# FROM TRIBULATION TO TRIUMPH – FLOTATION IMPROVEMENTS AT THE NEW LAC DES ILES CONCENTRATOR

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## ABSTRACT

North American Palladium commissioned the new concentrator at the Lac des Iles mine in the summer of 2001. The 15,000 tonnes per day mill replaced the existing 2,400 tonnes per day facility, as part of a major mine expansion.

At Lac des Iles, the grain size distribution of the platinum group minerals (PGM) is bi-modal. Roughly two-thirds of the PGM are relatively coarse-grained, and often associated with fast floating copper and nickel sulphides. The remainder is ultra-fine, and locked in silicates, which poses a special challenge to the metallurgist. The previous mill typically recovered just the fastfloating mineralisation, but to achieve target recoveries, the new mill has to recover a substantial amount of the ultra-fine PGM. The metallurgical challenges associated with the recovery of finegrained PGM in the talcous Lac des Iles ores, are described.

The paper describes the approach used in circuit optimisation, and how metallurgical and operational optimisation raised palladium recoveries by more than 6% in six months, by tuning the circuit to recover some of the ultra-fine PGM mineralisation.

## BACKGROUND

The Lac des Iles mine, owned and operated by North American Palladium Limited, is located about 115 kilometres north of Thunder Bay, Ontario. The mine originally opened in December 1993, and prior to 2001 included a mill capable of handling 2,400 tonnes per day of ore delivered from the nearby Roby pit.

Following an intensive exploration programme conducted in 1999, and a detailed feasibility study, conducted in 2000, North American Palladium initiated a mine expansion project, the objective being to expand milling throughput from 2,400 tonnes per day to 15,000 tonnes per day. This required construction of an entirely new mill, which was commissioned in May 2001.

## ORE MINERALOGY

Host rock mineralogy is dominated by silicates (Figure 1). Feldspars, amphiboles and chlorite constitute more than 75% of the ore. Pyroxene, a major constituent of the South African PGM ores, is relatively uncommon at Lac des Iles. Much of it is altered to talc. The talc content in the Lac des Iles ore varies between 2 and 4 percent.

Sulphides comprise about 0.6% of the Lac des Iles ore. In order of decreasing abundance, these include pyrite, chalcopyrite, pentlandite and pyrrhotite. PGM mineralogy consists, most predominantly, of palladium tellurides and arsenides, of which kotulskite and palladoarsenide are the most common minerals (Figure 2).

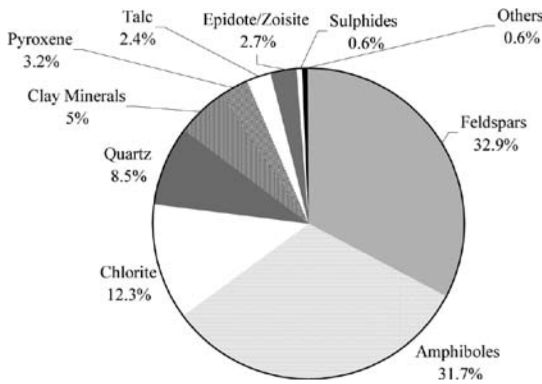


Figure 1: Typical Host Mineral Assemblage in Lac des Iles Feed (1,2)

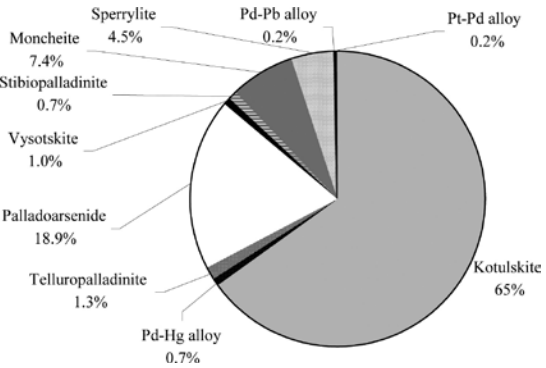


Figure 2: Typical PGM Assemblage in Lac des Iles Feed (1,2))

Liberated PGM float well, their kinetics typically being faster than the chalcopyrite in the ore. The key to their flotation usually lies in the grain size and association of the PGM. At Lac des Iles, mineralogical evidence points to a bi-modal distribution of PGM grain sizes (Figure 3). Coarser PGM (with an equivalent diameter of about 19 microns) comprise about 50-60% of the palladium in the ore[1]. Fine or ultra-fine disseminated PGM constitute the remainder – their association being mainly with silicates. The bi-modal distribution of PGM drives the palladium rougher/scavenger flotation kinetics curve, which includes a rapid flotation component, and a much slower flotation component (Figure 4). Mineralogy has confirmed that the faster-floating PGM are largely the coarser grained mineralisation.

