Learnings from Dry Stacking Fine Grained Nickel Residue in the Tropics

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ABSTRACT: Prony Resources Nouvelle Calédonie (PRNC) has been studying options for the long-term management of their nickel residue since 2014. In late 2015, a feasibility study was commissioned to review and engineer the opportunity to safely and economically place and compact dewatered residue cake at their facilities in New Caledonia. The site is located in the south-eastern corner of the country and is prone to high winds, moderate seismicity and cyclonic rainfall patterns. The average annual rainfall exceeds 2 500 mm. The non-typical gypsum stabilized residue material is fine grained ($D_{50} < 6$ μm) and exhibits challenging chemical properties, which influence characterization testwork.

During the project a demonstration facility comprising a tailings thickener, plate and frame filter press and materials handling system was constructed. The facility, designated as Dewatering Plant No. 1 (DWP1), was designed to treat 10% of the overall process plant residue production, or approximately 1 800 dry tonnes per day (dtpd). The authors were involved in the design and construction of the DWP1 plant and supporting construction methodologies for the demonstration stack. After commissioning and ramp-up, technical support was provided to PRNC site personnel, including the management of QA/QC to better understand the long term geotechnical and geochemical performance of the residue. During this 2-year trial, experience and knowledge was gained on material behavior, compaction and constructability issues (particularly trafficability) and surface water management for a laterite nickel residue filtered residue landform in a tropical climate.

This paper presents the results and learning gained from more than 2 years of fieldwork and describes some of the challenges faced during the journey to construction and implementation of a full-scale (20,000 dtpd) filtered residue landform in a tropical climatic setting.

1 INTRODUCTION

Prony Resources Nouvelle Calédonie (PRNC) currently operate an integrated Nickel processing facility, producing Nickel and Cobalt from laterite ore. The site is located in the southeastern corner of New Caledonia, a pacific island off the coast of eastern Australia. The site is located within a tropical climatic zone and experiences seasonal cyclonic weather patterns with an average annual rainfall exceeding 2 500 millimeters (mm) per annum.

The process uses High Pressure Acid Leaching (HPAL) technology to refine the primarily clayey silt laterite ore, referred commonly as limonite and saprolite ores, to produce a nickel cobalt concentrate. This concentrate is further refined to produce nickel and cobalt metal. The limonite ore at the site contains approximately 1.4 % to 1.5 % nickel and hence produces significant waste, or tailings. The tailings from the process is peculiar, in so much as it requires the addition of limestone to neutralize the acid used in the process. The addition of limestone to the acid rich limonite ore results in the precipitation of gypsum, which further bulks up the tailings volume and adds complex chemical behavior affecting the physical properties of the tailings. The combined gypsum and iron oxide tailings is referred herein as a residue

In 2014, PRNC started investigating options to extend the capacity of the tailings storage facility (TSF), initiating the design of a new large conventional TSF. However, due to initial capital cost and environmental constraints, this option was not pursued. A tailings technologies review identified filtration as a potential high value alternative to the conventional option. The filtration concept was developed through various phases of engineering between 2015 to 2018 and included the design and construction of a 1/10th scale demonstration plant and associated filtered residue landform.

This paper discusses the challenges faced and methodologies developed to first understand the dewatered residue physical behavior and then optimize mechanized placement of this challenging tailings material in a tropical environment.

2 METHODOLOGY

2.1 *Background and Layout*

Filtered residue landform of laterite nickel tailings (residue) at this scale in a site that commonly experience more than 2.5 meters (m) of rainfall annually, had no reference benchmark. Due to these risks and perceived challenges, PRNC elected to construct an 1 800 dry tonnes per day (dtpd) plate and frame pressure filtration plant, designated as Dewatering Plant No. 1 (DWP1). The plant was constructed to test the process and its ability to effectively dewater the complex residue material, but also to understand the behavior of the residue in the field and optimize the equipment used to construct the filtered residue landform. The DWP1 facility and filtered residue landform also provided a training facility for the future full-scale dewatering operation.

The facilities comprised a high rate thickener to ensure consistent quality feed (underflow density) to the filter press, a 90 plate fast filtration pressure filter, load out bunker and 500 000 tonne (t) design capacity filtered residue landform demonstration facility. The filtered residue landform was constructed within the existing tailings facility impoundment to ensure any runoff is captured and contained within the lined basin.

A site plan showing the layout of the existing lined basin, DWP1 plant and filtered residue landform are presented in Figure 1.

