Preconcentration strategies in the processing of nickel laterite ores Part 5: Effect of mineralogy

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ARTICLE INFO

ABSTRACT

Nickel (Ni) laterites are characterised by low Ni grades, complex mineralogy and high moisture contents which have significant technical and economic impacts on their processing. These limitations can be reduced by the choice of appropriate preconcentration strategies leading to the production of a material with more favourable characteristics (e.g. higher grade of values, more easily treated material) being sent to the metal recovery process. Underpinning all this is the critical importance of a detailed knowledge of the mineralogy of the material to be processed. In this paper, various techniques have been described which can interrogate the mineralogy and associated chemistry of these ores, leading to a better understanding which can be used to determine the optimum preconcentration flowsheet for processing the material. Examples have been given for various scales of operations including commercial operating plants, pilot plants and laboratory investigations. Detailed mineralogy and examples have been given concerning several Western Australian Ni laterite ores that have been processed commercially, the Falcondo Mine in the Dominican Republic, and the complex, low Ni grade chromite overburden at Orissa, India. In all cases, the wide variation and complex mineralogy of these deposits compromises any simple upgrading processes, leading to complex and expensive flowsheets. It is the aim of this paper to review how detailed mineralogical and chemical knowledge of Ni laterite ores is essential in determining cost-effective methods for preconcentration of these ores prior to the recovery of metal values.

1. Introduction

This is the next in a series of papers by the author concerning various preconcentration strategies in the processing of nickel (Ni) laterite ores. Previous papers have addressed such aspects as a literature review on various preconcentration processes, laboratory investigations, flotation testing and preliminary dewatering studies. It is the purpose of this paper to show how knowledge of the mineralogy of Ni laterite ores is essential in any contemplated processing of these ores. Examples are given for various scales of operation including commercial operating plants, pilot plants and laboratory investigations. It must be emphasised that this paper is only concerned with the preconcentration stages of a process to extract Ni and often pay-metal cobalt (Co) from nickel laterite ores. Elias (2001) and Oxley and Barcza (2013) have reviewed the classic view of processing options for Ni laterites that involves the processing of the high Fe Ni limonitic laterites by acid leaching, higher Ni transition laterites by either acid leaching or the combined pyrometallurgical (reduction roasting) followed by hydrometallurgical (ammonia leaching) Caron process and the processing of the saprolitic Ni laterites by smelting. Oxley and Barcza (2013) suggested that integrating hydrometallurgical processing with pyrometallurgical processing could have environmental and economic benefits.

The economic justification for upgrading Ni laterites by some form of preconcentration is that, per tonne of Ni, less material has to be transported and smelted or leached (Crundwell et al., 2011). These authors state that laterite ores are always upgraded before smelting or leaching. This preconcentration step lowers the energy and reagents requirements, the equipment needed for shipping, smelting and leaching and the effluents produced while increasing the production rate of a given plant expressed as tonnes of Ni per year. All these factors result in lower costs for the production of Ni. The downside of the upgrading of the laterite ore is the loss of Ni in the rejected material from the preconcentration stage of the process. This loss is the consequence of the complexity of the Ni association with a number of mineral phases leading to the loss of the intrinsic Ni content of the rejected minerals and any accidental losses of some Ni-rich minerals with the reject stream. Each process must balance the benefits of preconcentration against these losses.

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Ni laterite ores are notoriously mineralogically and chemically complex and inherently variable in their characteristics (e.g. Canterford, 1975, 1978a, 1978b, 1983; Brand et al., 1998; Narasimhan et al., 1989; Elias, 2001; David, 2008). Onodera et al. (1987) used a wide variety of analytical and mineral separation tests on a Ni laterite ore from New Caledonia, and reported that, "in spite of the wide range of tests, the results were disappointingly poor".

Ni laterite ores are mainly classified as silicate and oxide deposits, where each laterite type may contain both silicate and oxide gangue minerals in varying proportions. The oxide deposits are characterised by three different zones: goethitic/limonitic, saprolitic and bedrock (Chen et al., 2004). On the basis of the mineralogy of the dominant Ni host for instance, laterite deposits are classified as limonitic, saprolitic or silicate deposits.

Limonitic oxide deposits are dominated by iron oxyhydroxides such as goethite, with subdominant hematite. Massive oxide deposits typically contain ~1.5% Ni and 0.1% Co as seen in goethite. Chandra et al. (1983), Golightly (1979) and Beukes et al. (2000) all report the preferential association of Ni with goethite in preference to other iron oxide minerals. Landers et al. (2011) and Dublet et al. (2012) showed that Ni was mostly incorporated in the structure of goethite, although it may be associated with other minerals (e.g. manganese oxides). Zhu et al. (2012) reported that the main Ni carriers in an Indonesian Ni laterite ore were asbolane, goethites (earthy and vitreous) and silicates. They also reported that no independent Ni minerals were observed in the laterite.

Saprolitic deposits are dominated by hydrated Mg-Ni silicates. These types of ore constitute ~80% of global Ni laterite resources. The Ni in this type of ore is commonly found within well crystallised and poorly defined Ni bearing hydrous silicates (e.g. garnierite) (Brand et al., 1998). The grade of these ores usually lies between 2 and 3% Ni.

