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Lessons learned on cemented paste backfill strength prediction at the Odyssey Mine

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Abstract

Backfill is an integral component of mining studies at Agnico Eagle Mines (AEM), considered even during the earliest stages of project evaluation. From scenario evaluations to feasibility studies, best practices in backfill management are consistently applied across projects and tailored to reflect each project's specific characteristics. These guidelines were implemented early in the Odyssey Underground Project, part of the Canadian Malartic complex. New complexities emerged from blending ore sourced from both open pit and underground orebodies, each with distinct geological characteristics, variable daily blends, and high-tonnage demands.

AEM's backfill practices had to evolve significantly to address the challenges posed by the Odyssey mining plan, including capex allocation, rising binder costs, high-volume backfill production requirements, and the need for advanced engineering solutions. Multidisciplinary collaboration, supported by cutting-edge data collection and interpretation, along with the continuous refinement of production procedures during commissioning and daily operations, enables the Odyssey project to consistently deliver high-quality engineered backfill in this Western Quebec, Canada mining operation. Strength prediction adapted to various rheological constraints, stope size, curing-time requirements, and mining strategy have been a key element from the beginning of the project to control the binder consumption ensuring paste delivered at the right time and place with sufficient strength. This paper will cover how mineralogy can dramatically affect the strength development of cemented paste backfill and how to gather relevant operational data to predict efficiently for each pour the strength of cemented paste backfill depending on given curing time. With more than 2 years' production, comparison between project stage assumptions and everyday performance will be evaluated, as well as how these learnings can be applied for other projects and operations.

Keywords: *cemented paste backfill, mineralogy, case study, binder usage optimisation, best practices*

1 Introduction

The Odyssey underground mine is part of the Canadian Malartic complex (CMC). The backfill paste plant's current production is 6,000 t, but construction over phases will bring its daily production to 20,000 t, making it one of the biggest cemented paste backfill operations in the world. Even before the development of the underground portion of this mining complex, the mill was measuring the impact of ultramafic (UM) lithology on the reduction of dewatering efficiency at the thickener. Over the years, the team observed that a higher percentage of ultramafic means a lower efficiency of water removal. The solids percentage is an important parameter for tailings disposal – at the CMC, the target is set at 63%. At the CMC, the first underground stopes were backfilled in July 2023. The high ultramafic created challenges not only at the thickener but also at the disk filter, which had been added to increase the solids content to the 75% target required for cemented paste backfill (CPB). Tailings at approximately 75% solids are typically mixed with a slag–cement blend (90%/10%) mixed with water to produce CPB ready to be pumped in empty stopes underground. If the target is not met at the thickener, there is a higher probability that it won't be met at the disk filters, which

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means that the CPB will be produced with a higher water content which will affect the development of CPB strength. The first phase of the Odyssey CPB plant, completed in Q2 2023, provides a backfilling capacity of approximately 4,000 t per day. Recent upgrades at the paste plant now brings the capacity at 6,000 t per day.

Early on, the backfill team knew that the ultramafic lithology content could be challenging due to the presence of phyllosilicates minerals in high percentage. The content of detrimental minerals composed of layered structure was hard to predict, especially since each mining zone had a various amount of phyllosilicate minerals. At the project stage, composite samples were prepared which means that an average ultramafic content of 20% was considered. Literature is present regarding the impact of phyllosilicates, known to negatively affect the strength of CPB with work from Cavusoglu & Fall (2023), Elkhoumsi et al. (2025), Zhao et al. (2020) and Wang et al. (2023). AEM also had experience with detrimental mineralogy for CPB production such as muscovite at Pinos Altos (Ouellet & Brunet 2010) and at the LaRonde complex (Gélinas & Alcott 2024), but each mining tailing is not the same, and specifically, the operational conditions vary. At the CMC, there are 3 main lithologies: sediment (SED), porphyry (PO) and ultramafic (UM). Their proportions vary daily depending on where the ore is coming from – either the underground or open pit sector of the mining complex. A tailing sample is taken every day, and it is sent to an external lab to get the chemistry content (4 acid digestion inductively coupled plasma mass spectrometry [ICP-MS]) which gives the operation the percentage of chromium which is then used to correlate the daily content of ultramafic. Figure 1 shows this imperfect yet daily-used linear correlation between chromium and ultramafic content. These results are received weeks after, which is why the geology department is projecting with their best knowledge the amount of ultramafic mineral one week in advance.