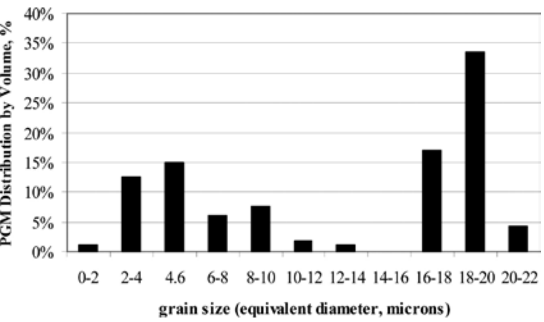


Figure 3: Palladium Grain Size Distribution

[1]The reader should be aware of the statistical variability associated with this analysis as the coarser (+16 micron) group of PGM grains are represented in the mineralogical database by just 10 grains.

## INITIAL TESTING AND FLOWSHEET DESIGN

Prior to start-up of the new mill, Lac des Iles recoveries were in the order of 73%, from a head grade of about 3.5 g/t palladium. Losses were due to inadequate grinding and short flotation residence times (1). Consequently, the new mill was designed to achieve a primary grind $k_{80}$ of 75 microns (finer than the $k_{80}$ of 150 microns achieved using the old milling circuit). Rougher/ scavenger flotation residence time was increased from 19 minutes in the old mill, to 55 minutes. Initial testing, conducted at Process Research Associates in Vancouver, led to the creation of the flowsheet described in Figure 5. Representing a departure from previous milling practice, the concept behind this flowsheet was to depress the floatable talc prior to rougher flotation, and then float the PGM and sulphide minerals, together with any attached silicates. Accordingly, 750 grams of CMC depressant were used, per tonne of mill feed. Flotation was conducted using potassium amyl xanthate (PAX) collector, and di-isobutyl dithiophosphate (DTP) promoter. Methyl isobutyl carbinol (MIBC) was used as a frother. In-keeping with common practice in the PGM industry, two different cleaner circuits were included, each after a concentrate regrind, to a product size of 80% passing 20 microns.

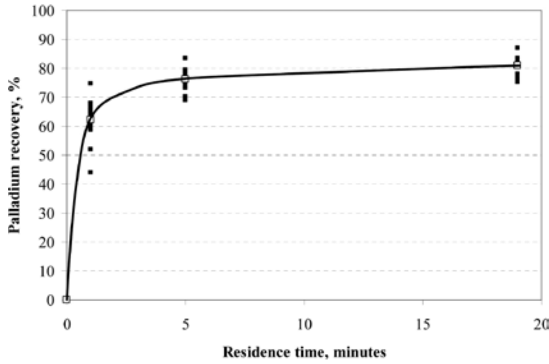


Figure 4: Palladium Rougher/Scavenger Flotation Kinetics (from Bench-scale Testwork)

This flowsheet was extensively scrutinised in a confirmation test programme comprising more than one hundred laboratory flotation tests involving several laboratories.

## ENGINEERING DESIGN

The plant was designed by Amec Mining and Metals in Vancouver. Primary semi-autogenous milling is performed using a 9.1m x 4.3m mill, driven by a 6.3MW drive, secondary milling is conducted using two 6.1m by 10.4m ball mills, each also drawing up to 6.3MW, and each operating in closed circuit with 380 mm cyclones. Pebbles from the SAG mill are crushed using a Metso HP800 cone crusher.

Ball mill cyclone overflow gravitates to a conditioning tank providing five minutes conditioning time, the tank overflowing into two parallel trains of flotation tank

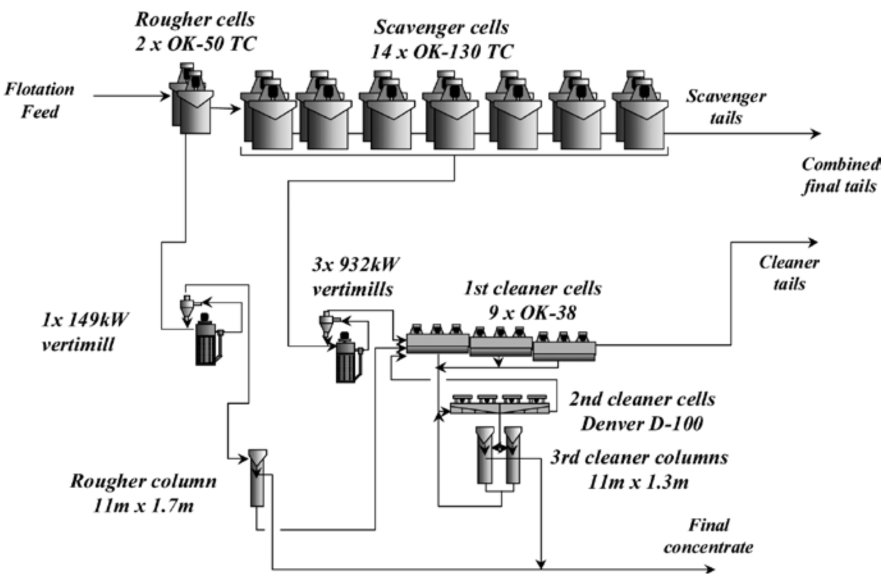


Figure 5: Flotation Circuit Flowsheet at Start-up

cells. Each train consists of a single 50 $m^3$ flotation cell, and seven 130 $m^3$ flotation cells, operating in series.