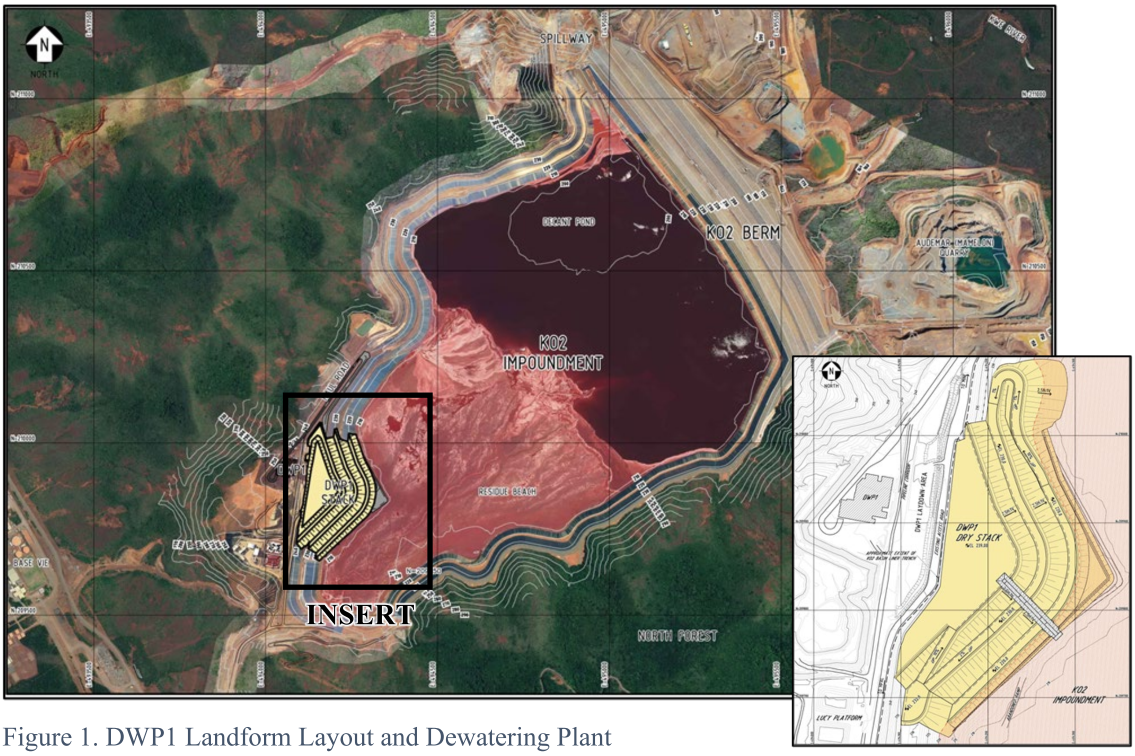

Figure 1. DWP1 Landform Layout and Dewatering Plant

At completion, the filtered residue landform will be approximately 29 m in height. The landform will be built in nominal 500 mm thick placed layers graded toward the east and south. This configuration will encourage surface runoff to the perimeter crest drains, with flows then directed into a rock lined batter chute to limit erosion of the surface residue and gully formation along the slopes and benches. The drains are constructed progressively as the filtered residue landform is raised. A 3D rendering of the final DWP1 filtered residue landform is presented on Figure 2.