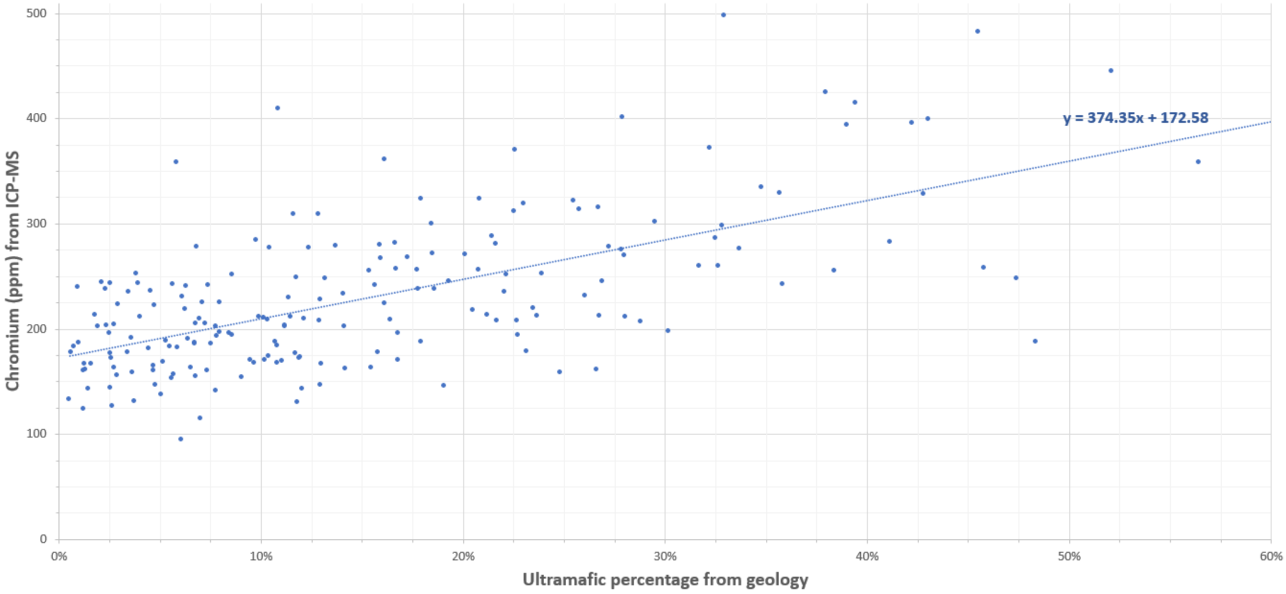

Figure 1 Chromium parts per million (ppm) from inductively coupled plasma mass spectrometry compared with ultramafic content (%)

The importance of QA/QC at Odyssey was identified at the initial project stage and a state-of-the-art laboratory was set up at the paste plant. A humid temperature-controlled chamber was also part of the initial construction. All pours are sampled with triplicates cylinders of 7.62 × 15.24 cm (3 × 6 inches) and cured for 2, 3, 14, 28, 56 and 120 days. An instrumentation project was also performed where thermistors were placed in situ of an underground stope to validate the curing temperature at 21°C.

2 Operational challenges associated with mineralogy

Early after the commissioning of the paste plant, a correlation emerged between the percentage of ultramafic and the percentage of chromium result from the ICP-MS. A significant drop in uniaxial compressive strength (UCS) from CPB samples could be measured when the ultramafic content was higher. This was discovered because the backfill team from Odyssey immediately began performing UCS tests from paste cylinders, and the results were interpreted as received. Early average results with various UM content were compared, for example between 10 and 50%. With a recipe of 4.5% slag–general use limestone cement (90%/10%), and slump of 7 inches, after 28 days of curing by going from 10 to 50% ultramafic (UM), the UCS changes from 1,057.4 to 265.6 kPa. During operation, these variations had significant impact, and to prevent this, the easiest fix is to significantly increase the binder percentage to prevent having results below target at the specified curing time. As this strategy would imply a dramatic impact on the opex cost, it was decided early on to investigate the root cause of UCS drop, find trackers and adjust binder percentage more precisely to reduce the impact on the opex. The CMC is using for binder a pre-mixed blend of 90% ground granulated blast furnace slag and 10% general limestone use cement, Terraflow 5228 (90%/10%).

At Odyssey, the UM lithology contains many minerals that could be problematic. Mineralogy is known to affect CPB strength. Muscovite, a phyllosilicate, is one of the most common within AEM operations. AEM collaborated with Menasria (2024) and Menasria et al. (2025a, 2025b) to investigate the multiple effects of talc on backfill operations. At Odyssey, all 3 major lithologies contain muscovite and the percentage measured is stable, even with various mineralogical campaigns which were done by taking 67 samples over 10 years. It was thus important to investigate more, and the initial step was to increase the number of tailings samples with complete mineralogy. X-ray diffraction (XRD) technique was chosen since ICP-MS and chemistry are not sufficient to obtain mineralogy. The project was then initiated to sample the tailings stream daily over a month at the paste plant and get a portrait on mineralogical variability. Thirty-one sets of UCS cylinders were prepared in April 2024 –one for each day plus 2 sets of samples on 11 April. Out of these daily samples, 9 sets of samples could be used to validate UCS projections of CPB. The values of 6, 9, 11a, 11b, 12, 13, 14, 16 and 21 April for a total of 9. A total of 120 cylinders (3 × 6 inches) were prepared and cured at the paste plant exactly like all the normal QA/QC cylinders. Three groups of recipes were compared with similar target recipes and various mineralogies:

- 6 and 11 April with 7.5% Terraflow 5228 (90%/10%) and % solids 70.5% (±0.5%)
- 9, 13 and 21 with 7% Terraflow 5228 (90%/10%) and % solids 69.1% (±0.7%)
- 11, 12, 14, 16 April with recipe at 4% Terraflow 5228 (90%/10%) and % solids 68.2% (±1.5%).

Three main sources of data were used to compare strength development: UCS, ultramafic content from chromium content and complete mineralogy from XRD. The 3 sets of data showed that the UM correlated well with high and low UCS values. The next step was to try and isolate the main problematic mineral coming from the ultramafic lithology. No real correlation with muscovite could be seen, which was the first hypothesis. Several minerals showed stronger correlations with UM content: dolomite, hornblende, clinochlore and talc as seen in Figure 2. At this point, the best correlation was with talc content, and this emerged as a key mineral of interest.

