March 30, 2016

Mr. Ian Simpson
KGHM Ajax Indiginomics Coordinator
Stk'emlupsemc te Secwepemc Nation
PO Box 188, 1030 Trans Canada Highway
Savona, BC V0K 2J0

Dear Mr. Simpson:

This letter is a report presenting the results of my review of KGHM's Ajax Project NI 43-101 Technical Report Feasibility Study Update, British Columbia, Canada, Effective Date: February 19, 2016.

The report fulfills the proposal (Attachment 1) I sent you by email on March 8, 2016.

1. Qualifications and Independence of QPs

Attachment 2 is a table showing who was responsible for each section of the report and listing each Qualified Person's (QP's) qualifications. While all the QPs meet the minimal qualifications required under NI 43-101, I have some reservations about independence. First, the law permits non-independent QPs. It even recognizes and allows QPs to be employed by issuing party – KGHM in this case. However, I personally believe all QPs should be independent. To be sure, nearly all big producing companies include employees as QPs on their reports. But they shouldn't, particularly in the area of resource definition and reserve declaration. In my opinion, these determinations should be undertaken by independent QPs.

Another question is why did M3 author the report if they only had two QPs on the job? Neither contributed in the area of their engineering specialty, but rather, both worked on cost estimating and one did the economic model. In fact, neither M3 QP declares any qualification in cost estimating or economic modeling.

M3 employs cost estimators and financial professionals who perform NI 43-101 economic models. Generally, these experts are not QPs within the narrow NI 43-101 definition, as they are not geologists or engineers. If M3 used cost estimators and other financial professionals to perform the cost estimate and economic evaluation, they should have so disclosed in Chapter 3: Reliance on Other Experts.

Full disclosure: I worked for M3 as an engineer and study manager from 2003 to 2011 and managed several NI 43-101 studies.

According to the opening paragraphs, Fluor Canada was to carry most of the load on engineering. So it is puzzling why KGHM brought in M3 just to oversee the study and to supply two engineers, neither of whom specializes in cost estimating or economic modeling, to perform those two functions. As discussed below, the report discussions for both the capital cost estimate and the economic modeling are superficial.

Timothy S. Oliver, PE, P.Eng - Mine Project Consultant PLLC.
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2. Lack of Engineering Documentation

In general I found this feasibility report lacking in engineering support. Section 1.1.3 says "This report represents an update to the Ajax project feasibility study previously performed by Wardrop and continued by Fluor as a feasibility study update and a basic engineering phase and describes the work performed during this engineering phase." So, the level of engineering is Basic Engineering, one step more advanced than Feasibility Study.

Further, the study states "The basic engineering phase was executed between March 2015 and September 2015. In order to arrive at the desired level of estimate accuracy, over 50 equipment, materials and service packages were prepared, issued to selected suppliers, and evaluated for inclusion in the project scope and cost. Over 1,200 engineering deliverables (drawings, PFDs, P&IDs, etc.) were issued as part of this engineering effort."

Yet, this report contains only the most superficial engineering support documentation and references none of the "over 1,200 engineering deliverables" as appendices or even listed as references. Reports posted on SEDAR are sometimes summaries. If this is a summary, it should reference the full report and appendices and offer to make them available on request.

Here are some examples:

- Figure 1-1 is labeled "Site Layout." In my opinion it is a facility location map, not a site layout. It is the only layout drawing in the entire report, but lacks any useful detail beyond a general idea of the facility locations. A proper feasibility study should contain detail plot plans for all major surface facilities.
- The study contains two maps of the pit limits. A proper feasibility study should show annual pit maps including ramps, waste disposal facilities, haul roads, etc.
- The report shows only a single simplified process flow diagram. A proper feasibility study should show all process flow diagrams, detailed and complete, along with optimal heat and mass balances based on pilot testwork and process simulation modeling.
- A feasibility study should have a complete equipment list. The study references a "mechanical equipment list" four times, as though it is in the report somewhere. It also references an "engineering equipment list." None exist.

