissures, and porosity in the ore minerals is derived from the microscopic study. In Figure-2(A,B,C) the mineralogy and texture in various components of iron ore are shown to provide an apparent perception of granular martite.

2. ***Study of Modal distribution :*** Modal distribution of minerals by microscopy with image analysis system or by grain counting helps in the statistical distribution of ore and gangue minerals which is directly related to the grade of ore. Such study also helps in the liberation studies. It can also be extended to beneficiation products to find the efficiency of beneficiation

3. ***Liberation study by microscopy :*** The liberation of ore and gangue is achieved by size reduction (through grinding). The statistical count of interlocked grains, 'ore minerals free of gangue' (liberarated ore) and 'gangue minerals free of ore minerals' (liberarated gangue) gives the quantitative percentage of liberation. This data is useful in deciding the extent of liberation required for a desired economy of comminution and beneficiation.

$$\text{Liberation (\%)} = \frac{100 \text{ X } \{(\text{No. of free ore minerals}) + (\text{No. of free gangue minerals})\}}{(\text{No. of free ore minerals} + \text{free gangue minerals} + \text{interlocked minerals})}$$

Table 1 : Associated ore and gangue minerals in various ore types.

Ore-type	Ore minerals	Gangue minerals
Iron ore (Sedimentary and supergene enrichment)	Martite, Hematite Fe_2O_3, magnetite Fe_3O_4, goethite $Fe_2O_3.H_2O$	Quartz, jasper, kaoline, gibbsite, shale
Bauxite	Gibbsite, diaspore, boehmite	Goethite, kaoline, Ilmenite, zircon, anatase
Manganese (i) Sedimentary association (ii) Metamorphic association	Psilomelane, pyrolusite, cryptomelane, manganite, wad Braunite, bixybite,, hollandite, jacobsite, hausmanite, wad	Quartz, feldspar, apatite, clay, micaceous mineral, pyroxene, amphibole, and barite, garnet (?), hematite, hydrated iron oxide (goethite)
Limestone	Calcite, aragonite, dolomite	Quartz, chlorite, shale
Beach sand	Ilmenite $FeTiO_3$, zircon ZrO_2, garnet(Ca,Mg,Fe)(Al,Fe,Cr)$(SiO_4)_3$, monazite (Ce,Th,Y)PO_4, xenotime TiO_2 etc. Sillimanite (?)	Quartz, amphibole, pyroxene, olivine, tourmaline
Copper (hydrothermal and porphyry type deposit)	Sulphides [chalcopyrite $CuFeS_2$, chalcocite Cu_2S, covellite CuS Bornite Cu_5FeS_4]Oxides [cuprite, Cu_2O]Carbonate [malachite $Cu_2CO_3(OH)_2$, Azurite $Cu_3(CO_3)_2(OH)_2$)]Trace: U, Mo, Au	Minerals in phyllite, schist, quartz schist, garnet-chlorite schist, chlorite, biotite, dolomite, shale, chert, quartz, feldspar
Lead-zinc (hydrothermal deposit)	Sulphides (galena PbS, sphalerite ZnS)Carbonate- Cerrusite $PbCO_3$ Sulphate- Anglesite $ZnSO_4$ HemimorphiteTrace: Ag, Au, Cd, In, Cu, Sb	Phyllite, schist, quartz schist, garnet-chlorite schist, chlorite, biotite, dolomite, shale, chert, quartz, feldspar, Barite, Pyrite, pyrrhotite, arsenopyrite, chalcopyrite, argentite
Chromite (magmatic deposit)	Chromitite $FeCr_2O_4$, Trace: Ni	Magnetite, dunite (olivine/ serpentine), pyroxene, gabbro (plagioclase, olivine, pyroxene)
Gold	Arseno-pyrite, native gold	Minerals of host rock (Phyllite, schist, quartz schist, amphibole, chlorite, biotite, dolomite, shale, chert, quartz, feldspar), pyrite, chalcopyrite