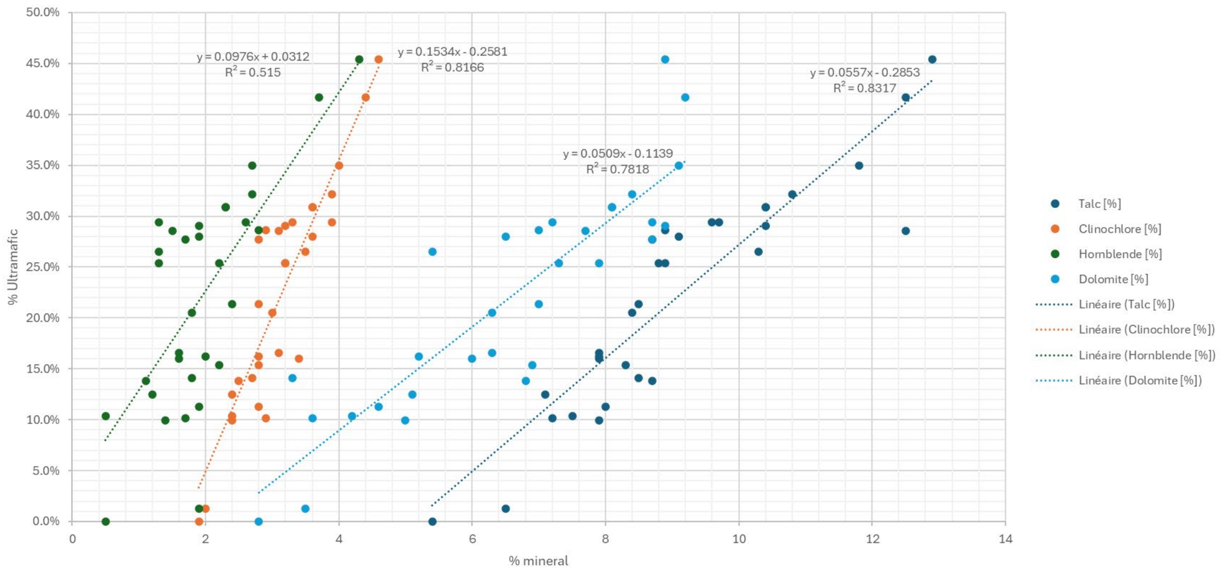

Figure 2 Correlation with ultramafic content and percentage of talc, clinochlore, hornblende and dolomite

Looking back at the average mineral content for each lithology based on historical values (Figure 3), the talc was a good indicator. At 18.97% for UM compared with 0.45% for the porphyry (PO) and 2.29% for the sedimentary rock (SED), the talc is significantly more present in UM compared to other lithologies, which is not the case for muscovite. There is a significantly higher total content of talc with UM explaining why the mineral is a good marker for UM and explaining why the UM content affects the UCS reduction more compared to other lithologies. From this point, the analysis was done by using the talc as a marker for low resistance in the CPB and a thorough literature review was conducted. Chlorite or biotite content could also be used as a good mineral marker, but the literature does not indicate that these minerals are as problematic.

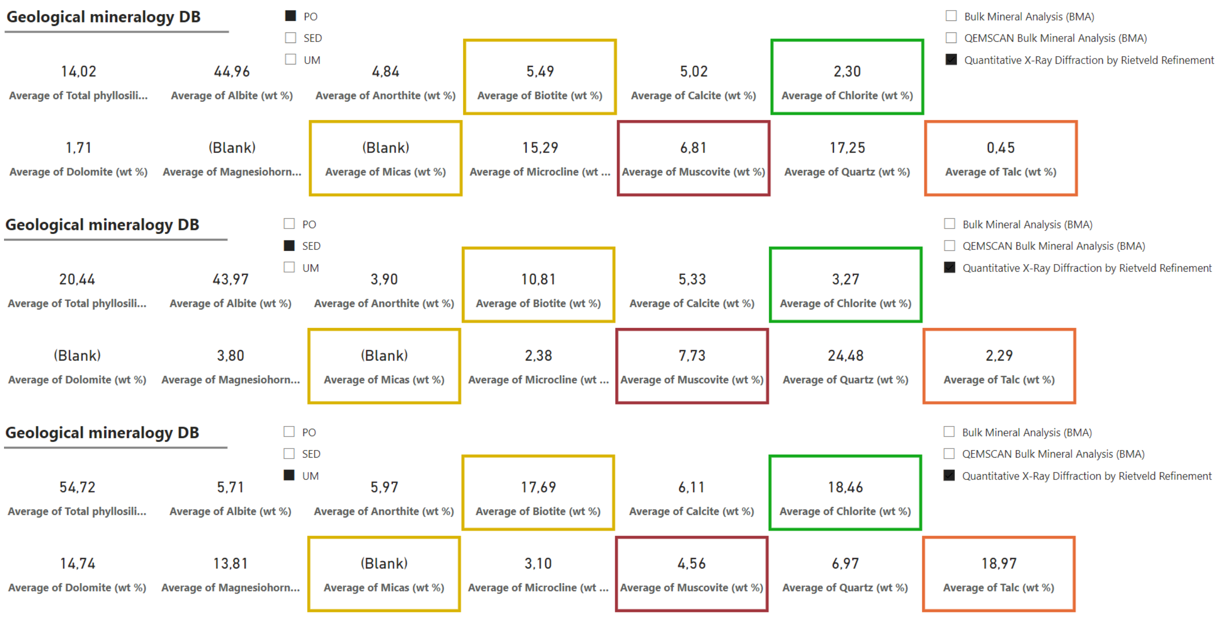

Figure 3 Mineral content per lithologies, ultramafic (UM), sediments (SED) and porphyry (PO)

3 Key findings on talc impact on cemented paste backfill performance

3.1 Comminution effects

The talc can have multiple effects. Its starts at the comminution circuit with an ore containing a high proportion of talc, which is going to be easier to grind. Since limited changes are made daily to adjust the grinding energy, the mill tends to overgrind softer mineral such as the talc when the tonnage throughput goes down. Talc is described by Katircioglu-Bayel (2020) as a soft mineral because of its layered structure, where weak van der Waals forces hold the layers together. The crystallography makes the mineral fragile during grinding due to its layered structure, contributing to its ease of comminution. By isolating recipes with the same binder content and various UM content now correlated with various talc content, the impact on the P_s, solid percentage, particles less than 20 µm and then on UCS can be measured. It is not always the case, but in general, more talc means a finer P_{80} if the comminution target are not adjusted, and a finer P_{80} generally correlates will more fines, and particles less than 20 µm. Currently at the CMC, the operational target is a P_{80} of 80 µm. Figure 4 shows binder content of 3.0% (curve #3 and curve #4) with various P_{80} (58.3 µm, 75 µm) that represent 47.6% <20 µm and 43.0% <20 µm. At 28 days, the UCS is 228 kPa instead of 644 kPa for a coarser tailings particle size distribution (PSD). In Figure 4, the UCS shows a binder content of 6.3% (curve #1 and curve #2) with various P_{80} (89.3 µm, 67.9 µm) that represent 38.2% < 20 µm and 43.1% < 20 µm. At 28 days, the UCS is 1,299 kPa instead of 1,499 kPa for a coarser tailings PSD. There is a strength reduction of 65% at 3.0% binder and 13% at 6.3% binder. The strength reduction is higher at low binder content proposing that the binder in a higher proportion can reduce the impact of detrimental PSD and mineralogy.