As commissioned, concentrates were cleaned in two cleaner circuits. The first was designed to clean the relatively high-grade rougher concentrate, and included regrinding in a 149 kW vertimill and a single stage of cleaning, using a 11m high by 1.7m diameter flotation column. The second, regrinding the lower-grade scavenger concentrate, employed three 932 kW vertimills, and three stages of cleaning, using a combination of conventional flotation cells and flotation columns. This circuit included nine 38 $m^3$ cells employed as the first cleaners, eight 3 $m^3$ cells as the second cleaners, and two 1.3m x 11m flotation columns, operating as the final cleaner circuit.

Concentrate from the two cleaner circuits are combined, thickened and filtered in two Larox pressure filters.

## START-UP

From start-up, the plant encountered operational problems. Froth stability within the rougher and scavenger cells, proved very difficult to maintain. This was ascribed to:

- A very small amount of available hydrophobic species in the concentrate to stabilise a froth. The ore contains just 0.6% sulphides, only some of which, are floatable. However, the testwork indicated a need to float over 20% of the feed to the rougher and scavenger concentrates, to be sure to recover a significant fraction of the low-grade middlings.
- The dynamics of the 50 and 130 cubic metre tank cells. Samples of flotation feed, when extracted from the plant, could be readily floated in the laboratory cell, the float consistently working as it had in the laboratory test programme.

Attempts to mitigate the problem of poor froth stability, using the polypropylene glycol frother, Dowfroth 250, failed. A more workable solution to the problem was found by reducing the CMC dose to a level where enough floatable talc was available to enhance froth stability. While overdepression hampered froth stability in the large tank cells, under-depression was equally problematic as it created an over-stable froth, which the plant was never designed to handle. Such froths proved very difficult to transfer (pump) to the concentrate regrind and cleaner circuits. Consequently, the rougher and scavenger circuits are operated in a narrow "window" of CMC dosage representing a compromise between both conditions, the objective being to maximise the mass pull to concentrate. This window moves depending on the inherent stability of the froth, itself dictated by certain, hitherto unidentified facets of the ore. This window ranges from 0-200 grams per tonne of CMC depressant.

Although this ensured the plant was able to function, its overall performance fell well short of target, as shown by the October monthly metallurgical performance statistics, included in Table 1 below:

Table: Performance of Lac des Iles Mill during October 2001
Compared to target

| | | TARGET | October 2001 |
|---|---|---|---|
| PLANT HEAD GRADE, | g/t Pd | 2.00 | 1.90 |
| PLANT RECOVERY, | % Pd | 82.0 | 67.5 |
| PLANT TAILS GRADE, | g/t Pd | 0.48 | 0.60 |
| PLANT CONCENTRATE GRADE, | g/t Pd | 170.0 | 175.0 |
| | % MgO | 7.0 | 9.9 |

While the problem of high tails was serious, at the time it was somewhat overshadowed by the high MgO content in the concentrate, which the smelters in Sudbury are not designed to handle. This problem had not been foreseen during the test programme. Before start-up of the new mill, concentrate production had always been too small to create MgO-related problems at the smelter so MgO had never featured in any smelter contract. With the increased concentrate production resulting from the expansion, this situation changed, and tight restrictions were placed on concentrate MgO contents.

## PLANT OPTIMISATION

A formal, structured plant optimisation programme was initiated in October 2001. The objective of the programme was to achieve significant improvements to plant performance by "quick fixes" such as the relocation of middlings streams, or changes in reagent dosage strategy. This programme included detailed surveys of the plant, supported by certain diagnostic examinations in the plant – such as size-by-size flotation recoveries, modal mineralogical analysis and tailings floatability testing.

### Surveys 1 and 2

The first two surveys revealed the following significant shortcomings in the circuit:

- The talc that was required to ensure froth stability in the roughers and scavengers could not be adequately removed in a single stage of cleaning, as was conducted on the rougher concentrate.
- The combined mass recovered from the rougher and scavenger cells was too low, leading to excessive losses to the scavenger tails.
- The flow of first cleaner concentrate was much higher than expected, due to the continued presence of talc. Accordingly, the second cleaner circuit was overloaded and second cleaner recoveries were very poor.