3. Capital Cost Basis is Superficial

The discussion of the basis for the capital cost estimate is superficial. A feasibility study should leave no question about the source of the cost information whether it be quotes from vendors for plant or mine equipment, material takeoffs and supplier quotes for civil works, steel, and buildings, or labor costs. All should be spelled out in detail. This report offers only superficial discussion and reveals little. For example, the capital cost summary presents labor rates but does not explain their origin. Labor rates can be tricky. Local conditions make a difference. The report contains no discussion whatever of the origin for the capital costs given other than for mining equipment. That is, no cost for mill equipment, earth moving, infrastructure, shops, etc. These costs are well over half of the total initial capital cost, yet, there is no clue as to the basis for the costs.

4. Economic Model Lacking

Feasibility studies nearly always include a table detailing the inputs and outputs of the discounted cash flow model. This report contains only a bare bones summary. It is impossible to track the derivation of the final economic predictions. For example, working capital is typically not included in the capital cost or operating cost calculations, but is included in the economic model spreadsheet. A rule of thumb for working capital is ninety days of operating costs. In this case, that is over $43 million out of pocket during the first three months of cash flow. It is significant. It is impossible to determine working capital in the model. This shortcoming makes it impossible for a reviewer to independently check the cash flow calculations.

5. Revenue Escalation Without Cost Escalation

The study improperly escalates future commodity prices, and therefore revenue, but holds costs static. You can't have it both ways. In my opinion, a feasibility study is a snapshot in time. The author should pick a reasonable commodity price for the estimated time of startup and leave that price static.

The forecast economic performance is relatively low with an internal rate of return (IRR) estimated to be only 11.1%. A general rule of thumb is for a minimum IRR of 15% for a project to be approved for development. Had the study included economic model spreadsheet, I could have calculated the effects of the copper price (revenue) escalation compared to no price escalation. Since the project is most sensitive to commodity prices, the change could conceivably render the forecast performance to be uneconomic.

6. Tailings Management

Abacus Mining and Exploration Corp. published a feasibility study by Wardrop in January 2012. Golder Associates was the tailings system design subcontractor and QP. Golder recommended a thickened, "non-segregating" tailings slurry for discharge into a new tailings storage facility. The percent solids, or pulp density, was to have been 70%. This is a very thick slurry which required expensive thickening equipment and positive displacement pumps. The advantage is that the tailings stream does not separate, or segregate, into two phases—solid and liquid. According to Golder, the non-segregating material provides a more stable mass of tailings than conventional thickened tailings. I've attached a paper by Golder Associates describing their views on the advantages of this type tailings management (Attachment 3).

In August 2014, the Mt. Polley tailings dam failed in British Columbia, resulting in a comprehensive and critical review of tailings management practice in the Province. One recommendation was that all future tailings designs undergo a Best Available Technology (BAT) review prior to design approval.

This feasibility study makes several references to a BAT review for the Ajax tailings management. The final recommendation is for placement of a 60% solids slurry in the tailings management facility. This material uses a less expensive thickening system and can be pumped using much less expensive centrifugal pumps.

The fact is, even after the Mt. Polley disaster, and the subsequent investigation and report, KGHM elected to incorporate the less expensive 60% pulp density tailing system. Is that system as safe as the more expensive 70% density system suggested in the earlier study?

Please let me know if you have questions or require further information.

Very truly yours,

Timothy S. Oliver, PE, P.Eng.

Attach. (3)

Proposal – Overview of KGHM's Ajax Project Feasibility Study

Introduction

KGHM owns an 80% interest, and is the operating partner for the Ajax Project, a proposed 65,000 tonne per day open pit copper-gold mine and associated ore concentrating plant including substantial infrastructure. KGHM recently published an updated Feasibility Study. The study was posted for public review on SEDAR on February 23, 2016.

This is a proposal to do a high-level review of the updated Feasibility Study. The review will examine the study according to ten criteria I have established, published and used in this type review of other projects on numerous occasions.

The review procedure does not evaluate the actual project characteristics. Rather, the purpose is to determine whether or not the study is of sufficient quality and engineering rigor to support an investment decision.

Criteria

Here is a list of the ten criteria to be used in the evaluation. I've attached a report I wrote detailing an exercise I undertook last year where I reviewed 34 separate studies according to the criteria. You will see how it works. Here is the list:

1. Qualified Person (QP) Conflict of Interest
2. QP Unqualified
3. Unrealistic Commodity Price Deck
4. Unrealistic Metallurgical Recoveries
5. Signs of Desperation
6. Lack of Engineering Documentation
7. Unrealistically Low Contingency
8. Lame Cost Basis Discussion
9. Absent or unrealistic project schedule
10. New or Exotic Technology

This is a relatively superficial review. It's a first look at the study and is intended as a "go no go" exercise, allowing the reader to determine if the project owner is serious about developing the project and has endeavored to present a realistic determination of the project's chances for success.

