2 MINERALOGY, MAGNETIC PROPERTIES AND PROCESSING OF LOW GRADE NICKEL SULPHIDE ORES

2.1 Introduction

A deposit's mineralogy is probably the most important feature to consider when evaluating the development of a low grade ore body. The mode of occurrence and the physical properties of the valuable minerals will determine the metallurgical extraction route. For low grade nickel deposits, froth flotation is traditionally used to produce a sulphide concentrate, but the complex mineralogy often makes it difficult to successfully concentrate these ores (Sizgoric, 1981).

In this study the occurrence and distribution of nickel minerals are explored. It is also important to understand which minerals associated with the nickel ores will influence the flotation performance of the valuable sulphide minerals. Finally, the magnetic properties of minerals relevant to this study are discussed.

2.2 Mineralogy of nickel bearing minerals

Economic quantities of nickel occur in either sulphide deposits, laterite deposits or deep-sea manganese nodules. In sulphide deposits nickel is present in the sulphide minerals, while in laterite ores the nickel occurs in oxide minerals. Nickel is primarily produced from sulphide minerals and to a lesser extent from laterite ores. According to Terry et al. (1987) the recovery of nickel from deep-sea manganese nodules will not be economically possible until well into the 21st century. Low-grade nickel sulphide ore bodies typically contain an average nickel grade of below 1%. The nickel is primarily present as pentlandite, a nickel sulphide mineral.

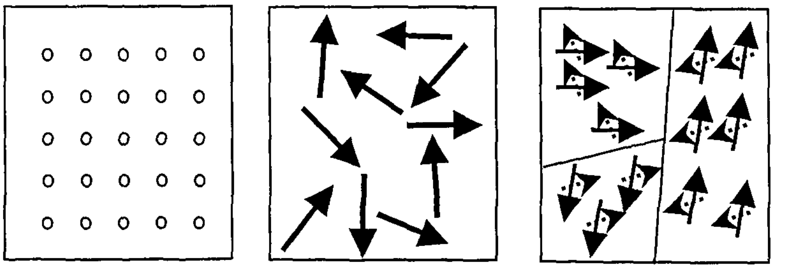
The successful extraction of nickel from an ore is dependent on the mineralogy of the ore body. When the primary nickel sulphides are altered, it may result in a reduction in flotation recovery. For example, the alteration of pentlandite to violerite and magnetite is usually accompanied by the transformation of pyrrhotite to nickelferrous pyrite and magnetite (Alcock, 1988). During liberation, violerite maintains its association with magnetite which forms a rim around the violerite; this shields the violerite surface during flotation causing the violerite to be lost to the residue. Sulphide minerals are invariably intergrown with each other and with the gangue minerals. Where the intergrowth is fine grained and complex, liberation and concentration of the sulphides are problematic.

The host rock, associated with the nickel sulphide minerals, can affect the recovery, grade, and the character of the sulphide flotation concentrate. The host rock of nickel sulphide deposits is either serpentized dunite, serpentized peridotite or gabbros. The gangue minerals of the serpentized dunite and serpentized peridotite typically contain fibrous or asbestiform silicates such as antigorite or chrysotile serpentine, or platy silicate minerals such as talc or chlorites which are difficult to reject during flotation. Gabbro host rock minerals consist predominantly of feldspar and pyroxene, with minor amounts of chlorites, biotite, muscovite mica, and asbestiform amphibole as troublesome silicates (Alcock, 1988).

2.3 Magnetic properties of materials and minerals pertinent to the present study.

The orbital motion of electrons around the nucleus of an atom, and the spin of the electron around its own axis creates a microscopic current loop, which generates its own magnetic dipole moment. These magnetic dipole moments of materials react in various ways in the presence of an external magnetic field.

Diamagnetic materials do not have permanent magnetic moments as is shown in figure 2-1 (a). However, in the presence of a magnetic field, the electrons are slightly unbalanced and small magnetic moments that oppose the external magnetic field are created. Diamagnetic materials are repelled by a magnetic field and reduce the external magnetic field. Magnetic susceptibility is negative in this case. Quartz (SiO_2) is an example of a diamagnetic material (Lawver and Hopstock, 1985).



(a) (b) (c)

o Diamagnetic material

→ Magnetic dipoles

⋯→ Antiferromagnetic dipoles

Figure 2-1 :Schematical representation of magnetic structures of materials, a) Diamagnetism (quartz), b) Paramagnetism (pyrite), c) Ferromagnetism (pyrrhotite)

In the presence of an external magnetic field, the magnetic dipole moments of paramagnetic materials align themselves parallel to the external field. When the magnetic field is removed, the magnetic dipole moments return to a random distribution as shown in figure 2-1 (b). Pyrite (FeS_2) is paramagnetic with a specific magnetic susceptibility of 0.004×10^{-6} to 0.013×10^{-6} (Lawver and Hopstock, 1985).

