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# Preconcentration strategies in the processing of nickel laterite ores part 2: Laboratory experiments

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ABSTRACT

A number of physical separation techniques for nickel (Ni) laterites have been investigated at laboratory and pilot plant scale and reported in the open literature. These included sink–float (or dense media) separation, gravity separation, magnetic separation, electrostatic separation, (roasting) and flotation. The information located so far and reported in the literature review by Quast et al. (2015) suggests that all these techniques, although providing some degree of upgrading, have not been incorporated into full plant operations as yet. The only successful preconcentration technique incorporated into some commercial operations has been the removal of a coarse product containing lower Ni values than the feed. In this work, the application of a number of physical separation techniques (screening, gravity and magnetic separation with and without roasting) has been investigated in the laboratory for upgrading three Western Australian low-grade Ni laterites (goethitic, siliceous goethitic and saprolitic). Roasting of the goethitic laterite caused a noticeable increase in Ni and Co (and corresponding mass) recovery into the magnetic product with temperature up to a certain point, but this effect was reversed at 650 °C. Overall, the application of the selected techniques failed to produce any significant Ni grade enhancement for these three laterite ores. These tests confirm that the complex mineralogy of these three Ni laterite ores compromises any significant upgrading in Ni values by standard physical separation techniques.



## 1. Introduction

To date, preconcentration of complex, low grade Ni laterite ores poses considerable challenges. In our previous paper (Quast et al., 2015) a review of publically available literature concerning a number of physical separation techniques for the preconcentration of Ni laterite ores that had been tested at laboratory or pilot plant scale, and some which have been incorporated into commercial operations, was reported. By far the most common preconcentration process used ahead of commercial hydrometallurgical processing of Ni laterites is the removal of a coarse fraction from the feed which has a lower Ni content than the finer material. This results in the production of a coarser reject product which is either stockpiled or processed by heap leaching. The application of a number of other physical separation techniques for Ni laterites that have been investigated at laboratory and pilot plant scale were also reviewed. These included sink–float (or dense media) separation, gravity separation, magnetic separation, (sometimes incorporating roasting) and electrostatic separation. This information suggested that these techniques, although providing some degree of upgrading, have not been incorporated into full plant operation as yet. The general conclusion was that the complex mineralogy of Ni laterite ores compromises any significant upgrading in Ni values.

The aim of this paper is to provide information on the laboratory testing of various physical separation processes applied to three Western Australian Ni laterite ores as part of an investigation of possible preconcentration techniques for enhanced Ni recovery. The key strategy is to reject a stream with low Ni values, generating a higher Ni head grade feed to the main process for the recovery of Ni (and possibly Co) values. A brief mention of the application of attritioning and the rejection of a coarse fraction lower in Ni and the effect of roasting the goethitic sample ahead of dry, low intensity magnetic separation has been presented at the International Mineral Processing Congress held in Santiago in October, 2014 (Quast et al., 2014). More detailed information,

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including the effect of selective comminution, has been included in the current paper.

## 2. Experimental materials

The samples of Ni laterite selected are three ores studied as part of a larger CSIRO Minerals Down Under (MDU) supported Ni laterite beneficiation program of research. The samples were designated "siliceous goethitic", "goethitic" and "saprolitic" as suggested by their generic mineralogy. These are Western Australian Ni laterites from the same overall deposit, but with different mineralogical characteristics. A summary of their chemical and mineralogical characteristics are given in Tables 1 and 2 respectively. Chemical analysis was conducted on <2 mm run-of-mine (ROM) head samples using standard X-ray fluorescence (XRF) methods against known Ni laterite standards. Mineralogical analysis used Rietveld based quantitative X-ray diffraction (QXRD) methods. In order to investigate any significant changes in mineralogy with size, QXRD was conducted on various size fractions of the <2 mm ROM samples and summarised in Table 2. An example of the complexity of the goethitic Ni laterite as shown by a QEMSCAN image is given in Fig. 1.