Cost Proposal

As I told you on the phone, the review for a Feasibility Study generally takes me about one working day. I require another two hours for report preparation. The report is a letter presenting my overall impressions and summarizing the findings under each criteria. My hourly rate is $150. The cost would therefore be $1500.

Timing

I can easily complete this review by March 31, 2016. Chances are it will require no more than a week after I get the go-ahead.

Sent via email from Tim Oliver to Ian Simpson dated March 8, 2016.

Attachment 2

KGHM AJAX FS QP LOG

Chapter		QP												
		Dagel	Roth	Ennis	Tolmer	Chubb	Wild	Stoiber	Watson	Yue	Mehmedbegovic	Rahmatian	Laylabadi	Farmer
1	Executive Summary	1.1, 1.8.1, 1.8.2 1.9, 1.11, 1.12, 1.13, 1.14		1.8.3, 1.8.4	1.5, 1.6	1.10	1.2,1.3,1.4			1.7				
2	Introduction	*												
3	Reliance on Others	*												
4	Description/Location					4.5	4 exc 4.5							
5	Accessibility, Climate, Infrastructure etc.			5.3, 5.4			5.5				5.1, 5.2			
6	History						*							
7	Geological Setting and Mineralisation						*							
8	Deposit Types						*							
9	Exploration by Previous Operators						*							
10	Drilling						*							
11	Sample Prep, analysis and security						*							
12	Data Verification						*							
13	Mineral Processing and Met Testing							*						
14	Mineral Resource Estimates						*							
15	Mineral Reserve Estimates				* exc 15.1.2.5				15.1.2.5					
16	Mining Methods			16.2.1	* exc 16.2.1									
17	Recovery Methods									*				
18	Project Infrastructure	18.3.11, 18.3.13, 18.5.1 to 18.5.3, 18.7, 18.8		18.2, 18.3 (exc 18.3.11&18.3.13)							18.1, 18.5.4, 18.5.5	18.4	18.6	18.9
19	Market Studies and Contracts	*												
20	Environmental and Social					*								
21	Capital and operationgCosts	21.3(not 2.3.1) 21.4 (not 21.4.1), 21.5, 21.6	21.1,21.2 (not 21.2.5)		21.2.5, 21.3.1, 21.4.1									
22	Economic Analysis	*												
23	Adjacent Properties						*							
24	Other Relevant Data		*											
25	Interpretations and Conclusions	25.1, 25.3, 25.6		25.4		25.5	25.2							
26	Recommendations	26.1, 26.3,26.4				26.5	26.2							
27	References	*												
28	References													

Name	Title	Degree	Year	Specialty	Experience	Reg.	IND	visit
Keith Dagel	Engineer and Project Manager, M3	BS	1979	Met	36	PE	Yes	Yes
Daniel Roth	Civil Engineer and Project Manager, M3	BS	1990	Civil	25	PE, P.Eng.	Yes	Yes
Sean Ennis	VP, Mining, Norwest	BS, MS	1991, 1997	mining, goeenv	21	P.Eng.	Yes	Yes
Danny Tomler	Sr. Mining Engineer, Golder Vancouver	B.A.Sc.	2004	Mining Eng.	12	P.Eng.	yes	yes
Derek Christopher Chubb	Senior Partner, ERM Canada	B Chem E	1990	Enviro	23	P.Eng.	Yes	no
Christopher Wild	Chief Geologist and Mine Manager, KAM	B.A.Sc.	1984	Geo, Mining	31	P.Eng.	No	Yes
Claus Stoiber	Eng. & Mineral Processing mgr, KAM	BS		Meallurgy	25	PE	no	yes
Julian Matherw Watson	Corp Sr. Mgr, Geotech Eng & hydrology, Rol	MS eng	1999, 2009	Geo, Mining geomech	15	RPEQ Aus	claims yes, but	
Jian Yue	Principal Process Eng., Flour Canada	M.A.Sc	2,003	Process		P.Eng.	Yes	Yes
Emir Mehmedbegovic	Engineer, Flour Canada	yes			12	P.Eng.	Yes	Yes
Pehman Rahmatian	Engineer, Flour Canada	M.A.Sc		Infra	18	P.Eng.	Yes	Yes
Maz Laylabadi	Electrical Engineer, Flour Canada	MS, EE		elect	14	P.Eng.	yes	no
Stephen Farmer	Control Systems Engineer, flour Canada	B.A.Sc.	1989	Mechanical	7 mining	P.Eng.	yes	yes