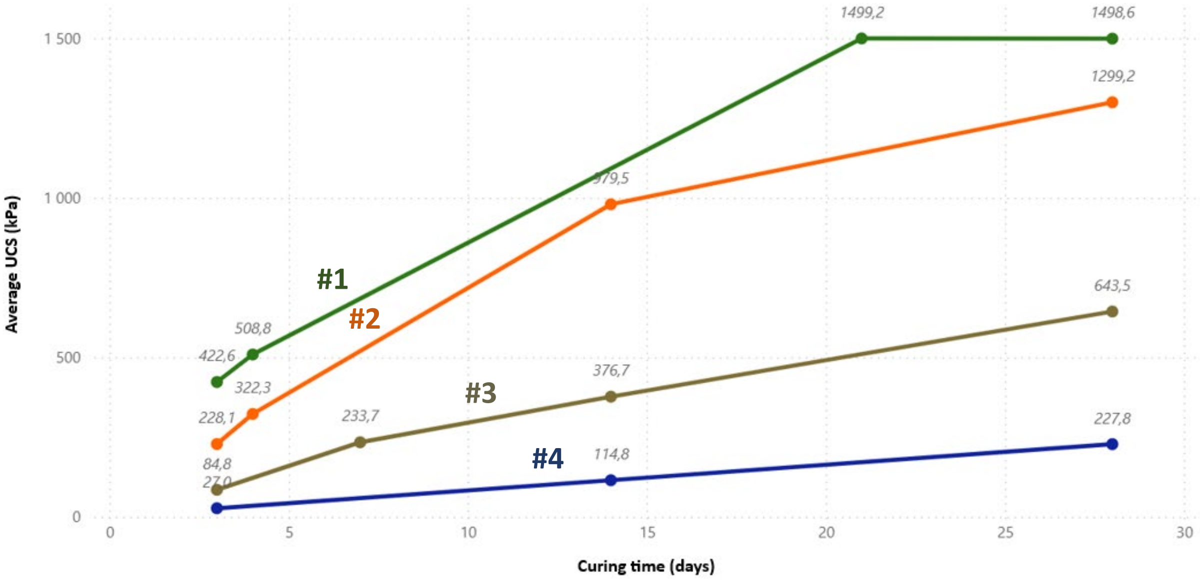

Figure 4 Four uniaxial compressive strength curves generated with various D_{80}, P20, µm content, %solid, %binder

Table 1 shows the details of the 4 tailings compositions that generated UCS curves at Figures 4a and 4b. Multiple factors vary in operation at the same time, but these examples show that the increased percentage of ultramafic affects the comminution circuit with the generation of a finer tailings, and the performance of dewatering.

Table 1 Combined values of particle size distribution, mineralogy, 5 binder and uniaxial compressive strength from the results shown in Figure 4

Curve #	P_{80}	% < 20 µm	%UM	%wt	%binder	Slump (in)	UCS (28 days, kPa)	UCS (56 days, kPa)
1	89.3	38.2	9.6	73.1	6.3	6.5	1,499	1,499
2	67.9	43.1	21.9	70.2	6.3	6.5	–	1,299
3	75.0	43.0	8.4	75.0	3.0	7.0	644	857
4	58.3	47.6	24.3	72.0	3.0	6.5	228	453

3.2 Dewatering challenges

Talc's platyness, softness, and hydrophobicity make it particularly susceptible to overgrinding, especially when grinding parameters are not adjusted to account for its softness. The correlation between more UM and higher generation of fines (<20 µm) could be measured at the CMC. Ulian et al. (2014) describes that the effect of talc continues at the thickener and disc filter for tailings water removal prior of CPB preparation. Trioctahedral layered silicate, exhibits a platy morphology, softness, and a high water-retention capacity, all of which significantly affect dewatering processes in mineral processing circuits. Its lamellar structure, held together by weak van der Waals forces, allows talc to retain water within its layers, making it difficult to remove moisture during thickening and filtration. This leads to slower settling rates in thickeners and increased flocculant demand. In disk filters, talc's fine, platy particles form dense, low-permeability cakes that clog filter pores, reducing filtration efficiency and increasing maintenance needs. The impact on thickener and filter disk was also measured at the CMC. In Figure 5, the tonnage feed ratio of UM is compared with the achieved % solids, which shows a general trend that an increase of ultramafic feed ratio negatively affects the thickener performance. In Figure 5, the UM content and finer PSD also means lower solids percentage.