The problem of the overloaded cleaner circuits was suspected prior to the surveys, but the surveys proved and quantified the shortcomings of these circuits. Consequently, extra cleaner capacity was needed, and this was found in the form of the flotation section from the old 2,500 tonne per day mill, decommissioned earlier in the year. The first cleaner concentrate was pumped 1 km to the old mill, to conduct the second and third cleaner floats there, and return

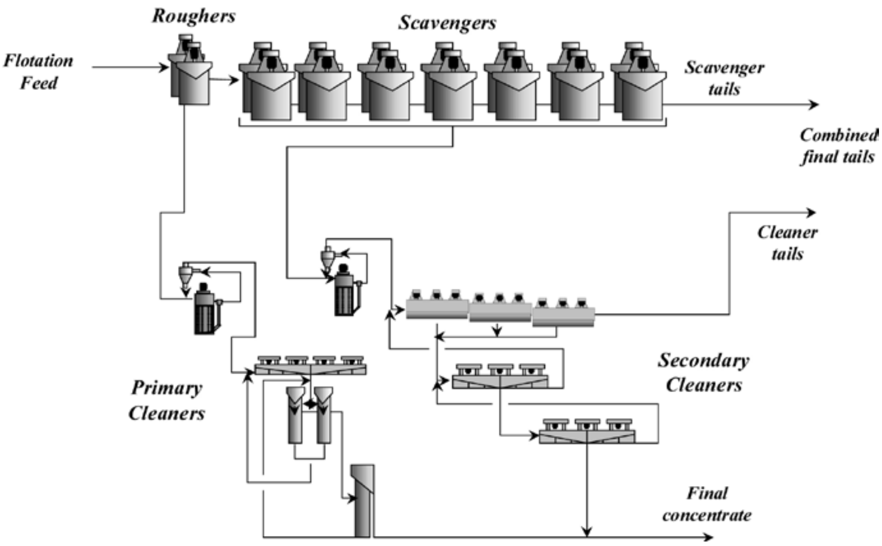


Figure 6: Circuit Commissioned in Late October 2001

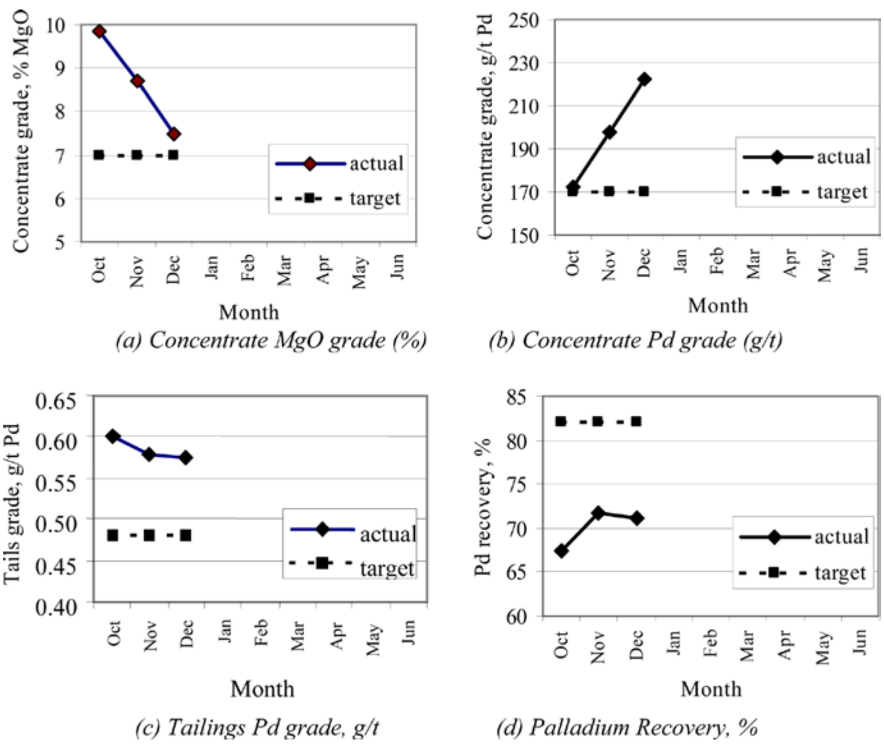


Figure 7: Change in Plant Metallurgy from October to December 2001
(showing effect of circuit change in November 2001)

the products to the new mill. This made the existing second and third cleaner stages available for upgrading the rougher concentrate, so considerably improving talc rejection. This modified circuit was commissioned in November. The circuit operated in November and early December is shown in Figure 6. Concentrate quality improved substantially, while concentrate pump upgrades and an improved focus on rougher/scavenger mass pull rates had a beneficial effect on overall palladium recovery rates, and final tails palladium assays (Figure 7).

