Geo-Metallurgical Mapping for Tailings Management Design

Glenn Barr, Twin Metals Minnesota, USA
Rachel Jansen, Black & Veatch, USA
Ashley Rasmussen, Paterson & Cooke, USA
Nicole Hoffmann, Hoffmann Geoscience LLC, USA

Abstract

Designing a responsible and economic tailings storage facility requires confidence in tailings variability and knowledge of how this variability will impact tailings management. Obtaining answers to key tailings-related questions early in study phases with a tailings test work component during the geo-metallurgical mapping stage can support critical design decisions.

Geo-metallurgical mapping is a common practice to inform processing plant design and operation decisions based on the variability of the ore to be processed. The mapping process starts with the costly collection of drill core samples, followed by a series of laboratory tests, analyses, and modelling. The "waste stream" generated from the tests (laboratory produced tailings) are a valuable resource that can be used to characterize the variability of the anticipated tailings at minimal additional cost.

This paper presents an add-on approach to any geo-metallurgical mapping program where the laboratory generated tailings are subjected to an additional series of brief indicative tailings characterization laboratory tests. Identifying the tailings variability in terms of dewatering, transport, geotechnical or geochemical aspects can highlight root causes for potential future tailings challenges. This adds significant value to the tailings design with minimal additional cost so that owners can implement an informed and optimized tailings management plan from project initiation. The Twin Metals filtered tailings project is presented as an example to share tailings mapping testing protocols, results, and lessons learned to better future endeavors where this practice may be applicable.

Introduction

Geo-metallurgy is a well-established field that enables economic modelling and risk evaluation of undeveloped ore bodies. Rather than relying solely on ore grade to assess project economics, geo-

metallurgy incorporates the metallurgical performance of the ore (e.g., grinding energy, recovery, and other processing characteristics) to better understand ore variability and optimize metallurgical processes.

Drill core samples are collected and tested to generate metallurgical performance data at individual locations throughout the ore body. Geo-metallurgical test programs must consider sample availability, as drill core collection is expensive and core quantities are limited. Cost and schedule constraints must also be considered, particularly because the number of samples tested can range into the hundreds.

The resulting data are used to develop a 3D model of the ore body using statistical geospatial techniques. This model enables informed decisions regarding the management of poorly performing material through mine planning and/or blending strategies. Most geo-metallurgical programs incorporate mining and beneficiation processes; however, to date, less attention has been given to tailings management processes, potentially due to the widespread use of conventional wet tailings storage facilities.

As the industry moves towards alternative tailings management systems, such as high-density thickened tailings and filtered tailings, incorporating these unit processes into geo-metallurgical programs could significantly de-risk projects. Dewatering processes, including thickening and filtration, are sensitive to tailings material properties. Therefore, it is essential to understand and design for the full expected operating envelope to avoid persistent bottlenecks during operation.

Samples supplied for test work to support alternative tailings engineering are often composite samples, which provide limited opportunity to assess variability. Figure 1 shows laboratory-scale filtration test results for drill core samples and a composite sample, “C Blend,” from a confidential mine in South America, where all test parameters were kept consistent (Wisdom, 2019).