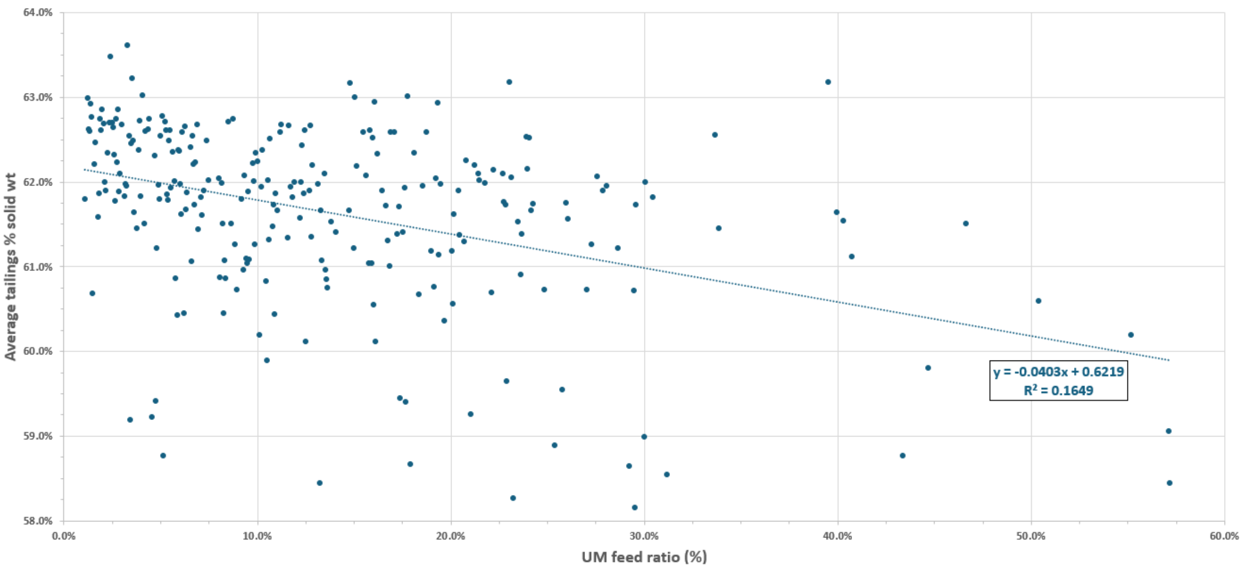

Figure 5 Dewatering (% solids) performance compared with the UM feed ratio in 2020–2023

3.3 Cemented paste backfill production implications

Talc influences backfill operations even before CPB production begins. Feeding CPB mixer with a filtered tailings at 72% solids rather than 75% targeted at the study stage in the paste mixer will mean a higher water-cement (W-C) ratio, so for the same UCS, more binder will be required. Figure 6 shows this phenomenon; there is a clear reduction of percentage solids when ultramafic content increases. The average percentage solids was calculated with various recipes over a 2-year period. Another point is that PSD and dewatering challenges are not varying to the same extent the same day – the correlation is not perfect. There are a lot of moving pieces in a mining complex, but the trend over time is always the same – the increase in ultramafic lithology, known now to be mainly associated with talc variation is affecting comminution, dewatering and strength development of CPB. An increase in talc means that the PSD tends to be finer, the dewatering less effective and the cured samples of CPB exhibit lower strength.

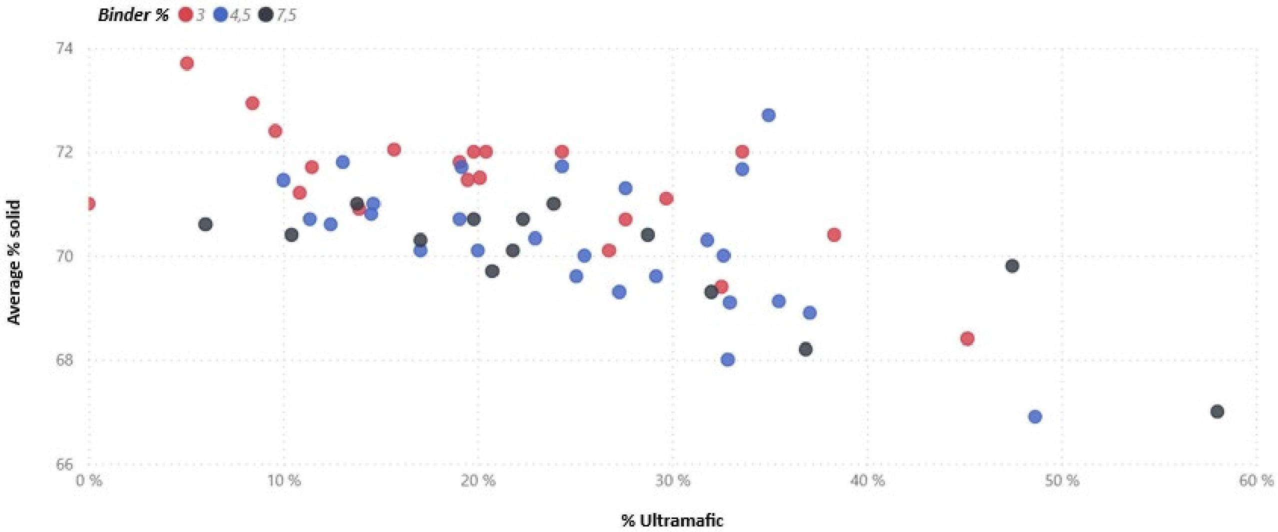

Figure 6 Percentage solids over ultramafic content

4 Implications of various talc content at Odyssey

Once a month of tailings collected daily were analysed for chemistry and mineralogy, these results were combined with the paste UCS database. After 28 days of curing, the 6 April samples developed an average strength of 1,027 kPa with 7.5% 90%/10% at 28 days and 10.4% talc. With a similar PSD (<20 µm passing of 43.8 and 43.4%) and the same recipe, the triplicate samples developed strengths of 1,626 kPa with 7.9% talc. The notable strength difference between these 2 sets and the main difference is the talc percentage, which corresponds to 13.8% UM and 28.8% UM as seen in Figure 7. The reduction trend continues at 56 days with an average resistance of 2,125 kPa for 7.9% talc and 1,641 kPa for 10.4% talc. A log regression is also presented in Figure 7.