Attachment 3

ACG AUSTRALIAN CENTRE FOR GEOMECHANICS

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Joint Venture

The following paper appeared in the Paste and Thickened Tailings 2013 proceedings published by the Australian Centre for Geomechanics.

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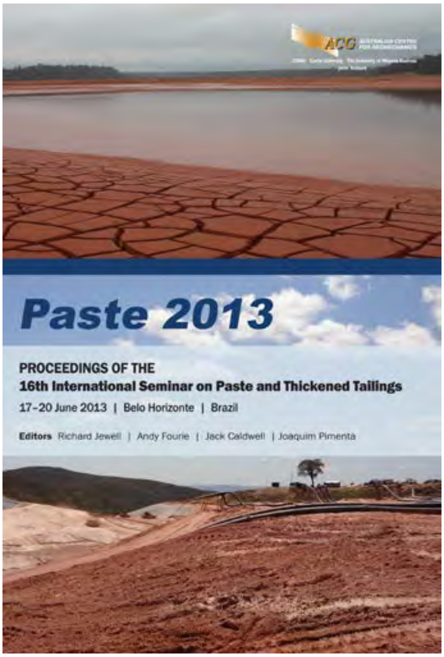

Paste 2013 — R.J. Jewell, A.B. Fourie, J. Cadwell and J. Pimenta (eds)
© 2013 Australian Centre for Geomechanics, Perth, ISBN 978-0-9870937-6-9

Trends in mine tailings disposal from a global perspective and in Brazil

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Abstract

Globally, mining environmental regulators are under increasing pressure to apply restrictions to both existing and proposed mining operations. The ability to profitably exploit large very low-grade resources once thought to be uneconomic through increased efficiencies and economies of scale demands new solutions in every area of the operation. The scale of mining operations has increased tenfold during the last 30 years, with similarly increased requirements for disposal of large tonnages of tailings and waste rock. As a consequence, the mining industry needs to search for greatly improved long-term solutions for tailings, rock, and water management to meet the existing and future operational, environmental, technical, financial, risk, and social constraints.

One area of innovation that is in continuous development is in the application of advanced dewatering technologies to produce non-segregating tailings slurry, ultra-dense, paste, or filtered tailings for disposal under a range of scenarios. The application of such technologies can contribute to reduced energy demands and lower ancillary equipment costs associated with the movement and storage of low density tailings slurry. Other advantages include reduced water use and water retention, reduced seepage, lower land usage for tailings storage, etc, which translate to reduced environmental liabilities. This objective is critical in terms of the sustainability of the mining industry and its perception by society at large.

What is the status of these technologies in Brazil? For many years, the Brazilian mining industry has investigated surface disposal and underground mine backfill using thickened tailings products. However, except in the case of Caraiba, where Golder developed a backfill project more than 10 years ago, other applications have not been documented.

This paper provides an update and a description of the current practices and studies conducted for mine waste management by Golder in Brazil. It describes the technology used and discusses the challenges resulting from site topographies, significant variability in wet and dry season climatic conditions, and advantages to be gained by adopting such solutions for tailings management.

1 Introduction

In the last 30 years, the scale of mining operations has increased tenfold as a consequence of improved efficiencies and product development with respect to drilling, explosives, haulage, bulk materials handling, crushing, and grinding. Low grade mineralisation now makes mines. Ever-increasing production rates and volumes of ore at lower grades have resulted in massive increases in the scale of tailings management, and a need to find low-risk solutions for today and to navigate recent climate changes. This situation is motivating the world mining industry to search for alternative methodologies for tailings disposal and for solutions to a number of complex environmental, technical, financial, and social issues regarding mine waste disposal.