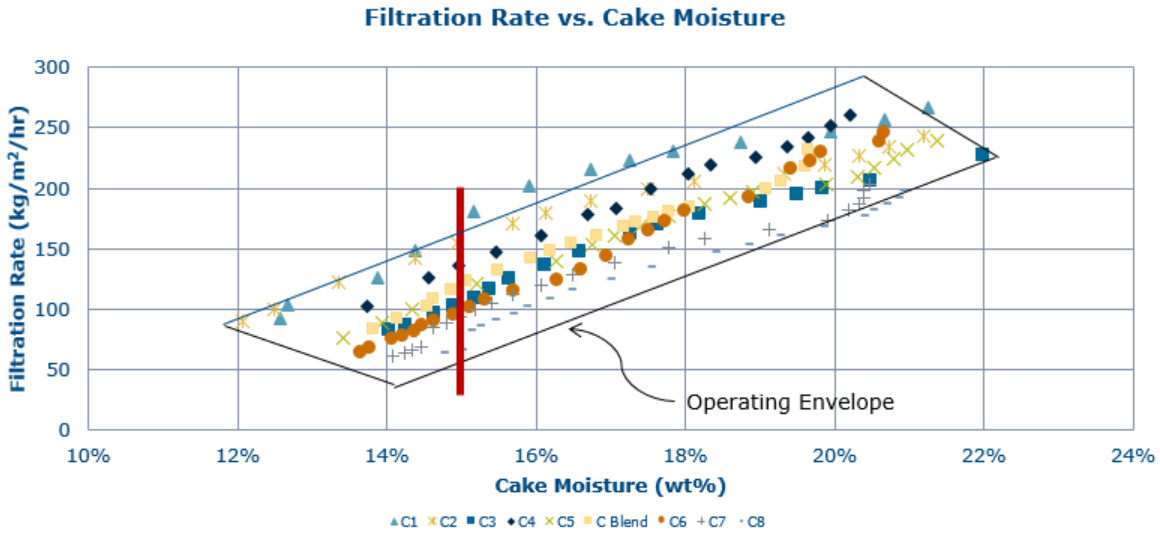


Figure 1: Laboratory-scale pressure filter test results (Wisdom, 2019)

For a target filter cake moisture content of 15% (indicated by the red line), the filtration rate varies from approximately 50 to 160 kg/m²/h for the samples tested. The composite sample has a filtration rate of 100 kg/m²/h. If the filter plant was sized based solely on the results of the composite sample and operating parameters were not adjusted, production would decrease when processing the tailings with lower filtration rates. Tailings with a filtration rate of 50 kg/m²/h require double the filter equipment capacity versus tailings with a filtration rate of 100 kg/m²/h.

Once the tailings variability is well understood, the results of the tailings geo-metallurgical mapping can be used to select individual samples or samples to form composites for full comprehensive test work to define the operating envelope and finalize the tailings system design.

Twin Metals Tailings Geo-Metallurgical Program

The Twin Metals project is presented as an example where tailings processing is incorporated into the overall geo-metallurgical program. Twin Metals Minnesota, LLC, a fully owned subsidiary of Antofagasta Minerals, owns the Maturi copper-nickel-PGM ultramafic deposit located in Minnesota. Based on the 2019 mine plan, the mine will process approximately 18,000 metric tons (20,000 short tons) of ore per day producing copper and nickel concentrates, with platinum, palladium, gold, and silver byproducts (Twin Metals Minnesota, 2019).

The Twin Metals proposed flowsheet includes a tailings thickener followed by pressure filtration to produce filter cake for stacking and for engineered tailings paste backfill production (approximately 40% of the dewatered tailings). To support this flowsheet and the overall geo-metallurgical program, tailings variability test work was performed. The test campaign included individual and composite sample characterization for flotation tailings from 119 spatially distributed drill core samples for the 25-year mine plan. Figure 2 shows the Maturi deposit and the drill core sample locations used for this test campaign.

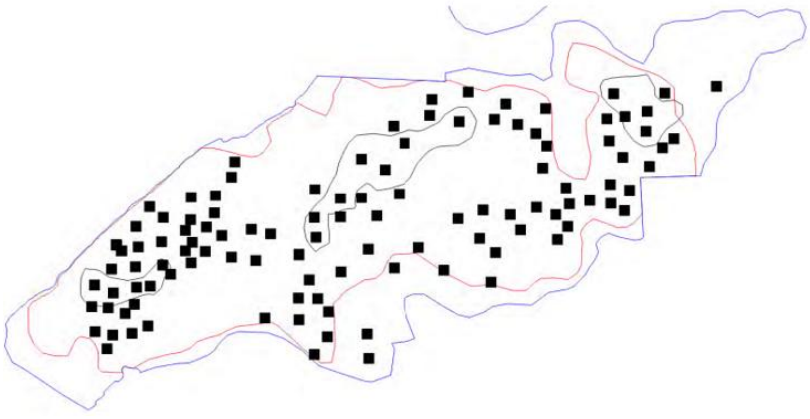


Figure 2: Twin Metals Maturi Deposit Drill Core Sample Locations

Individual drill core flotation tailings samples produced from Blue Coast Research's geo-metallurgical test campaign contained an average of 1.5 kg solids each in slurry form, therefore comprehensive material characterization and dewatering tests were modified for smaller sample sizes and faster turnaround time. Figure 3 and Figure 4 show how the indicative indexing for the Twin Metals testing relates back to typical comprehensive test work for material characterization and dewatering. For this project, the mineralogy data from the geometallurgical test campaign was shared, and tailings mineralogy was not tested separately as part of the index testing.