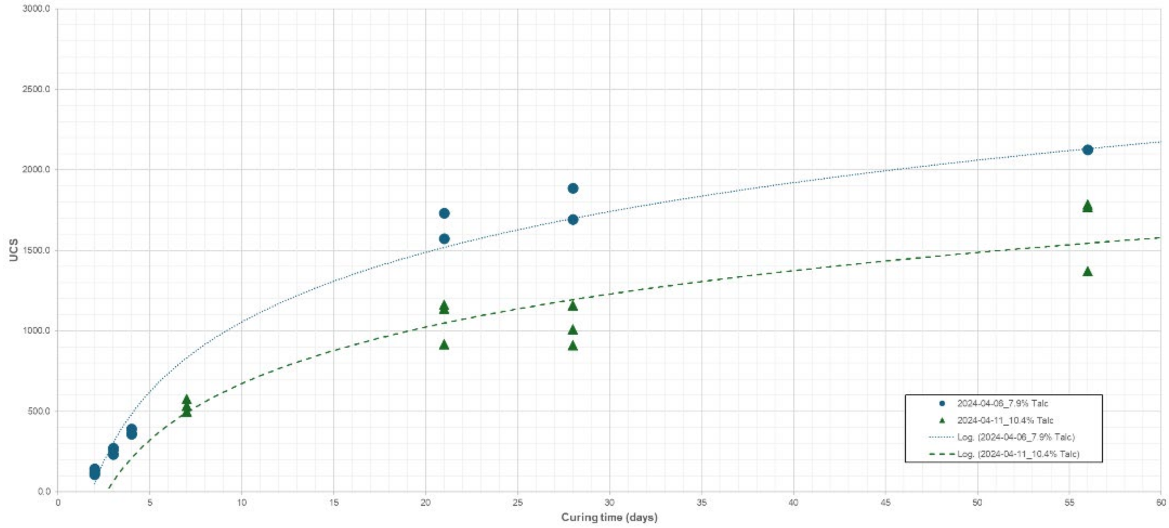

Figure 7 Uniaxial compressive strength development of samples from 6 April with various talc content

Another set of samples from 9, 13 and 21 April are presented in Figure 8. There is a bit more variability with this series of samples with a recipe between 6.7 and 7% and a similar solid percentage. The samples of 9 and 13 April had identical talc compositions (12.5%), were combined and are presenting an average resistance of 1,004 kPa at 28 days, while the samples of 21 April with 9.6% talc have an average resistance of 1,117 kPa at 28 days. At 56 days, the tendency is not that clear, with a lot more variability in UCS. The PSD is similar in terms of P_{80} and <20 µm passing.

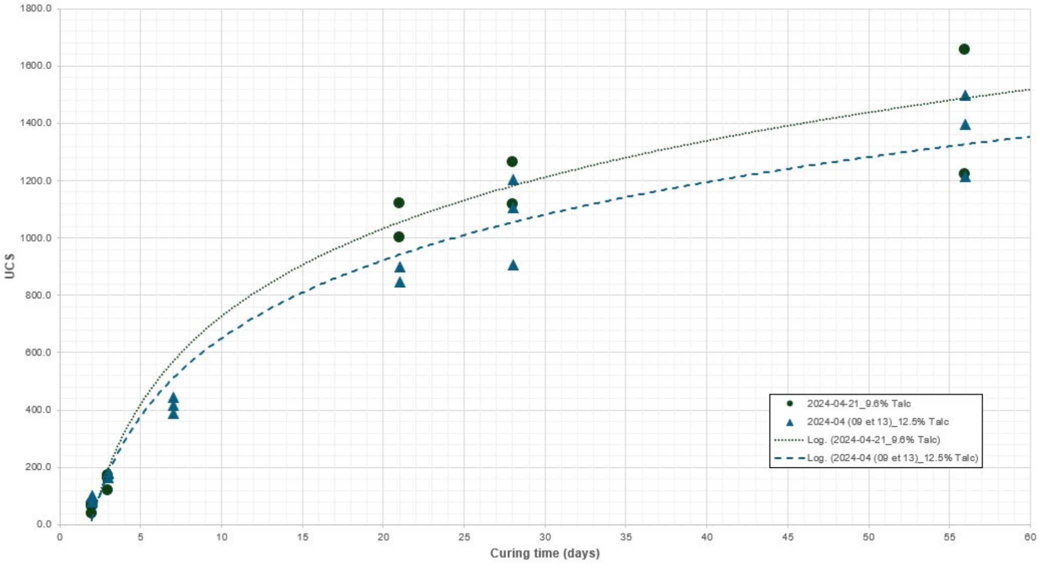

Figure 8 Uniaxial compressive strength development of samples from April (9, 13 and 21) with various talc content

The third series exhibits minimal talc variation, but the interpretation of results is not as easy as seen in Figure 9. For this set of samples, the PSD and percentage solids varies a lot more, showing that mineralogy is not the only parameter controlling development of strength. The P_{80} varies from 66.3 µm (12 April) to 73.8 µm (16 April) and the percentage solids is varying more between 66.7 and 68.3%, which is on the very low side when comparing 10%.

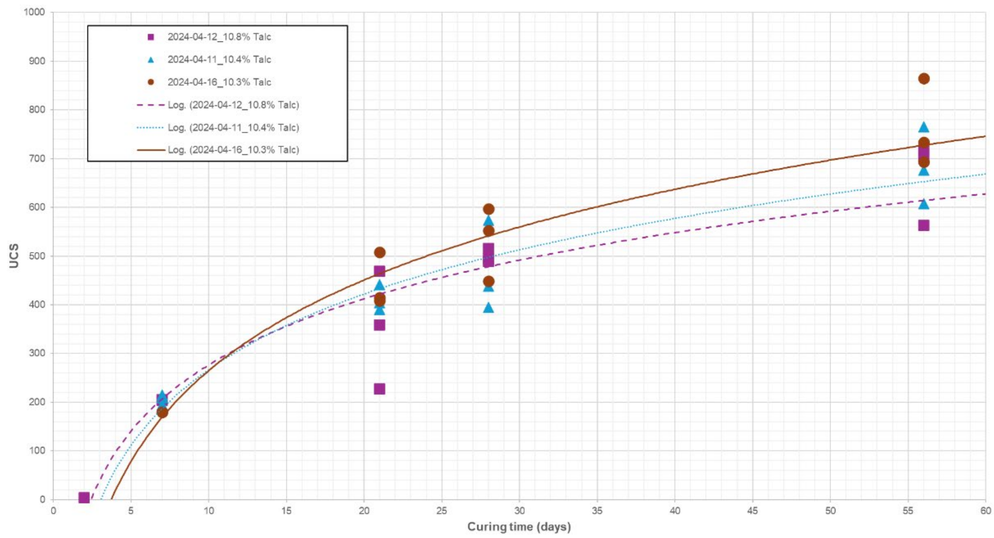

Figure 9 Uniaxial compressive strength development of samples from April (11, 12 and 16) with similar talc content