The application of dewatering technologies to produce non-segregating tailings slurry for surface disposal or high density slurry (paste) for backfill is increasing day by day around the world. This technology allows the operation to recover process water within the dewatering plant, reduce the water management within the tailings facility, increase the potential placement density, reduce water discharged to the tailings facility, reduce seepage loss, and, consequently, to reduce efforts to pump back recovered water to the process plant. In fact, this situation offers the opportunity to manage solids and water streams separately and makes a tailings disposal systems safer. For most tailings management facilities, the most effective method to reduce risk is to eliminate the supernatant ponds formed on the facility. The most embarrassing and costly failures are associated with the migration of tailings after a breach of a dam that was designed to provide containment. This is critical in terms of the sustainability of the mining industry and its reputation before society at large.

Paste, or non-segregating thickened tailings technologies are lower risk, cost effective, and consistent with the public expectation that mines comply safely with the environmental regulations. This available technology allows mining companies to develop new strategies to reduce financial budget to cover potential environmental liabilities. The mining industry worldwide has recognised for some time that an assessment of the following drivers can cause a shift from the conventional management of large tailings impoundments to facilities with lower slurry water content:

- Economic concerns, such as net present value (NPV), capital, operating, closure, and post-closure land use costs.
- Risk and liability issues.
- Land use and land availability constraints.
- Recognition of social impacts.
- Surface and ground water resource management challenges.
- Cost shift in environmental requirements.
- Recognition of significant environmental and public safety benefits.

This assessment summarises the scenario in the world mining industry currently using thickened, non-segregating tailings for disposal over conventional dilute slurry systems. To the knowledge of the authors, while studies have been developed for the application of non-segregating tailings or paste backfill in Brazil since the early years of the century, existing operations have invariably adopted segregated thickened tailings. One exception is Caraiba, where a paste backfill system has been used for more than 10 years. This mine is applying, at this time, for surface disposal as well.

2 Overview

From a global perspective, it is useful to note, first, the efforts made by countries to raise awareness, and second, to force the industry to comply with environmental regulations that are increasingly demanding and certainly proven to be necessary for sustainable development of communities.

The first reference is undoubtedly the year 1970, 42 years ago, when the U.S. established the U.S. Environment Protection Agency (EPA). In fact, it could be said that an engineer, of any specialty, who graduated before 1969 from any university would not have been made aware of what it meant to dump tailings directly into the streams and rivers around the environment in which he worked.

Since then, the mining industry has had to comply with requirements based on the concepts of sustainability at local and national levels wherever projects are operating. These concepts were defined by the UN in the 1987 Brundtland report for socio-economic development of nations, and are related to the interaction of environmental, social, and economic factors.

The order in which these factors have been addressed is most important for the mining industry. The environment is closely associated with the assessment of water resources in social communities. Our interest is to emphasise the availability of the technology developed to date to maximise the use of water in the mining process and to use little fresh water replenishment to compensate for normal losses by evaporation in storage allocated for the containment of tailings. Today, the economic factors are assessed last in a mining project, once the environmental concerns have been fully addressed through a pre-feasibility study and environmental impact assessment (EIA).

The low rainfalls in the Andean region facing the Pacific Ocean, from northern Peru to southern Chile, are well known, as is the fact that these are privileged mining areas. It is here that the tendency to maximise the use of water resources with advanced technologies is being manifested by the magnitude of the number of projects, from large to small, seeking sustainable development in the sector. The trend is to discharge zero wastewater with metal contents above permitted limits for social uses into the environment.

3 Background

Typically, tailings management deals with a degree of dewatering that can range from simple, high-rate thickener to obtain a dewatered but segregated slurry (yield stress generally less than the 30 to 40 Pa range); to thickened, non-segregated slurry (materials in the range of about 40 to 150 Pa); to high density pulp or paste. In those cases where footprint, flooding, or seismicity is significant, thickening may be followed by filtration. Careful technical evaluation is needed to assess the cost-benefits for any of these options. The following main advantages can be considered if non-segregating thickened consistency is applied:

- Reduction of containment costs.
- Water conservation by means of reducing evaporation in dry environments:
  - Water conservation is a sustainability issue that is ever increasing in mining operations.
- Less water bleed on the tailings disposal area:
  - Reduction or even elimination of the construction of earth structures to retain water and tailings, with the exception of those to manage runoff around the perimeter.
  - Reduction of failure risk due to the reduction of water that could transport the tailings.
- Less water to be managed in the tailings basin:
  - Recycled water pumping costs are minimised.
- Minimal or no segregation as a result of little or no liquids/solids separation on the deposited area making possible the following:
  - Higher deposited density.
  - Reduced erosion.
  - Reduced storage volume.
  - Reduced oxygen ingress (therefore, reduced rate of oxidation and acid generation in sulphur bearing tailings).
  - Reduced dusting and leachate.
- Increased possibility of progressive closure, thus facilitating the reduction of environmental impacts.