While paramagnetism and diamagnetism are only induced in the presence of an external magnetic field, ferromagnetism can exist in the absence of an external magnetic field. Domains exist where the magnetic dipole moments are aligned in the same direction and the antiferromagnetic dipole moments are aligned in a different direction; several domains can co-exist in a single particle and this is shown in figure 2-1 (c). In the presence of an external magnetic field, the magnetic dipole moments align themselves parallel and non-parallel to the external magnetic field.

Pyrrhotite is a non-stoichiometric compound and can be represented as $Fe_{(1-x)}S$ where x varies from 0 to 0.13 in natural samples. Monoclinic pyrrhotite has the highest metal deficiency, while hexagonal pyrrhotite has the lowest (Lawver and Hopstock, 1985). The iron deficient or monoclinic pyrrhotite is highly ferromagnetic.

2.4 Processing of nickel sulphide ores

The first processing step after mining of the ore is the liberation of the valuable sulphides from the gangue minerals by crushing and grinding. The sulphides are usually concentrated by froth flotation. The flotation concentrate is further treated pyrometallurgically and/or hydrometallurgically to produce nickel metal.

Conventional nickel flotation circuits are made up of rougher and scavenger stages followed by a cleaning stage. The exact configuration of the flotation plant is determined by the mineralogy of the ore body. Xanthate collectors are predominantly used for the flotation of nickel sulphide minerals. Various reagents like sodium carbonate, sodium cyanide, carboxymethylcellulose (CMC) and sodium chloride can be used to selectively depress or disperse different gangue minerals present in the ore.

Fine pentlandite intergrowths in the pyrrhotite result in high nickel losses when monoclinic pyrrhotite is magnetically rejected. On the other hand, excessive amounts of pyrrhotite in the flotation concentrate cause high SO_2 emissions during the pyrometallurgical treatment of the flotation concentrate. To counter this, flotation circuits are typically modified to include a pyrrhotite rejection stage. Various methods are used to depress the flotation of pyrrhotite, which include the exploitation of particle size, coupled to a pH change and reagent control, as reported by Senior et al (1995). The addition of sodium cyanide is a good depressant for slightly oxidised pyrrhotite (Agar, 1991).

According to Agar (1991), talc is a naturally floatable mineral and when present in sulphide flotation, it produces a voluminous froth with low sulphide recoveries. Talc is depressed using CMC, but with low-grade ores the high dosages of CMC necessary to successfully depress the talc, makes the process uneconomical (Wellham et al, 1992).

Serpentine minerals, which include chrysotile and lizardite, are also reported to reduce the flotation recovery of nickel sulphides (Edwards et al, 1980). The serpentine minerals form a slime coating on the sulphide surfaces thereby inhibiting the flotation of sulphides. CMC and NaCl could be used to disperse the slime coating and improve flotation (Wellham et al, 1992).

Talc and serpentine minerals, present in the flotation concentrate, lower the concentrate grade and increase the magnesium content of the concentrate. During the pyrometallurgical treatment of the concentrate, especially with the use of a reverberatory furnace, the magnesium raises the melting temperature as well as the viscosity of the slag; consequently the nickel losses to the slag are increased (Agar, 1991).

2.5 Application of magnetic fields in separating processes

Magnetically susceptible minerals, like magnetite and monoclinic pyrrhotite are frequently associated with nickel deposits. Sulphide minerals, with the exception of monoclinic pyrrhotite, are all non-magnetic. Magnetic intergrowths of magnetite or pyrrhotite may render some of the valuable sulphide particles magnetic.

The difference in the magnetic properties of minerals is frequently used to concentrate or separate the nickel rich minerals from the gangue minerals. Low intensity magnetic separators are sometimes used to remove monoclinic pyrrhotite and magnetite from the flotation concentrate.

Yalcin (1993) explored the possibility of magnetoflotation, a process involving a magnetic drum at the froth collection zone, which feeds back any magnetic material that reports in the concentrate of the flotation cell.

Applying an oscillating magnetic field to a flotation column will affect the movement of the magnetically susceptible materials during flotation. The movement of the magnetic particles may increase the possibility of a hydrophobic surface on the particle attaching to the bubble. The movement may also cause the particle and bubble to lose contact with each other. The slime coating caused by serpentine minerals such as chrysotile could possibly be dispersed by the rotation of the particles. The magnetic field may also affect the chemical interactions between the sulphide minerals and the collector. In the present study, the possible effects of magnetic fields on the flotation process with special reference to nickel sulphide minerals were investigated.