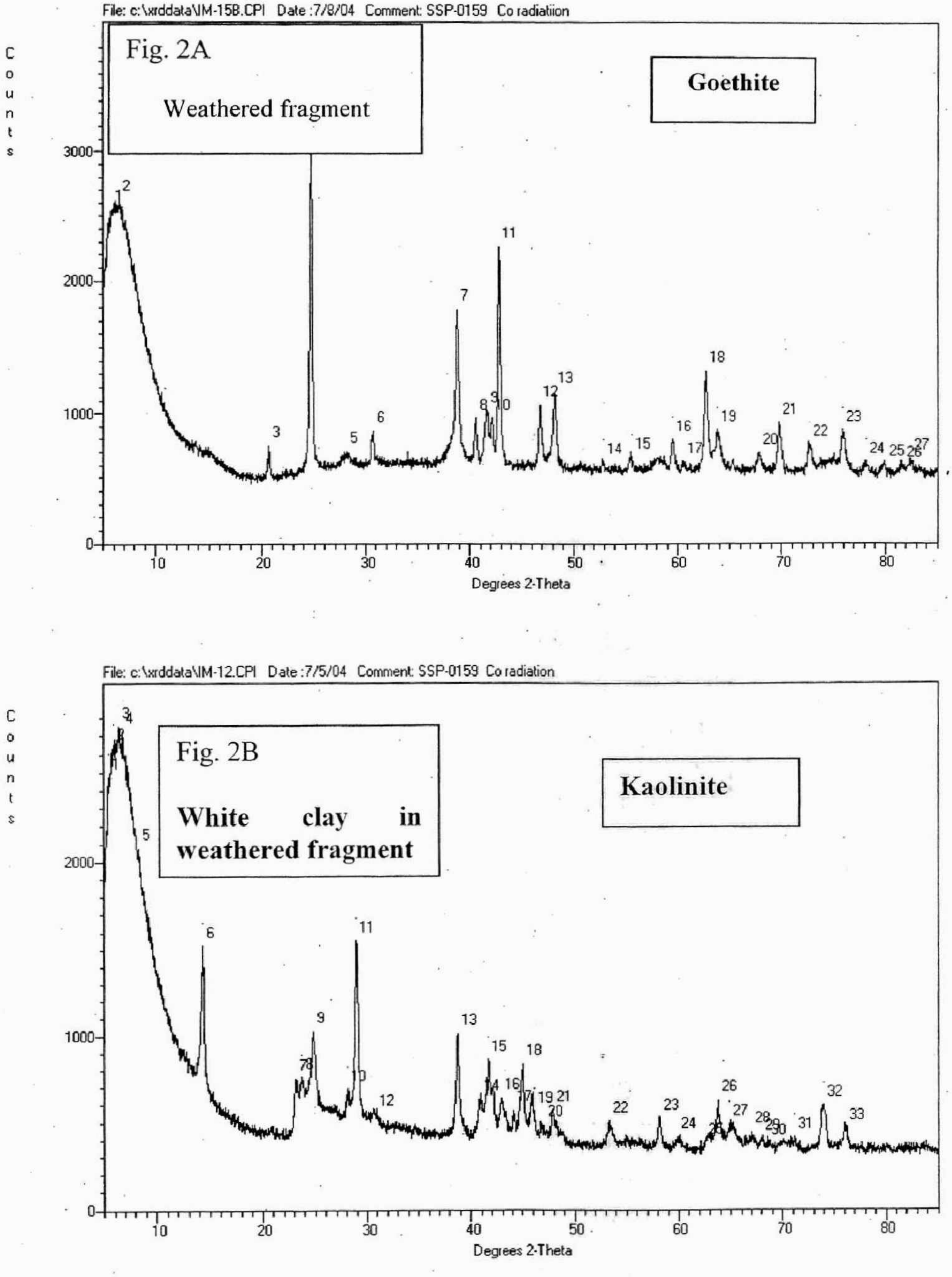

Fig. 1 : X-Ray diffractograms of selected ore fragments from the bulk iron ore sample.