The operational management of the tailings disposal system further considers a well-managed placement strategy for thickened tailings options, using natural evaporation as a potential aid to consolidating solids in slurry and to allowing the tailings to develop greater strength. A model of thin-layer desiccation can be adopted. This strategy is fundamentally opposed to that used in conventional dilute slurry impoundment, which often requires extensively long periods to reach final consolidation and strength once ponds are removed.

Increased density at placement reduces water losses through drain down and evaporation. Reducing the amount of process water reaching the supernatant pond means that the pond footprint itself can be further reduced, helping to increase the possibility of reduced evaporation. Water quality typically improves through the use of flocculant, often with possible improvements in mill recovery. Furthermore, the removal of ponded water from the top of the tailings contained mass, together with appropriate management of the slope of the deposit, also allows for diversion of storm water towards the collection system and facilitates the management of the tailings containment system, all at a lower risk.

Achievement of a dense, non-segregating tailings stream ensures a well-mixed fine, with medium and coarser solids at points of distribution and placement. Within as little as 24 hours, the reduction in consolidation bleed water characteristic of high density tailings permits the colloidal charges to pull the tailings into a denser phase, while continued consolidation and desiccation creates a low-void ratio stack. Segregated or beached tailings create a sand beach and slimes zones; sand particles do not exhibit this capability.

In some facilities, dry stack operations have reduced dusting events and erosion and have minimised mine process water discharge, to comply with the required water quality through water treatment plants.

4 Status of the technology in Brazil

Brazilian mining companies have started to evaluate the change of tailings deposition methodology in order to comply with the new environmental regulations and have developed investigations to assess the application of non-segregating thickened tailings and/or paste for surface disposal and/or underground mine backfill.

A number of mine waste management studies carried out in Brazil are listed in Table 1.

In general, the results of the trade-off and conceptual studies developed by Golder indicate that the application of dewatering technology for tailings disposal is attractive. In most cases, continuing the studies to a higher engineering level was recommended. However, few of these studies were actually taken to the next phase by the Brazilian mining companies that requested them. Most frequently, the decision not to continue studying this technology was explained by the absence of a large-scale operation in a country with tropical climate conditions, and by the assumption that high intensity rain over thickened slurry would result in uncontrollable erosion on the desiccated tailings mass. Erosion could also incur additional operational costs.

In an attempt to both refute this argument and to motivate Brazilian mining leaders to go forward with a year-round pilot plant study, two examples can be mentioned: an industrial practice and an investigation performed at Golder laboratories in Sudbury, Canada, and in Lima, Peru.

In the industrial practice, the Bulyanhulu mine in Tanzania chose surface tailings disposal as paste, based on the drive of water requirement for use in the milling and mining process. The site has a semi-arid climate but a very distinct wet/dry season and high evaporation. The annual rainfall is 1.2 m/yr (47 in); this falls in short duration, high intensity storms. The 100-year storm rating for the site is 200 mm (8 in) of rainfall in 24 hours. Figures 1 and 2 illustrate the fresh and desiccated tailings deposits at this site.

Table 1 Recent studies carried out in Brazil

Ore	Study level	Description	Production	Started
Zinc	Design completed	Trade-off study: non-segregating thickened tailings vs filtered tailings disposal and paste backfill	5,000 tpd	2012
Gold	Design completed	Trade-off study: paste backfill vs hydraulic fill	3,000 tpd	2012
	Design in progress	Conceptual study and lab testing program		2013
Copper	Design completed	Scoping study for non-segregating thickened slurry	48,000 tpd	2011
Copper	Design completed	Trade-off study, conceptual study, lab and pilot flow loop tests, and basic engineering for non-segregating thickened slurry for disposal	43,000 tpd	2010
Nickel residues	Design completed	Trade-off study for thickened tailings deposit based on lab test results	6,000 tpd	2010
Phosphate rock	Design completed	Desktop study based on lab testing results	41,000 tpd	2009
Phosphate rock	Design completed	Scoping study and conceptual study for non-segregating thickened tailings disposal based on lab testing results	20,000 tpd	2008 –2009
Fly and bottom ash	Design completed	Conceptual study, lab and pilot flow loop tests, and basic engineering for transport of densified ash for disposal	10,400 tpd	2007
Bauxite	Design completed	Conceptual study based on lab testing results	18,000 tpd	2007