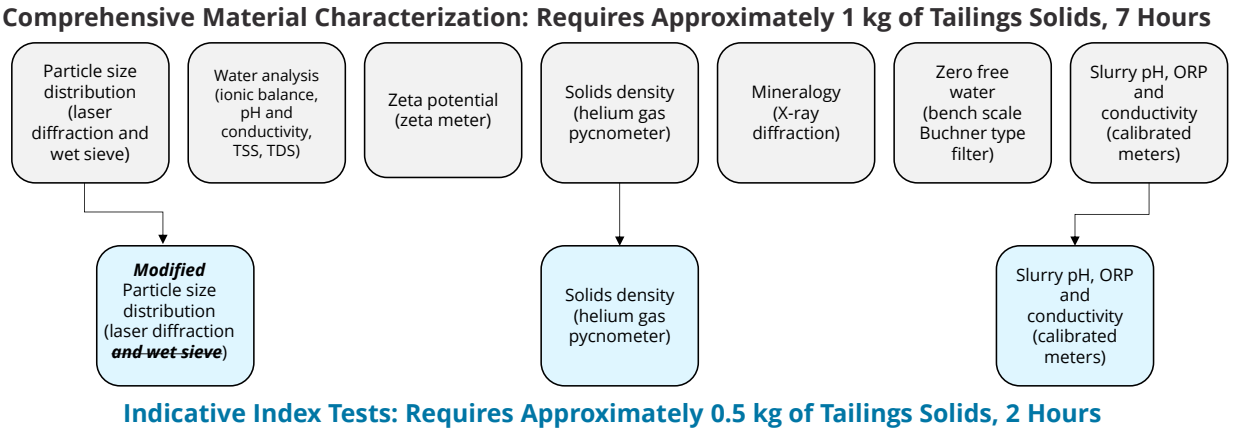


Figure 3: Comprehensive Material Characterization Tests versus Indicative Index Tests

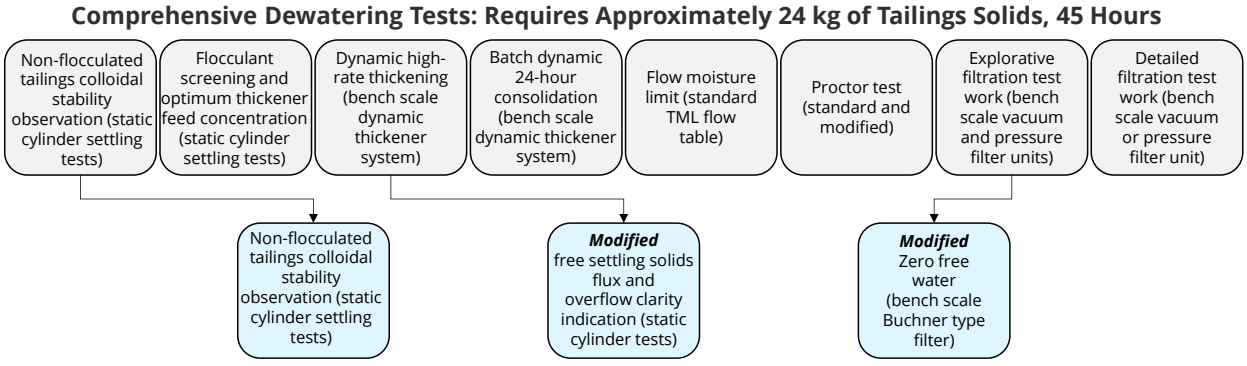


Figure 4: Comprehensive Dewatering Test versus Indicative Index Tests

Indicative Index Test Protocols

Indicative index tests were completed to assess variance within the ore body and to provide context to the dewatering results, if any trends existed. The pH, conductivity, oxidation-reduction potential (ORP), and solids concentrations of the as-received samples were measured. The particle size distribution was

measured via laser diffraction as opposed to wet sieving to minimize the sample size required. The solids density was measured using a helium gas pycnometer.