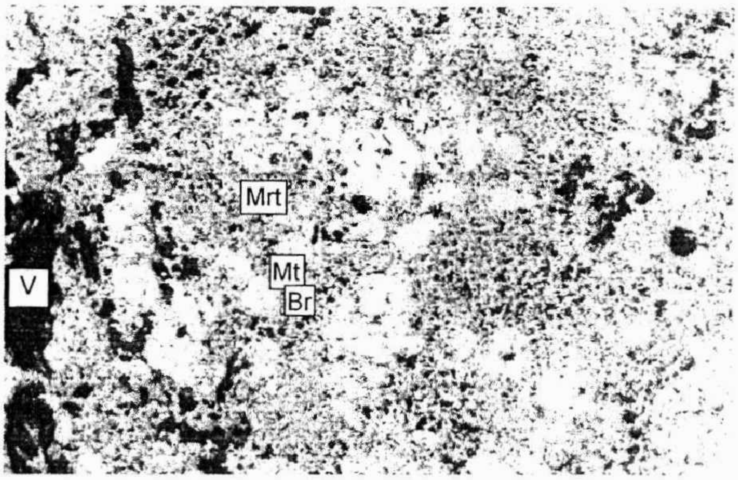

Fig. 2A : Microphotograph of partly martitised magnetite within a matrix of braunite (Br). The martitised magnetite have a core of magnetite (Mt) with an outer rim of martite (Mrt). Plane polarised light X200. The longer edge of photo equals to 0.6mm.

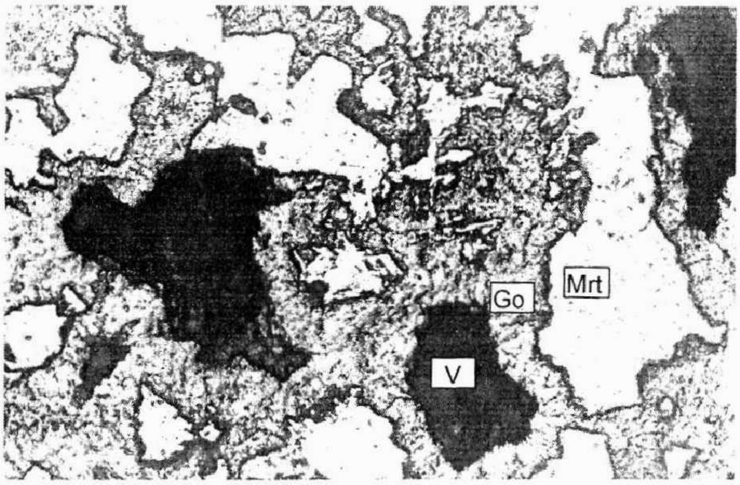

Fig. 2B : Microphotograph of martite (Mrt) and inconspicuously developed microplaty hematite around which goethite (Go) is deposited in the voids (V) by precipitation from solutions mobilised. Plane polarised light X200. The longer edge of photo equals to 0.6mm.

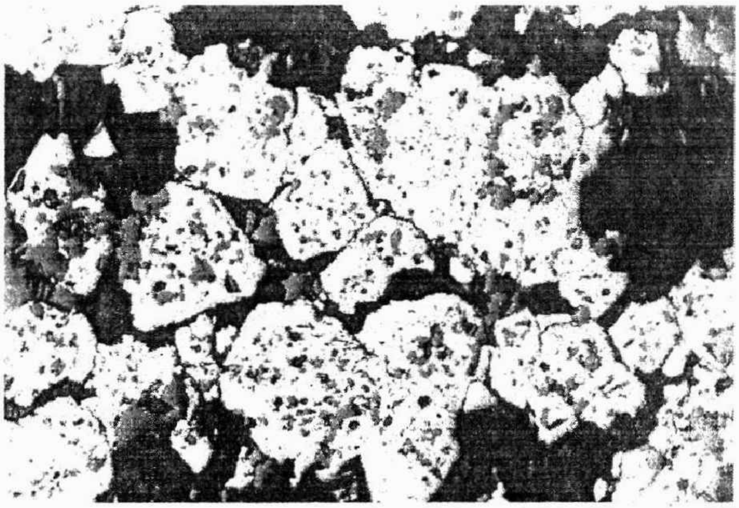

Fig. 2C : Microphotograph of martite (with high reflectivity) and quartz (grey colour with low reflectivity) association and void. Plane polarised light X200. The longer edge of photo equals to 0.6mm.