To simplify the above results and discussions, Table 2 can be useful. The general interpretation is clear: when comparing days when the recipes were similar in terms of PSD, water content, cement percentage and slump, the talc content affects the development of UCS resistance reducing the strength from 10 to 37% after 28 days of curing. Considering that talc percentage can be harder to measure in operation, the ultramafic content calculated with chemistry is an option. But again, getting the chemistry percentage is not easy and so using the solid% and slump of paste affected mainly by talc content is the right approach while operating. At Odyssey, a projection of ultramafic content is also prepared by the geology team weekly. If the prediction plans more than 20% ultramafic, the backfill team can be more reactive increasing the binder percentage to reduce the impact of mineralogy changes.

Table 2 Comparative table with particle size distribution, mineralogy and uniaxial compressive strength

Date	D_{80} (µm)	% < 20 µm passing	Binder %	Slump (in)	Solids %	Talc %	UM %	UCS 28 days (kPa)
6/4/2024	76.8	43.8	7.5	7.0	71	7.9	13.8	1,626
11A/4/2024	70.5	43.4	7.5	7.3	70.4	10.4	28.8	1,027
9/4/2024	80	41.1	6.7	7.3	68.4	12.5	43	976
13/4/2024	72.7	41.8	6.7	7.0	68.4	12.5	30	1,032
21/4/2024	81.7	42.1	7.0	7.5	69.7	9.6	28.9	1,117
11B/4/2024	70.5	43.4	4.0	6.5	69	10.4	26.5	523
12/4/2024	66.3	44.4	4.0	7.0	68.9	10.4	30.9	469
14/4/2024	72.8	41.2	4.3	7.5	66.7	10.4	35.2	515
16/4/2024	73.8	42.1	4.3	7.0	68.3	10.4	34.5	533

5 Uniaxial compressive strength prediction and operational controls

Early on at the project stage, Odyssey decided to include in the paste plant, a complete paste lab with a UCS press, rheometer, mixer, and a large curing chamber with controlled temperature and humidity. A database with not only UCS results but connected with a large set of operational values (pressure, slump, yield stress, paste temperature, binder%, and admixture%) and containing PSD and mineralogy is available. From 31 July 2023 to 15 October 2025, 5,300 samples were cured and tested at the paste lab. The multidisciplinary backfill team (engineer, technician and operators specialised in metallurgy, mining, construction and backfill) meets regularly and all players have a common goal. The objective is to deliver high-quality paste backfill at the right place, right time with the right strength. To achieve this goal, all projects are aligned weekly, and the right strength also means that no extra binder must be used to achieve the individual strength needed for a specific stope and a specific location. Binder percentage, slump, and throughput are dynamically adjusted even if the tailings PSD and mineralogy is far from stable. Highly trained operators and supervisors are always aiming to produce paste at the lowest water content while keeping safe operational pressure to stay away from distribution blockage. Key lessons learned are for the operator to be encouraged to reduce as much as possible the slump and if the percentage solids goes down, to increase the binder as seen in Table 3.

Table 3 Operational adjustment recommendations

Solids percentage in operation	Binder adjustment
Under 69% for more than 1 hour	+0.2%
Under 68% for more than 1 hour	+0.4%
Under 67% for more than 1 hour	+0.5%
Under 66% for more than 1 hour	+0.7%

At the planning level, one key lesson learned was for the backfill engineer to use the large database to help predict achievable strength with various operational parameters. Power BI and Excel are used to generate UCS curves divided by slump (6.5, 7, 7.5, 8 and 9 inches), various binder percentages (from 2–8.5% with increments of 0.5%) with average PSD and mineralogy for a total of 42 curves. Here are the main parameters that are used to generate various strength projections:

- At least 5 different curing times of between 3 and 120 days.
- A minimum of 30 cylinders total.
- Slump is kept within 0.25 inches of margins.
- The ultramafic content at 20% ± 5%.
- The P_{80} at the planned target 80 µm ± 10 µm.
- Binder content ±0.1%.

The data treatment is done with Power BI and then Excel is used to isolate various sets of UCS data for logarithmic regression. A special set of curves can also be prepared for example with various ultramafic content. In Figure 10, 4 curves are presented with 4.5% binder percentage and a fix slump of 7 inches where only the UM content is changing.