The sedimentation properties of the tailings were investigated with and without flocculant. The tests without flocculant (or coagulant) indicate the variance in natural settling behavior of the tailings. The slurry volume, solids concentration, and temperature are held constant for these tests. Clean decant water from the respective tailings samples are used for dilution. The settling was observed for approximately 20 hours. Examples of naturally settling and naturally non-settling Twin Metals tailings samples are presented in Figure 5. Without understanding the natural settling behavior variability, the thickening reagent process would potentially be executed based on a single sample test result. The naturally non-settling (or slow settling) tailings sample with suspended fine particles in the supernatant may require coagulant to modify the surface charges before efficient solid liquid separation in a thickener via flocculation can occur. The naturally settling tailings sample without suspended fine particles in the supernatant could likely be thickened using a flocculant alone, without the use of a coagulant.

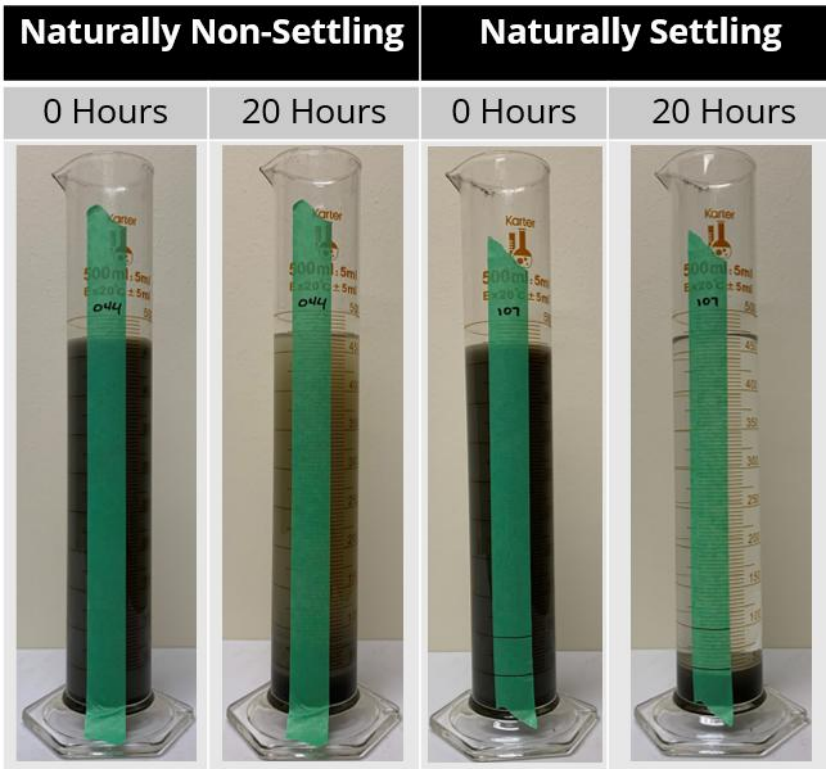


Figure 5: Naturally Non-Settling Versus Settling Tailings after 20 hours

The same cylinder test can be used to assess the settling rates with flocculant. The flocculated settling tests and variance in settling rates indicate the potential range in thickening performance for the varying tailings samples. Referring to previous test work or some scoping test work is necessary to ensure that the

flocculant dosage and type is suitable for the tailings. The cylinder size, slurry volume, flocculant type and dosage, mixing method, and temperature must then be held constant for the geometallurgical test program. The supernatant turbidity or suspended solids concentration should be measured at a set time for each test.