Ni silicate deposits are dominated by clays of the smectite type. The silica combines with Fe and Al forming a zone where smectite clay (nontronite) dominates instead of iron oxides. Nontronite plays a similar role to goethite by substituting Ni for Fe^{2+} ions in its crystal lattice (Brand et al., 1998). The methods for the processing of Ni laterite ores are governed by their mineralogy and chemistry.

2. Techniques for investigating the mineralogy of Ni laterites

There are a number of well-established techniques used in the mineralogical investigation of Ni laterites. The most widely used method involves scanning electron microscopy with energy dispersive X-ray analysis, often in association with QEMSCAN® software. Samples are often analysed using Rietveld based quantitative X-ray diffraction (QXRD) methods to verify the crystalline mineral phases present in the laterites as an aid to establishing the species identification protocol (SIP) used in the QEMSCAN software. Chemical analysis is usually by standard X-ray Fluorescence (XRF) against known nickel laterite standards.

A combination of XRD, chemical analyses, petrography, scanning electron microscopy (SEM), electron probe and SEM with Energy Dispersive mapping was used by Chandra et al. (1983) to investigate the mineralogical characteristics of Ni laterites from the United States as well as the Philippines. Initial separation was made using screening and magnetic separation prior to detailed mineralogical analysis. This combination of physical and instrumental methods allowed a better idea of the distribution of Ni and Co in the laterites to be obtained. It was established that the Ni was mainly associated with goethite, and the Co associated with the wad, which was a mixed manganese oxide mineral.

Another example of the use of various techniques to investigate bulk and surface characteristics of a laterite from California has been published by Sen et al. (1987). Techniques used included optical microscopy, particle size distribution, XRD, chemical analysis on size fractions, thermogravimetric analysis, Mossbauer spectroscopy, bulk chemistry leading to the calculation of ternary phase diagrams, infrared spectroscopy, electron probe analysis, scanning electron microscopy, Auger spectroscopy, electron spin resonance, settling tests and zeta potentials. Preliminary magnetic and flotation tests were also conducted to investigate the possible preconcentration of this laterite using these physical separation techniques.

Some other examples of various techniques using more modern instruments are given below.

2.1. Scanning electron microscopy

Andersen et al. (2008, 2009) have described the use of this technique for the analysis of Ni laterites. This method was used by Swierczek et al. (2011, 2012) to investigate the mineralogy of a number of Australian Ni laterites. Standard QEMSCAN analysis relies on the spectra collected with 1000 X-ray counts, which is usually suitable for major minerals. For this study, with the low Ni values distributed in fine sizes, counting was increased to 5000 X-ray counts allowing for lower detection limits. Moreover, further manual investigation with 1,000,000 counts was carried out to specify the elemental composition of unclassified phases including Ni-bearing minerals. (Andersen et al. (2008) used 1.6–1.7 million points per sample for investigating Caldag Ni laterite samples). This problem had previously been identified and discussed by Botsis et al. (2008), where high levels of elemental substitution are usually associated with weathered Ni laterites. Ni and Co are often present at very low levels and, as a result, very high count rates are required to accurately quantify these elements. Extending the counting time during automated analysis would increase sensitivity but it would also increase the total acquisition time to impractical levels. This is the result of the complex and often fine dissemination of Ni throughout multiple mineral phases. Swierczek et al. (2012) reported a mismatch between the Ni values measured by QEMSCAN and those recorded by chemical analysis. This was primarily due to the relatively low concentration of Ni in the ores and its wide dissemination among several host minerals in complex association.

2.2. Extended X-ray absorption fine structures (EXAFS)

Dublet et al. (2012) used EXAFS in conjunction with X-ray Diffraction, Energy Dispersive X-ray Fluorescence and SEM to examine a 64 m vertical profile of a New Caledonian saprolitic-lateritic regolith regarding the hosting of the Ni. They reported that the Ni hosted in primary silicate minerals (olivine and serpentine) in the bedrock was incorporated in secondary phyllosilicates (serpentine) and Fe-oxides (goethite) in the saprolite unit and mainly in goethite in the laterite unit. A significant concentration of Ni (up to 30% of the total Ni) was also hosted in Mn-oxides in the lowest part of the laterite unit which contained large amounts of Mn-oxides.

Fan and Gerson (2011) used a variety of synchrotron analyses to investigate Ni laterite profiles in limonite and saprolite ores from the Philippines. Synchrotron techniques used included X-ray adsorption spectroscopy (XAS) comprising both X-ray adsorption near edge structure (XANES) and EXAFS together with synchrotron microprobe X-ray fluorescence microscopy (XFM) and diffraction (XRD) to provide quantitative analysis of the mineral components and Ni speciation. EXAFS suggested that the limonite Ni was associated with phyllomanganate via adsorption onto the Mn oxide layers and substitution for Mn within these layers. Laboratory SEM, coupled with electron dispersive spectroscopy indicated that Ni was also associated with concentrated Fe containing particles, which was further confirmed by synchrotron bulk and microprobe analysis. In the saprolite ore, approximately 90% of the Ni was associated with a serpentine mineral, most likely lizardite, as a replacement for Mg.