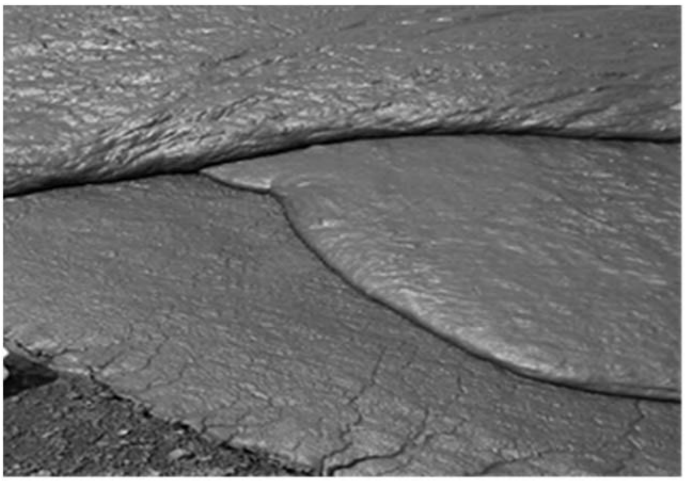

Figure 1 Fresh tailings deposited over heavily desiccated tailings

Figure 2 Desiccated tailings

Figures 3, 4 and 5 show that the heavy rains do not appear to liquefy the fresh tailings significantly at Bulyanhulu; instead, water collects and ponds on the surface of the fresh tailings. The older tailings hold up fairly well unless the flow is concentrated, and then erosion occurs.

Figure 3 Erosion in concentrated flow

Figure 4 Erosion in concentrated flow

Figure 5 Erosion in concentrated flow

In lab testing, the investigation simulated high intensity rain conditions in order to assess the impact of the effect of heavy rainfall on surfaces of non-segregated, thickened tailings. The last results showed that, as long as the non-segregating tailings mass is desiccated, the low permeability of the thickened tailings will impede the infiltration of rainwater deep into the mass. The fines on the surface are carried over and can be managed and controlled. Figures 6 and 7 illustrate a test performed on freshly deposited paste tailings, where a spray of 1.2 l/min of water simulated precipitation over an area of 1.11 m^2. The rain simulation test was performed on paste of 76w% solids; the parameters assumed for this test are summarised in Table 2.

Table 2 Hydrologic parameters

Parameters	Values
Precipitation (24 hrs) Tr = 100 years	197 mm
Storm duration	3 hours
Intensity	64.86 mm/h
Tailings deposited area	1.11 m^2