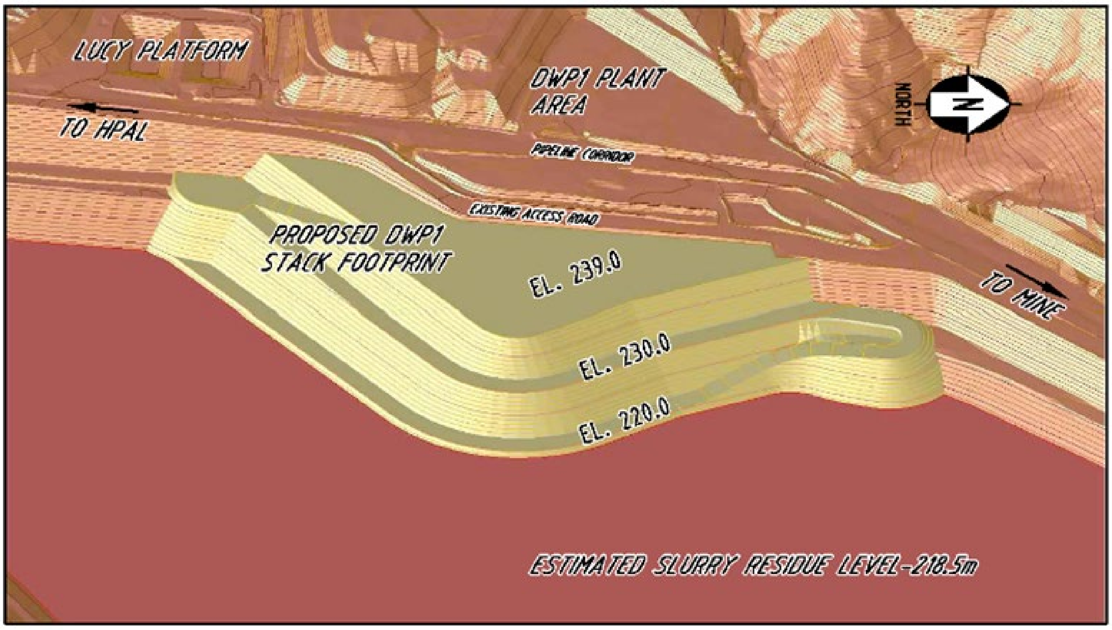

Figure 2. DWP1 Stack Layout, 3D Rendered View

2.2 *Test Objectives*

The DWP1 filtered residue landform was constructed to test the following key risks and unknown conditions prior to approval of the full-scale project. These included:

- Dry density of the compacted residue cake and ability to achieve the design compaction specification
- Trafficability of the residue and workability in a tropical climate
- Strength and compression of the residue over time (creep and shear strength losses or consolidation strength and density gains resulting from saturation)
- Infiltration of surface water through the residue and potential for re-saturation and phreatic level build-up (reduction in effective stress)
- Erosion of the residue surface and dissolution (leaching) of the gypsum present in the residue (internal erosion)

The dry density, trafficability and erosion (dissolution risks) were thoroughly investigated during 2017 to 2019 and are discussed further herein. The strength and infiltration properties for the landform have not yet been fully investigated. The performance of the stack (residue strength and saturation) will be analysed in the future using geotechnical investigation methodologies after sufficient thickness of materials have been placed.

2.3 *Design Criteria*

At the onset of the demonstration stack construction, the following key criteria were assumed for design development. These criteria were to be modified based field measurement and observations.

Table 1 Design Criteria for scale of DWP1 filtered residue landform

Design Criteria	Unit	Value	Comment
Compaction Density - Structural Residue Zone - General Residue Filling	%	 95% 90%	 Based on Standard Maximum Dry Density (SMDD) (NF P94-093)
Bearing Capacity	kPa	200	Adequate for traffic by 740 CAT articulated dump truck or equivalent (CAT Handbook, 2008)
Sediment loading from runoff	g/m^2/day	50	For confirmation of Pond dead storage
Vertical Permeability	m/s	1×10^{-8}	To limit infiltration measured using Guelph Permeameter (Soil Moisture Corp, 2008)
Level of Saturation	%	> 90	Assumed to be saturated

3 RESULTS AND DISCUSSION

3.1 *Dry Density and Compaction*

A total of 152 field density tests were completed between March and October 2018. Table 1 provides a summary of the average, maximum, and minimum results for density, moisture content, and degree of compaction. Moisture results from field nuclear densometer (Troxler) testing were recorded for comparison with site laboratory results. All moisture contents presented below represent corrected moisture readings from samples dried at 50° C or in-situ test data. These provide a more accurate measure of the true moisture of the gypsum rich residue and eliminates calcination of the samples and misrepresentation of results. Dry densities were adjusted accordingly, and the degree of compaction calculated using corrected moisture and density results.

Table 2 Summary of Field Density Test Results and Laboratory Reference Tests

Statistical Description	Field Results (Nuclear Densometer)				Laboratory Reference		Degree of Compaction
	Bulk Density	Oven Moisture	Troxler Moisture	Dry Density	SMDD*	OMC§	
Unit	t/m^3	%	%	t/m^3	t/m^3	%	%
Average	2.11	30.9	31.5	1.62	1.73	25.1	93.7
Maximum	2.29	45.7	46.6	1.83	1.77	28.5	112.1
Minimum	1.89	23.4	18.7	1.30	1.55	22.1	74.6
Standard Deviation	0.05	0.5	5.4	0.04	0.02	0.1	2.2

* Standard Maximum Dry Density or Standard Proctor Density
§ Optimum (Gravimetric) Moisture Content

The average in-situ dry density was 1.62 t/m^3. This value is higher than the conservative estimate of 1.29 t/m^3 used during the study phases. The dry density of 1.29 t/m^3 was defined by numerous standard proctor compaction tests performed on samples generated during pilot testing. The results show deficiencies and limitation in accurate determination of the residue dry density. The difference in density is a function of material variability and highlights the value of the larger scale field trial in the determination of this critical design parameter.