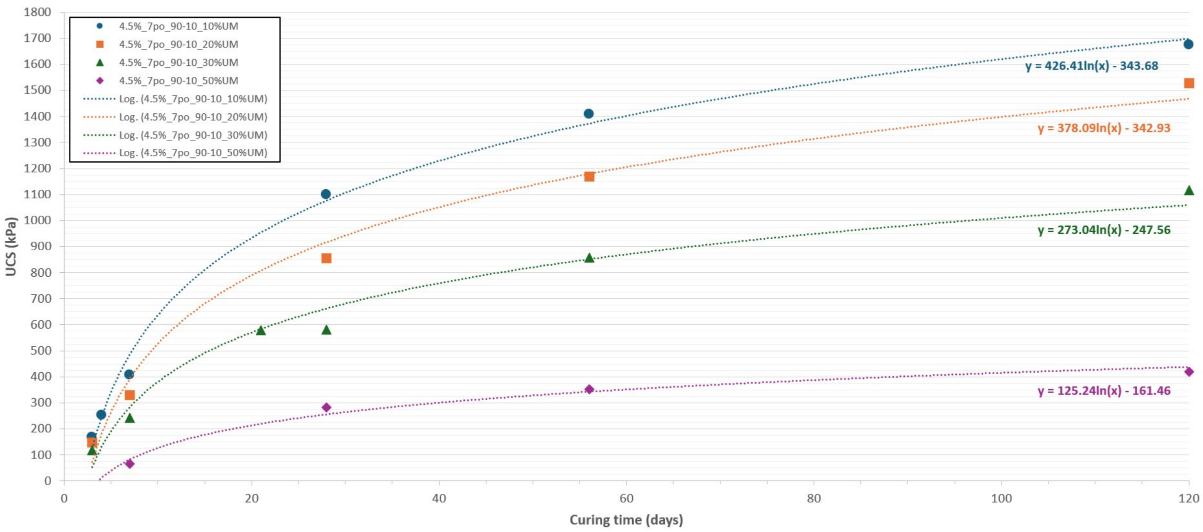

Figure 10 Average strength development with various ultramafic content

Power BI is used to aggregate all key parameters from the operation and link the information with the results that are obtained from operational samples. Pressure, slump, yield stress, paste temperature, binder%, admixture%, and solid% are known for all samples. Power BI is used to link all parameters with UCS results. Then those results are exported to Excel with a description of the operation parameters. Then by choosing the recipe with fixed solid%, fixed slump and fixed mineralogy, the log regression from Excel is used to get a function (Equation 1) that will project UCS from 3–120 days. It was observed that logarithmic regression is the most efficient function.

$$UCS = a * \ln(curing\ time) + b \quad (1)$$

Once the UCS in kPa is projected in a separate CSV table, the results can be brought back to Power BI for easier visualisation. Each CPB recipe can be seen with its specific strength development curves (Figure 11). Depending on the mining plan and position of the stope and the required strength, the backfill engineer can use the tool in Power BI to choose the required recipe. The database is kept alive and the projection updated monthly. With time, the variations of combinations of parameters make the projections increasingly precise.

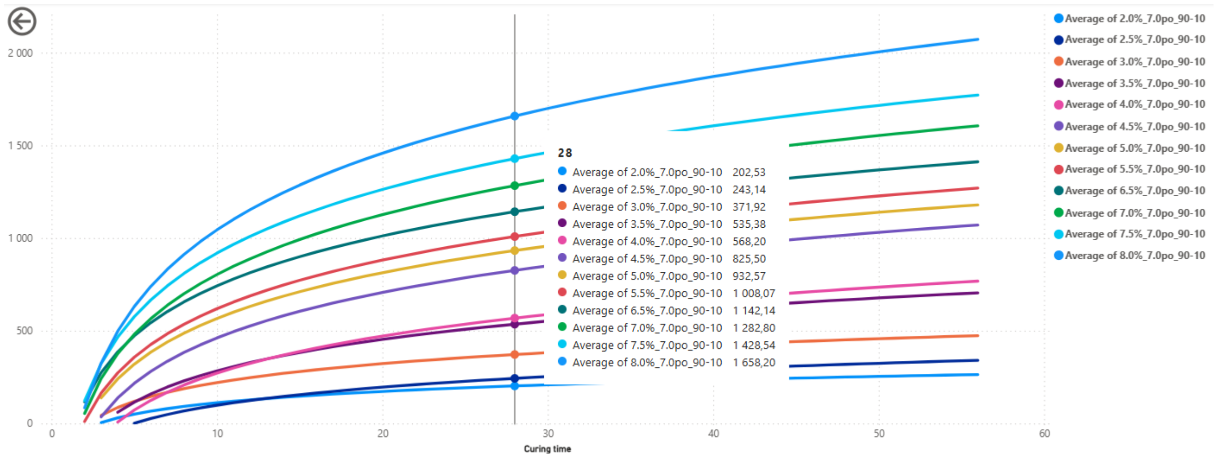

Figure 11 Power BI snapshot with all uniaxial compressive strength projection with 7.0 in slump from 2–8.5% binder

Figure 11 shows the power of having so much data. For example, if the paste backfill engineer calculates that the required strength is 850 kPa at 28 days, they can use the projected UCS curves and choose the recipe of 7 in slump with 5% binder knowing the UM projected by the geologists will be average on the day that stope is planned to be backfilled. If they are projecting a higher UM content to be fed at the concentrator, backfill engineers can adjust the binder content to a higher target. The backfill operators will also know in advance, and they can even adjust the binder percentage even more if the dewatering process is not as efficient and the tailings filtrate overall solids percentage goes down too much. This strategy enables the operation to adjust their paste recipe at the planning stage, but in reactive mode as well which reduces the surprises and risk in the mining plan. Knowing the projection of UM content can also trigger a change to the original backfill schedule postponing, for example, backfilling of a critical stope by a few days.

6 Conclusion

At the CMC, variation in ore mineralogy will affect the tailings characteristics from the moment the ore starts its journey at a concentrator. At the comminution circuit, lower-strength minerals such as clay-type will tend to get crushed in finer proportions. Once the dewatering process continues, clay-type minerals tend to be more difficult to separate from water and if their proportion is high, they will be fines which will also affect the efficiency of the process. Once these tailings are ready to be used to produce CPB, this paper showed that if those tailings have a higher proportion of ultramafic and more specifically talc, the overall strength of the CPB will be reduced between 10 and 37%. This reduction can be caught at the operational level when measuring lower percentage solids and finer PSD and even before, when the projected ore blends from the geologists will be generating higher ultramafic content. The multidisciplinary backfill team at Odyssey had the opportunity to measure such mineralogy and PSD impact with the help of optimised data gathering and exceptional communication.

Work is ongoing to reduce time between analysis and decision-making to optimise the binder consumption and keep the opex cost of backfilling at a minimum without compromising safety and the mining plan. The use of admixture has also been studied to reduce the mineralogical impact on CPB strength development. Various disk filter cloths have also been tested to reduce the impact of talc on dewatering effectiveness. PSD analysis and mineralogy testing are planned to be done in the future directly at the paste plant to get results within the same day to be more precise on strength prediction.

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