The zero free water test is used for filtration characterization. This test is essentially the form step of a vacuum filtration test. It should be noted that this test only provides indication of the cake formation step and does not inform the amenability of the material for a membrane press or air blow dry step. The test is performed with a Buchner-type funnel with filter paper. The Buchner funnel for the Twin Metals testing had a diameter of 110 mm. Filtrate is collected in a side-arm flask. A vacuum pump is set to the target vacuum level, for the Twin Metal's testing 60 kPa was used. The procedure is as follows:

- Feed slurry is decanted of clear water to increase the solids concentration and minimize coarse particle settling while sub-sampling the test sample and during the formation of the filter cake. The feed solids concentration is recorded.
- From the homogeneous feed, a sub-sample of known mass and volume is transferred to the Buchner filter. The feed mass and volume are recorded.
- Vacuum is applied.
- When the zero free water point is reached by visual determination (a matte finish on the slurry surface) the vacuum is removed and the end of test time is recorded.
- Filtrate volume is measured in a graduated cylinder and the filtrate mass and volume are recorded.
- A sub-sample of the filter cake is collected for solids mass concentration determination using oven drying.
- The remaining solids are set aside, and the filter is rinsed prior to completing the procedure an additional three times with fresh paper each time to eliminate any variables introduced should the paper quality be compromised.

The results of the four trials are used to determine an average zero free water cake solids concentration. The average zero free water cake solids concentration and other test measurements can be used to estimate the specific cake resistance. The specific cake resistance is a number that uniquely describes the filterability of a material during the cake formation step. Specific cake resistance values generally range from $1x10^9$ to $1x10^{14}$ m/kg. A sandy material that is easy to filter will have a lower specific cake resistance value than a material that is more difficult to filter (for example a material with a high clay fraction), as shown in Table 1.

Table 1: Qualitative Measure of Specific Cake Resistance

Ease of Solid-Liquid Separation	α, [m/kg]	Material Type
Very easy	$1x10^9$	Filter aid
Easy	$1x10^{10}$	
Moderate	$1x10^{11}$	Some clays present
Difficult	$1x10^{12}$	
Very difficult	$1x10^{13}$	
Extremely difficult	$1x10^{14}$	Highest resistance

The zero free water test does not provide all the parameters necessary to calculate the true specific cake resistance of a material. However, values from the zero free water tests can be used to provide an estimated specific cake resistance for comparative purposes. The estimated specific cake resistance assumes:

- The filter medium (Rm) has negligible flow resistance.
- The filtrate dynamic viscosity (μl) is equal to that of water at the tested slurry temperature.
- The maximum vacuum level in a test is achieved immediately and is constant throughout filtration.

The estimated specific cake resistance values presented in this document are calculated using equation (1). This is derived from the generalized filtration design equation (Coulson & Richardson, 1977), which has been rearranged in equation (2).

$$\alpha_{\text{est}} = \frac{2\left(\frac{t}{VF}\right)A^2\Delta P}{\mu(m_c x_c)} \quad (1)$$

$$\frac{t}{V_F} = \left(\frac{\alpha_{\text{av}}\mu_l X_s}{2A^2\Delta P_T}\right)V_F + \left(\frac{R_m\mu_l}{A\Delta P_T}\right) \quad (2)$$

where
- t = filtration time (s)
- V_F = filtrate volume (m^3)
- α_{est} = estimated specific cake resistance (m/kg)
- m_c = mass of wet filter cake (kg)
- x_c = solids concentration of filter cake (%m)
- μ_l = liquid dynamic viscosity (Pa·s)
- ΔP_T = total pressure differential (Pa)

A = filtration area (m^2)

α_{av} = average specific cake resistance (m/kg)

R_m = medium resistance (1/m)

X_s = mass of filter cake solids per filtrate volume (kg/m^3)

ΔP_T = total pressure differential (Pa)

Results

The indicative testing produced a large database of comparable data across the ore body. The results presented in this section are not exhaustive and are intended to provide examples of how comparative data may be visualized and used. The characteristics for a composite test sample used for various design aspects can be overlayed to provide comparison between the composite samples and the variability observed in the tailings mapping test work.

Figures 6 and 7 present histograms of the general characterization and dewatering characterization results, respectively. Histograms show the distribution curve shape and quickly identify outliers, however only single characteristics can be investigated. Figure 8 presents scatter plots to visualize the relationships between multiple characteristics.