3.1.1 *Compaction and Optimum Moisture Content (OMC)*

Figure 3 compares field compaction results to the line of optimums for dry density and moisture content. During the feasibility level studies, a target OMC of 33%, corresponding with a residue cake solids content of 75% was defined. The filter press struggled to produce residue cake drier than 73% solids. The field trial indicated that the residue OMC was lower than that which could be reasonably produced from filtration alone.

The field results show saturation levels ranging from 90 % to 95 %, whereas the line of optimums corresponds to a saturation level between 80 % to 85 %. This suggests a higher level of saturation than what was determined from the feasibility study residue cake testing campaign. Many of the samples tested show very high saturation levels, hence difficulty in field compaction was observed with pumping conditions in the wetter residue fill. Very few samples were at or dry of the lower bound OMC, and the majority of field samples ranged from 25 % to 33 % in moisture content. The results show a broad range in OMC and dry density, and hence why any construction specification needed to be appropriately flexible to account for the inherent variability in residue consistency and chemistry.

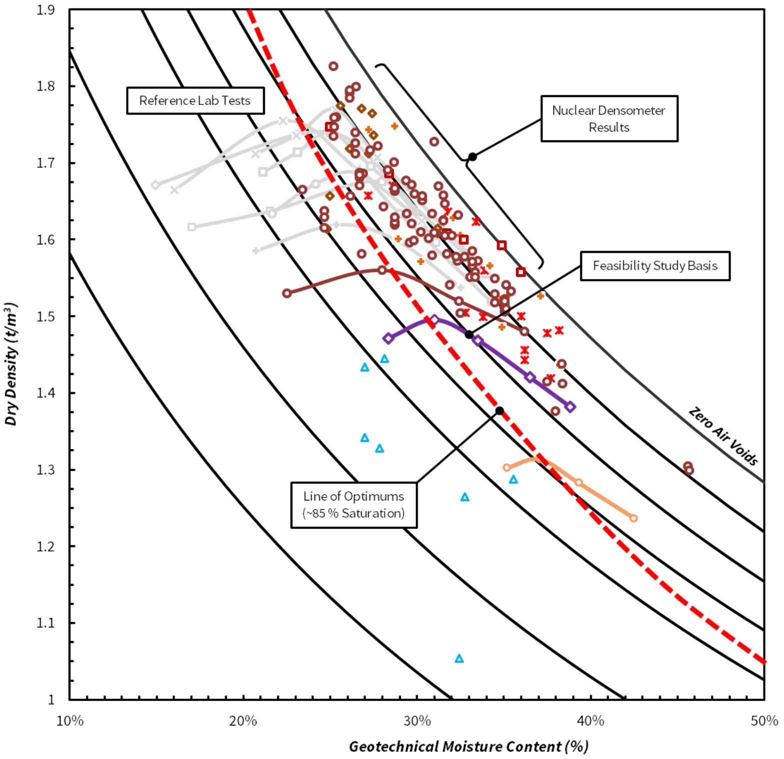

Figure 3. Comparison of Field and Laboratory Compaction Results

3.1.2 *Gypsum Effect*

Figure 4 presents the compaction curves for residue cake collected from DWP1 for the range of gypsum contents ranging from 12 % to 60 %. The Standard Maximum Dry Density (SMDD) for the residue samples ranged from 1.45 t/m^3 to 1.82 t/m^3, with an average value of 1.59 t/m^3 (1.55 t/m^3 if the two 12 % gypsum content, high iron sample results are excluded). Typically, the "line of optimums" falls between the 70 % to 80 % degree of saturation lines.

This range is presented on the graph and bounded by the dashed red lines. It should be noted that the low gypsum content sample (12.5 % gypsum content) has an SMDD corresponding to a much higher degree of saturation, which is unlikely to be readily achievable in the field. This result was repeated, but to a lesser extent in the second low gypsum sample at 12.8 %, which showed the OMC corresponding to approximately 80 % saturation.