## Survey 3

A third survey was conducted in mid-December, evaluating the circuit shown in Figure 6. This survey exposed some new issues:

- With the increased mass pull from the rougher and scavenger cells, the first scavenger cleaner circuit was proving to be too small. In fact, the residence time had halved since the previous survey was conducted, and was substantially below that assumed in the design. However, with three significant streams feeding this circuit, the circuit was now required to float considerable quantities of palladium. Of every 100 grams of palladium received into the plant, 73 grams reported, by some means, to this overloaded first cleaner circuit.
- Three stages of cleaning, of the scavenger concentrate were not always enough. A fourth stage appeared to be necessary, to complete final separation between low grade palladium-bearing middlings and residual, floatable talc. This would ensure consistently acceptable concentrate MgO levels.
- The primary cleaner circuit was highly effective, but oversized for the application, indicating an inefficient use of capacity in a plant already short of flotation capacity.
- The circuit was cumbersome and difficult to operate.

Throughout the start-up and optimisation programme, two separate cleaner circuits had always been employed, based on laboratory data. Such circuits are common in the South African platinum industry. There, particularly in Merensky plants a cleaner circuit is devoted to the recovery of platinum-rich slow-floating pyrrhotite, unimpeded by competition from fasterfloating minerals. This is not an issue at Lac des Iles, where the PGE are present as discrete platinum group minerals, and no evidence of a need for two cleaner circuits was revealed in the surveys.

Consequently, the two-cleaner concept was abandoned in the second half of December, and the circuit simplified to a single cleaner circuit. This circuit yielded steadily improved metallurgy in the ensuing months (January to March 2002), primarily due to a drop in the cleaner tails losses.

Further, to reduce the load on the under-sized first cleaner circuit, the second cleaner tails stream was directed back to the rougher feed, and the high-grade rougher concentrate delivered directly to the second cleaner circuit. The new circuit, shown in Figure 8, was commissioned on December 17, 2001, the results reported in the following months being shown in Figure 9. Plant performance, in terms of palladium recovery, reached 74%, and tails grades