**Table 1**
Summary of chemical analysis of samples of Ni laterites.

| Element | Siliceous goethitic | Saprolitic | Goethitic |
|---|---|---|---|
| Ni (%) | 1.0 | 0.92 | 0.96 |
| Co (%) | 0.068 | 0.039 | 0.065 |
| Mg (%) | 2.9 | 5.90 | 0.42 |
| Fe (%) | 20.0 | 21.8 | 42.2 |
| Mn (ppm) | 2800 | 2200 | 4600 |
| Zn (ppm) | 265 | 380 | 380 |
| Cu (ppm) | 20 | 25 | 130 |
| Al (%) | 1.85 | 3.55 | 5.06 |
| Cr (%) | 1.19 | 1.70 | 1.34 |
| Ca (%) | 0.03 | 0.03 | 0.02 |
| Si (%) | 23.0 | 17.0 | 5.10 |
| Cl (%) | 1.23 | 1.70 | 1.57 |

**Table 2**
Summary of major mineral deportment in Ni laterites according to quantitative X-ray diffraction analysis.

| Mineral | Goethitic | Saprolitic | Siliceous goethitic |
|---|---|---|---|
| Goethite | Dominant in all size fractions | Sub-dominant | Dominant in all size fractions |
| Hematite | Dominant in coarser sizes | Sub-dominant | Minor in fine sizes |
| Quartz | Minor | Dominant in coarse fractions | Dominant in coarse fractions |
| Kaolinite | Sub-dominant | Minor | Very minor |
| Serpentine | Minor | Dominant in coarse fractions | Minor |
| Smectite | Very minor | Dominant in fine fractions | Dominant in intermediate size fractions |

## 3. Procedure and results

Since Ni laterites are characterised by the presence of soft materials that break down during handling and processing, attempts were made to generate "clean" Ni laterite surfaces on particles for subsequent test work. For this reason a variety of preparation techniques were used to generate particle size distributions similar to those encountered in industrial processing. These are detailed along with each of the specific procedures used in the test work described below.

### 3.1. Attritioning and screening

In order to investigate the possible beneficial effects of the removal of coarse material containing lower Ni values, as discussed in the literature review (Quast et al., 2015), a sample of <600 μm siliceous goethitic (SG) laterite was passed through a Mozley 25 mm diameter hydrocyclone, and the overflow (slimes) discarded. The underflow sample was agitated at 900 rpm in a laboratory Denver flotation cell for 4 periods of 10 min each, with the slurry wet screened at 38 μm between each 10 min period. The >38 μm material was returned to the flotation cell for further attritioning. The final slurry was screened, and the screen fractions assayed for Ni. Since the slurry was dispersed at 900 rpm, it was believed that all the naturally occurring agglomerates would be dispersed in this time rather than stirring slowly for more than 1 h at 100 rpm as reported by Ma et al. (2013).

The results plotted in Fig. 2 show the Ni and Si distributions as a function of mass in cumulative size fractions of SG laterite where successive amounts of coarse fractions have been removed. A similar plot for wet screening the <2 mm ROM SG laterite is shown in Fig. 3. The Ni grades for the <600 μm attritioned sample are shown in Fig. 4 and Ni/Fe and Ni/Si ratios shown in Fig. 5. For this particular SG laterite sample, quartz predominates in the coarser size fractions (see Table 2 and Swierczek et al. (2011, 2012)). Figs. 2 and 3 show that as the coarse material is removed, nickel distributions become greater than mass distributions, and silica distributions become less than mass distributions. This means that minerals containing Ni are concentrated in the finer fractions and minerals high in silica in the coarser fractions.

### 3.2. Preliminary tabling tests

Preliminary tabling tests were conducted on specific size ranges of the attritioned SG sample to investigate the possibility of gravity concentration as a form of preconcentration. Samples were passed over the deck of a laboratory Wilfley shaking table, with photographs of the splitter end and the resulting products resulting from tabling the $-75+38$ μm fraction given in Figs. 6 and 7 respectively. Two size fractions were tabled, with the results given in Tables 3–6. These data show that while Fe and Co preferentially report to the table concentrates, Ni distribution follows weight distribution showing that Ni is distributed through a number of minerals of varying specific gravities. It does not appear possible to produce a lower Ni, high Si tailing product, because even though the Si distribution is high (approximately 90%), the Ni distribution follows weight distribution so this product cannot be discarded without significant loss of Ni values.

### 3.3. Magnetic separation tests

Since Kim et al. (2010) reported upgrading of Ni laterite using roasting and magnetic separation, magnetic separation was tested on the three Ni laterite samples using both a low intensity ($0.10 \pm 0.02$ T) dry magnetic separator and a Wet High Intensity Magnetic Separator (WHIMS) unit. Roasting tests ahead of dry, low intensity magnetic separation were conducted on the goethitic laterite size fractions. WHIMS testing on roasted material was only conducted on the <38 μm goethitic sample. The WHIMS machine was an Outotec 3 × 4L machine.

#### 3.3.1. Low intensity dry magnetic separation

Samples of laterite all passing 300 μm were dispersed in water using an overhead stirrer and carefully wet screened to generate three size fractions: $-300+150$ μm, $-150+75$ μm and $-75+38$ μm. These samples were dried and processed using the