The results also show an increase in SMDD with negligible change in the OMC as gypsum content reduces. This is due to the increase in Specific Gravity (SG) associated with the lower gypsum samples (i.e. lower proportion of gypsum which typically exhibit SG values around 2.3) but would expect the OMC to follow a discrete saturation or air voids and therefore reduce proportionally to the change in SMDD.

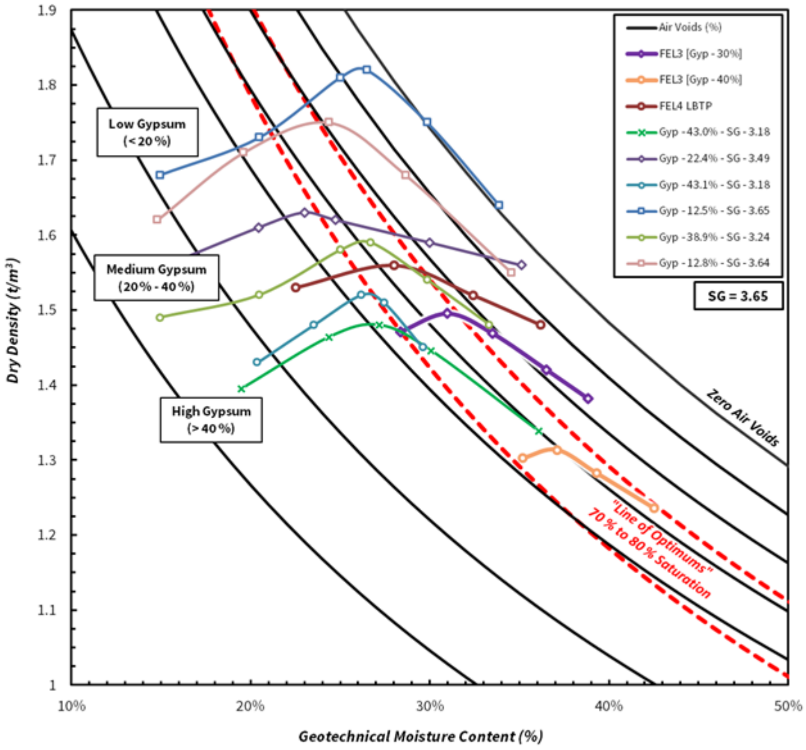

Figure 4 Compaction Curves for DWP1 Residue Cake based on Variation in Gypsum Content

3.1.3 *Trafficability and Materials Workability*

Trafficability to and on the stack was impacted by wet ground conditions. This was particularly noticeable where the 30 t articulated dump trucks (ADTs) fitted with standard width tires drove over previous tracks and discrete rutting was observed. However, even during this rutting the six-wheel ADTs were never bogged in the residue materials. Under wet conditions the largest challenge was slippery conditions. This was most noticeable when attempting to traffic the surface with the standard four-wheel drive site vehicles fitted with narrow tires.

Due to the constrained size of the DWP1 platform, trucks traversed over the same area multiple times to access the filtered residue landform. It was also difficult to allow adequate time for the residue to dry in these areas in order to achieve acceptable bearing capacity. To improve the workability and trafficability within the stacking area, a designated buffer zone was constructed to provide an option for storage during inclement weather. The additional area of the buffer created more work for the contractor to load and back haul materials (double handling) but added the necessary increase in area to drastically improve the residue workability. For larger (full production scale) operations, it will be critical to designate multiple placement fronts and include temporary wet weather stockpiling capacity near the plant. These measures will help reduce double handling requirements and therefore costs.

3.2 *Erosion and Dissolution*

Surface water management best practices were followed during filtered residue landform construction, however heavy rain events still severely affect productivity and materials placement quality. The filtered residue could not be compacted during or following such a rainfall events (i.e. with typical threshold exceeding 10 mm per 24 hours). If loosely placed residue were exposed to wetting, it was harrowed and left out to desiccate prior to attempting further compaction. The timing between spreading and compacting of material was determined to be a critical factor to avoid double handling and thereby increase operating costs. A batter slope of 1V:2H at a nearby stacking trial showing the condition of the residue surface after approximately one year of exposure presented negligible erosion or dissolution (refer Figure 5).

Figure 5: Condition of Compacted Residue Slope Batters approximately One Year after Construction

Mass leaching tests were carried for a range of inflows to evaluate the potential for Calcium (Ca), Magnesium (Mg) and Sulphates (SO_4) to leach from the residue. These tests were performed on bulk samples placed at the design compactive effort in a controlled laboratory environmental. The samples were subjected to a range of rainfall intensity events with both flat and sloping grades, to simulate the conditions likely to occur during field placement of the residue. For a maximum leach ratio of 10 litres per kilogram (l/kg), approximately 42 grams (g) of major elements leached from an equivalent1 kilogram (kg) residue sample.