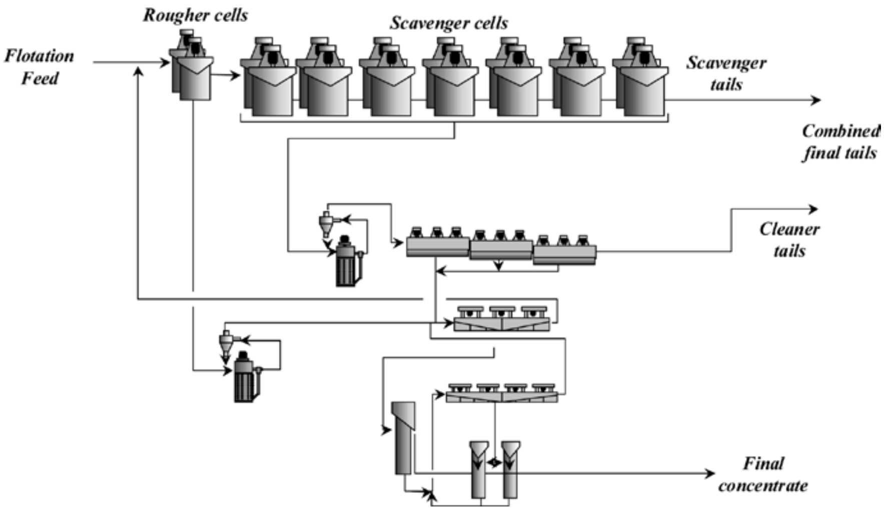


Figure 8: LDI Flotation Circuit Commissioned on December 17, 2001

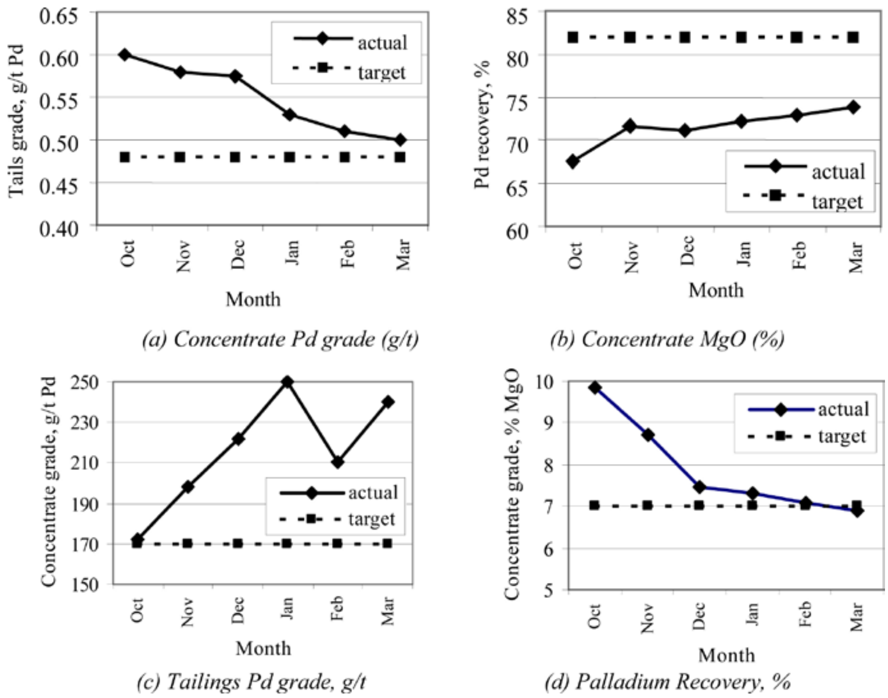


Figure 9: Change in Plant Metallurgy from October 2001 to March 2002 (showing effect of circuit change in December 2001)

dropped to around 0.50 g/t palladium – close to the target of 0.48 g/t. Concentrate grades fluctuated with ore type but, more importantly, the grade of the penalty element, MgO, dropped to an acceptable 7%. In the months since March, plant performance has varied on a monthly basis, probably reflecting the different ore types milled during the period, but has averaged about the same as in March.

### Surveys 4 and 5

Surveys 4 and 5 were conducted in January and April, 2002, on the circuit commissioned in midDecember. The results continued to support earlier observations that certain cleaner circuits were too small, but no further "quick-fix" opportunities for improvement were noted.

Phase 1 of the process optimisation programme was therefore concluded in March 2001. At that time, concentrate palladium grades were considerably above the target set in the feasibility study, and MgO impurity grades were slightly better than the yardstick 7%. Tails grades, at 0.50 g/t palladium were slightly higher than the target 0.48 g/t, but recoveries were well below the target 81%, a reflection of the head grade being somewhat lower than that used to calculate the target recovery.

## LESSONS LEARNED DURING THE OPTIMISATION PROGRAMME

The above is a broad brush overview of the first phase of optimisation work. Within the studies, however, various discoveries of note were made:

- Care must be taken in scaling up PGM flow sheets from laboratory to commercial scale. The problems of froth stability at LDI are not observed in laboratory flotation testing. Pilot scale testing may also not reveal the problem, and clear departures from conventional PGM processing techniques should only be taken with great care. There is much debate in the South African industry about cell size and cell dynamics, and solutions may in time arise from advances being made in this area. A closer look at the relationship between cell dynamics and froth stability appears warranted, based on the Lac des Iles experience.
- Flotation columns can be effective in PGM ore processing. Lac des Iles is unique in the PGM industry, in that the mill produces all its final concentrate using flotation columns. Aside from Lac des Iles and the Stillwater Mine in Montana, columns are not used anywhere in PGM flotation – numerous installations elsewhere being de-commissioned due to poor recoveries. However, the Lac des Iles column circuit produces one of the most silicate free concentrates in the PGM industry, at a stage recovery of 85%.

  The keys to the success of the column circuit at Lac des Iles are:

  - the matching of regrind size and optimal size-by-size recovery profile of the column, and,
  - the use of mechanical flotation cells equipped with paddles to maximise mass pull, so creating a high circulating load of middlings between the columns and the column scavengers.

- Lac des Iles is the only PGM concentrator regrinding all its rougher and scavenger concentrates. Repeated flotation testing on samples taken from the plant has shown that regrinding at Lac des Iles aids concentrate upgrading (Figure 10). The reasons for this need for regrinding are unclear, and do not appear to be mineralogical:

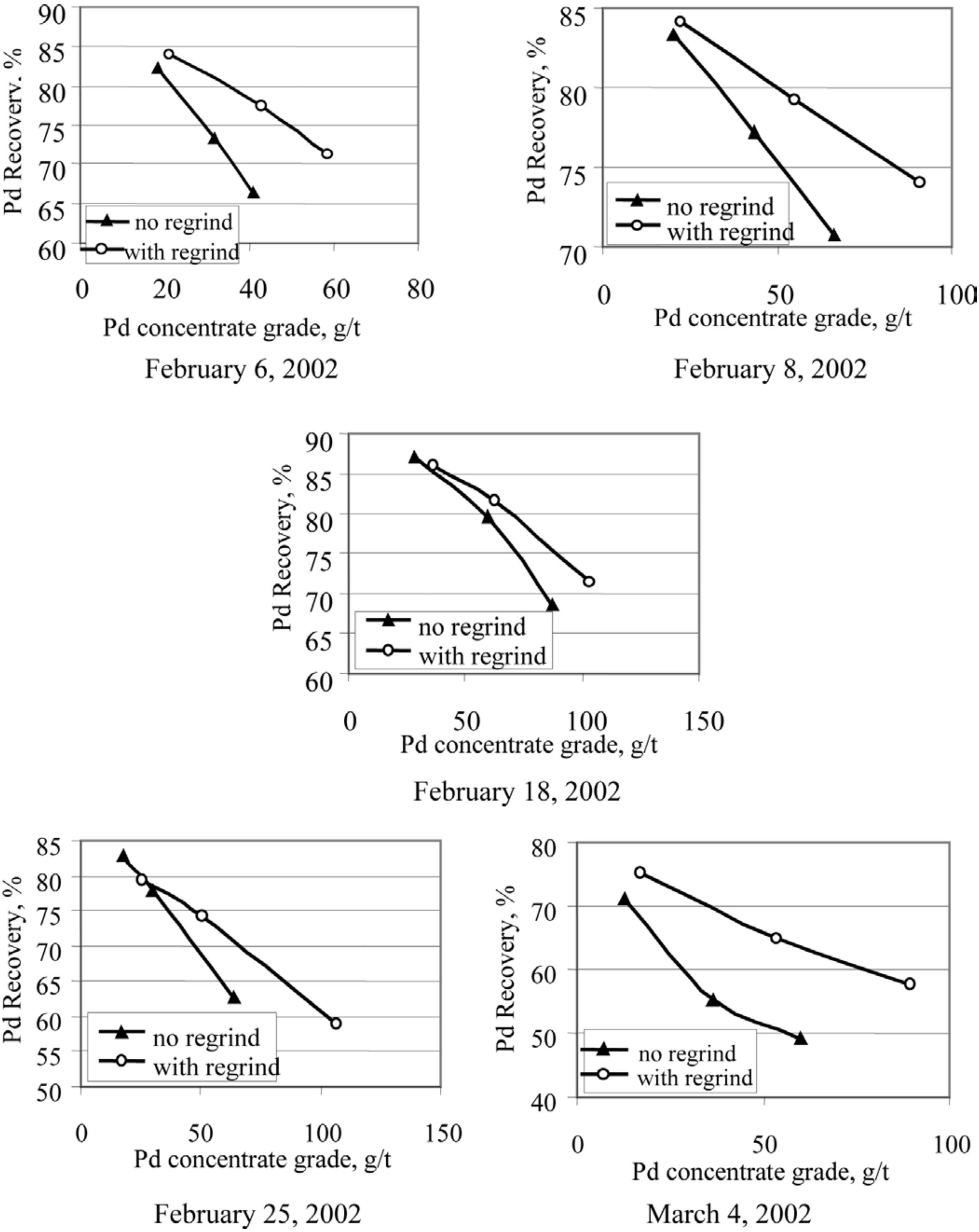


Figure 10: Effect of Regrinding on the Concentrate Grade and Recovery of Cleaning Lac des Iles Scavenger Concentrate

- QemSCAN analyses have demonstrated that the sulphide and gangue components, in the rougher and scavenger concentrates are well-liberated.
- The palladium-bearing grains are usually present as low-grade locks, but they represent an insignificant mass proportion in the concentrate

Regrinding may somehow improve gangue/depressant interaction. However, the results clearly demonstrate that concentrate regrinding may, for reasons not yet understood, have an important role to play in some PGM circuits[1].

## CHARACTERISATION OF LOST PALLADIUM AFTER INITIAL OPTIMISATION

There are three causes of palladium losses from the Lac des Iles mill:

- Incomplete liberation after primary grinding.
- Poor flotation of palladium slimes in the scavenger tank cells
- Incomplete residence time in the first cleaner circuit.

Eighty percent of the lost palladium, or roughly twenty percent of the palladium in the mill feed, is lost through the scavenger tails. Laboratory simulations of the rougher/scavenger float on the second cleaner tails stream (which is delivered to the rougher feed) indicated that 20% of the circulating palladium from this stream was lost to the scavenger tails. This source of loss represents about 9% of the lost palladium. Consequently, it is estimated that more than 70% of the lost palladium never floats. These losses are in two forms

- Unfloatable palladium, locked as minute, low-grade inclusions in silicates. Copious evidence of inadequate liberation exists, including size-by-size assay profiles, with the palladium assays highest in the coarser fractions (Figure 11), tails re-flotation testing which revealed the best recoveries being achieved after fine regrinding, and mineralogical studies which identified considerable lost palladium as sub-6 micron inclusions in silicate hosts.
- Losses of ultra-fine palladium-bearing material, which can be floated using different equipment. Pilot plant tests conducted in parallel to the main plant, and using
- identical conditions to the main plant, achieved the same overall recovery, but the size distribution of the lost palladium was markedly different, with the pilot plant
- equipment losing less ultrafine palladium (Figure 12).