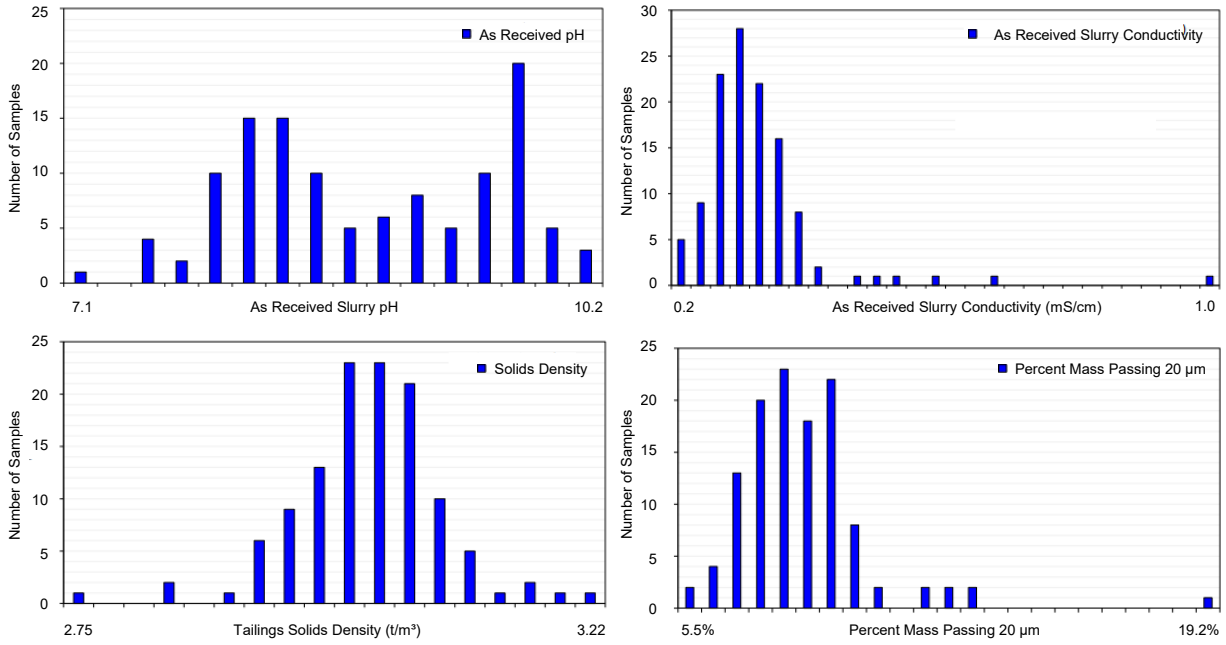


Figure 6: Index Test Characterization Histograms

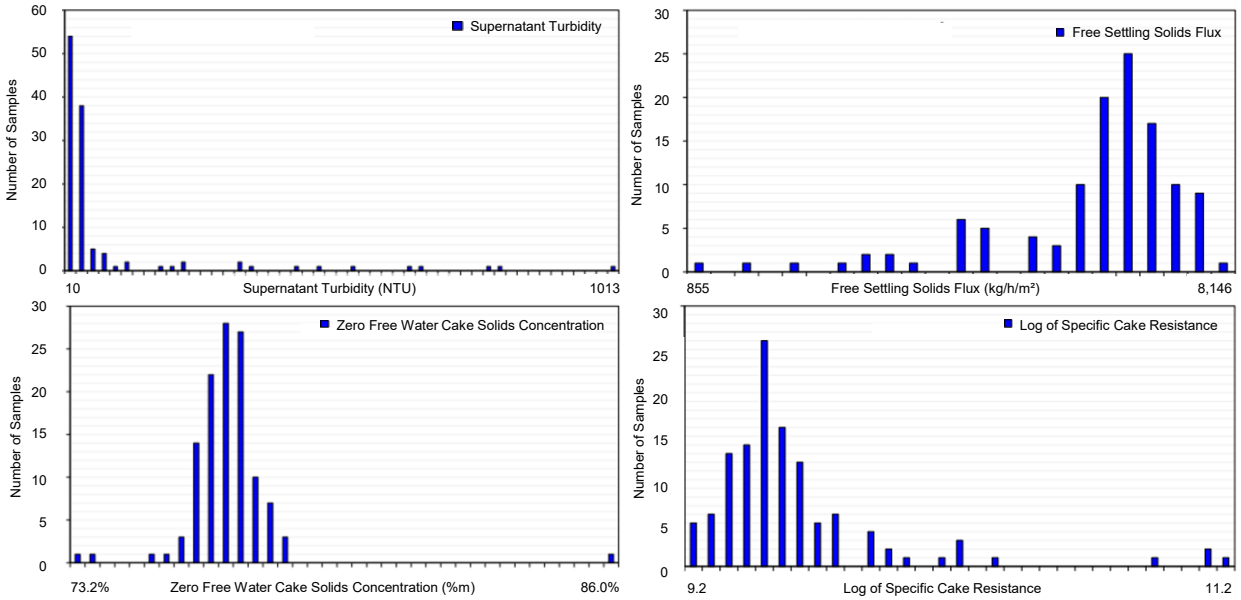


Figure 7: Index Test Dewatering Characterization Histograms

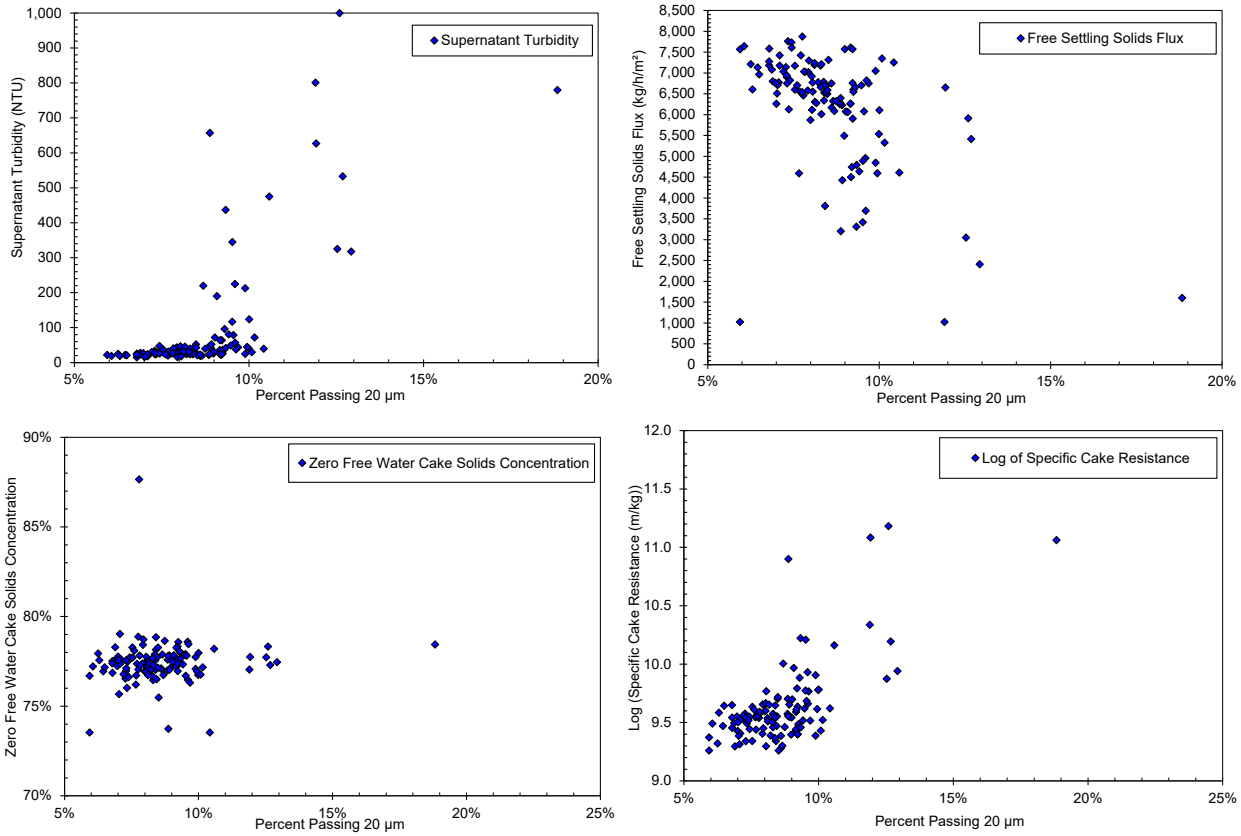


Figure 8: Index Test Scatter Plots

Both the histograms and scatter plots allow outliers to be highlighted and correlated to the drill core map to help determine if there are trends between samples with poorer dewatering performance and the location in the ore body, as shown in Figure 9. This information can be used directly in the tailings dewatering system design, a topic which will be covered in a future paper on the potential design impacts from the Twin Metals Tailings Mapping test work, and to inform the mine planning and blending strategies.

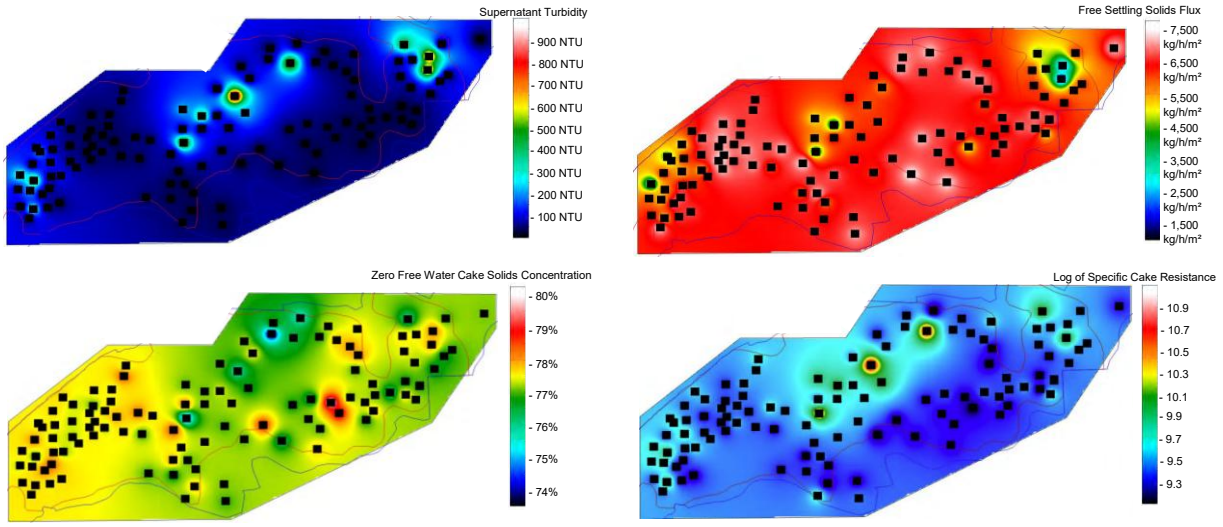


Figure 9: Ore Body Map with Index Test Results

Learnings

The following learnings should be considered for future tailings geo-metallurgical programs:

(1) A quality control plan is essential to isolate variables wherever possible in the test program. This is a goal for any test program but especially for when a comparative sample database is being produced. Sample receipt, labelling and storage protocols, test photograph plans, probe calibrations, test temperature control, oven temperature control and oven drying times are examples of testing controls implemented throughout the Twin Metals test program.

(2) A quality assurance plan should be included in the test program. For the Twin Metals testing, tests such as solids density, particle size distribution, and zero free water were completed in triplicate. For future programs, it is recommended that testing repeats are built into the program as a second pass. The second pass tests do not need to be for every sample but will allow for another data point for select samples. This testing should be completed a set number of days after the initial tests on a sample to help indicate the impact of sample aging.

(3) The index testing can be modified to accommodate project specific goals and sample quantity availability. For example, tests such as Methylene Blue Index and zeta potential measurements utilize minimal sample and may be extremely informative for a higher clay content ore body.

Key Take Away

Indicative index tests on tailings are a valuable add on to the typical geo-metallurgical mapping exercise. They use a small sample that is produced as a byproduct of the metallurgical performance testing and inform the tailings variability of an orebody. Understanding this variability is key in the development of cost effective and responsible tailings management designs.

References

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