From transient seepage analysis, adopting a typical range of saturated permeabilities for the residue, it was estimated that between 9 % to 28 % infiltration could be expected for compacted and loosely placed residue respectively. Applying the average rainfall of 2.85 m/yr over the approximately 5 hectare (Ha) area of the DWP1 filtered residue landform footprint, the peak infiltration rate for the facility was calculated to be approximately 0.5 l/kg annually. From field testing on the residue columns, the results indicate a potential for 7 g/kg of solids could be removed from the residue column. This suggested approximately 0.7 % potential loss in mass annually due to leaching and dissolution of the Ca, Mg and SO_4 within the residue.

4 CONCLUSION

4.1 *Residue Moisture Content*

Moisture contents in the filter cake were measured on discharged samples from the DWP1 plant and were determined to be generally >3 % wet of the estimated target OMC tested during feasibility studies. This suggests that filtration alone was not able to meet the field requirement and the residue will require some conditioning in the field to achieve the higher compaction specification for structural materials. Conditioning the residue during the wet season is difficult due to the frequent and intense rainfall events. It is therefore critical that any filtered residue landform in such an environment comprise a non-structural or off specification zone whereby the “wetter” cake produced during the wet season can be stored without a requirement for unnecessary double handling. Other options such as temporary wet weather stockpiling at the plant may be considered depending on space availability.

Once placed in the field it is imperative the residue is spread and compacted to prevent further moisture infiltration. During drier periods, the surface may be opened using harrowing equipment or rippers to increase exposure of the residue to solar drying. The dark colored iron rich residue materials proved to dry out rapidly when exposed to solar drying as a result of lower albedo.

4.2 *Compaction*

The compaction methodologies adopted for construction of the DWP1 filtered residue landform proved that more than 40% of tests performed in the field achieve a density ratio at or above 95 % SMDD. Approximately 70% of the tests achieved a degree of compaction greater than 90 % SMDD, which would exhibit adequate undrained shear strength (S_u) for non-structural fill (in non-critical bulk fill areas within the filtered residue landform). A steady improvement in the results was observed as the contractor became more familiar with the material behavior and optimized their placement methodologies.

A small sample of tests were used to assess the number of passes to achieve compaction by a tamping foot compactor and roller compactor. These tests showed that the same degree of compaction can be achieved with four to six passes. The testing also showed that more passes or high pressure equipment degraded density over time. Therefore, less effort proved more beneficial for these unique materials. Decreasing the number of passes for compaction also allows for a reduction in the fleet size and overall optimization in costs for compaction.

4.3 *Workability in a Wet Climate*

The results from the DWP1 stack construction have shown challenges in placement and compaction of the residue during moderate (>10 mm) or greater rainfall events. These findings were anticipated for the fine-grained residue material and similar challenges are faced in the placement of natural silt and clay materials for civil construction projects. The residue material with higher gypsum content did however perform better than the lower gypsum rich residue. The reason for this improved performance is likely due to cementation and hardening properties as the gypsum continues to dehydrate the residue. This was particularly noticeable after rain events, whereby the gypsum rich residue appeared to recover quicker. Due to the fine-grained nature of the residue, infiltration was negligible during the trial provided positive slope gradients, in the order of 2% were constructed to promote runoff.

4.4 *Final Observations*

The trial performed by PRNC has shown that although challenging it is possible to effectively place fine grained dewatered tailings or residues in a tropical environment. However, key considerations such as equipment fleet, temporary storage areas, available drying area and positive surface drainage are critical to any successful filtered residue landform operation in the tropics. For neutralized tailings comparable with those produced by the laterite nickel HPAL process (which included pressure oxidation gold tailings), moderate levels of gypsum aided in workability and improved trafficability but increased brittleness and potential for dissolution.

5 ACKNOWLEDGEMENTS

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6 NOMENCLATURE

ADT	Articulated Dump Truck
DWP1	Dewatering Plant No. 1 (1/10th scale demonstration plant)
FEL3	Front-end loading phase 3 (feasibility level study)
HPAL	high pressure acid leach
NF	French Norms
OMC	optimum moisture content
SG	specific gravity
SMDD	standard maximum dry density (or standard proctor density)
TSF	tailings storage facility
PRNC	Prony Resources Nouvelle Calédonie (Operator)