[1] Care should be taken not to over-grind talcous PGM concentrates, Pilot tests at Lac des Iles have demonstrated that polymeric depressants are considerably less effective on ultrafine talc, markedly reducing the efficiency of concentrate regrinding when regrind targets of 80% passing 10 microns or finer, are sought.

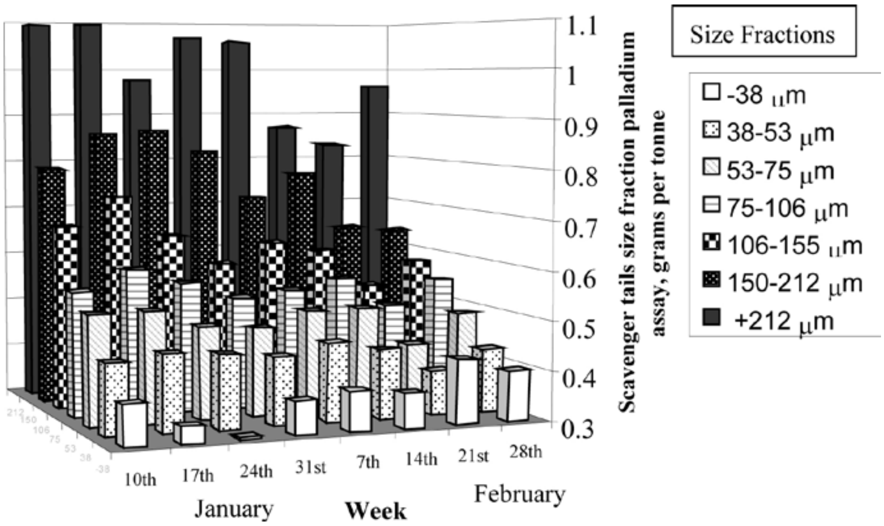


Figure 11: Palladium Analyses from Coarse Size Fractions, of Eight Weekly Composites of Plant Tailings from January and February 2002

The remainder of the losses report through the first cleaner tails. These losses are usually attributed to incomplete flotation, rather than incomplete liberation. PGM cleaner circuits tend to incorporate extensive residence times, 1-2 hours being typical in the South African plants. The first cleaner residence time at Lac des Iles is relatively short, at 30 minutes.

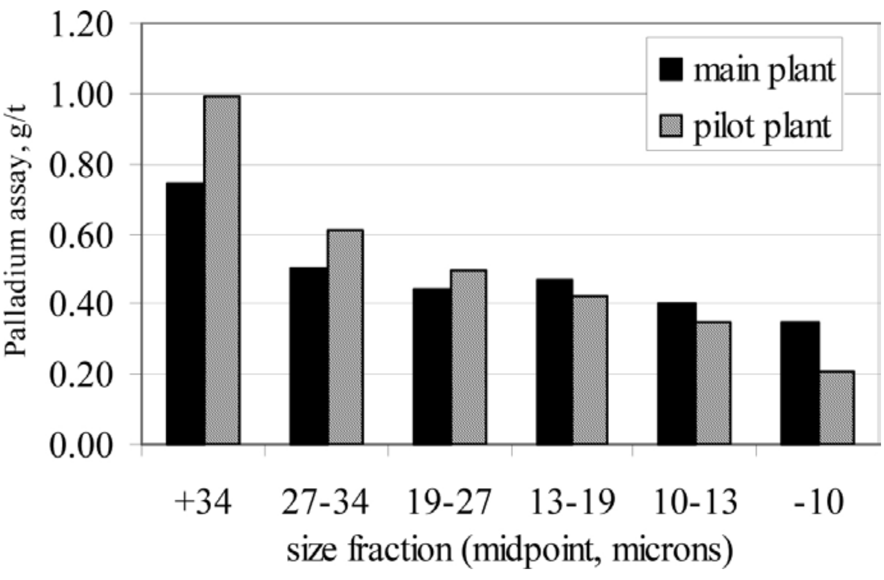


Figure 12: Comparison of Size-by-size Assay Profiles of Tailings from Parallel Production Plant and Pilot Plant Rougher/scavenger Circuits

## FUTURE DEVELOPMENTS

Work continues at improving plant performance at Lac des Iles. The benefits of tertiary grinding have been explored extensively in recent months, the aim being to improve liberation of the palladium. Results indicate that recoveries will continue to improve as finer grinds are adopted, and studies to date have shown that tertiary grinding to a product size as fine as eighty percent passing 35 microns is economic.

The problems of ultra-fine palladium losses are being studied by evaluating the operation of the tank cells. Using techniques developed at McGill University, studies have recently begun, to better understand the dynamics of these cells with the hope that this understanding will lead to opportunities for improved recovery of ultra-fine palladium values.

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