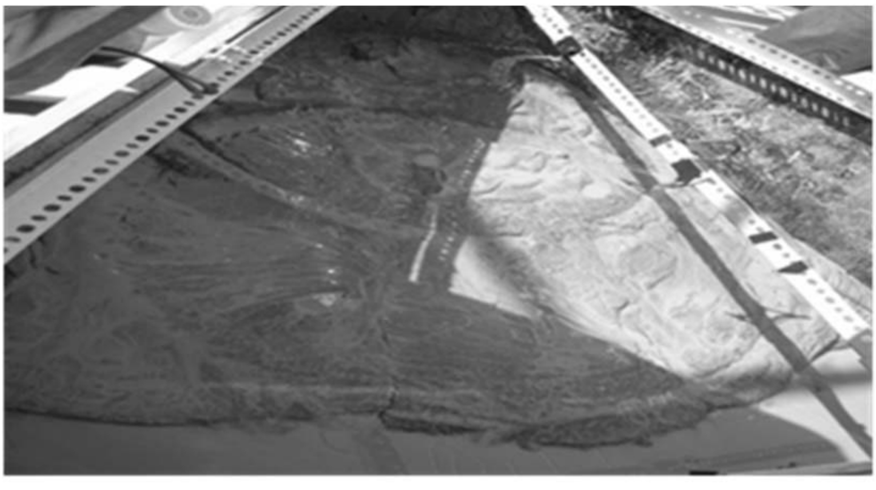

Figure 6 During raining simulation

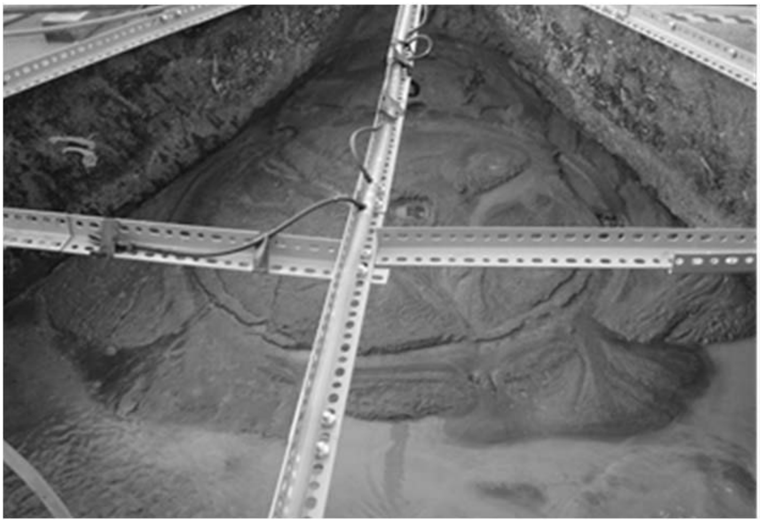

Figure 7 After raining simulation

The results obtained on the raining simulation were evaluated according to the reference values of erosion levels recommended by recognised institutions like the Unites States Bureau of Reclamation (USBR) and the Food and Agriculture Organization of the United Nations (FAO). These agencies have conducted several studies of erosion and transport of solids for different terrains with varied characteristics concerning stability, coverage and rainfall variability, and setting levels of erosion for each soil type.

The quantification of the particles obtained in the test was 754.94 grams over an area of 1.11 m^2 tailings yielding a ratio of 680 g/m^2. Quantification was obtained assuming the occurrence of precipitation for wet, dry, and average years, in which there were 12, 7, and 9 possible storms, respectively. Using the reference values of the USBR, the estimated erosion levels were 143–242 t/ha/year. The summary of the test results are shown in Table 3.

Table 3 Erosion level

	Erosion level	Surface	
		USBR	**FAO**
Wet year	242 t/ha/year	Strong	High
Average year	176 t/ha/year	Strong	High
Dry year	143 t/ha/year	Strong	High

According to the test results, the erosion level shown is strong and high if compared with the USBR or FAO erosion level references. However, these reference values correspond to a free surface without large roots, plants, or grass, in loose soil and wasteland, with a slope of not less than 30%. These characteristics are similar to the surface of the desiccated tailings deposition, and therefore, the estimated level of erosion is considered to be acceptable.

Another misconception is that dewatering systems for tailings management are prohibitively expensive when compared to conventional diluted tailings disposal. In this case, holistic evaluation of options from conventional diluted slurry to dewatered tailings disposal strategies should always consider measurable cost-benefits such as capital costs for containment systems versus dewatering plants, return water systems (pumps, pipelines), operating costs, reduced risk and associated bond payment, permitting, closure, environmentally safety, and social acceptance. Regulators are now familiar with these concepts and in some jurisdictions will not issue operating permits for conventional tailings facilities unless it can be clearly shown that the application of a dewatering system, as described in the best available technology (BAT) guidelines cannot be reasonably implemented. As the public at large is becoming more sophisticated, it now has access to greater and wider sources of information, and as seen recently, can communicate actions in seconds across the globe using text and images. The ability to manage tailings sites within the context of safe management practices is paramount to maintaining licenses to operate these facilities.

5 Key research findings

Variables such as transport velocity influencing depositional or impacting energy of the fresh non-segregating slurry against previously deposited non-segregating slurry, slump, temperature, and precipitation can influence the deposition angle of the stack. Steeper deposited slope angles are largely influenced by desiccation of the flowing non-segregating slurry, resulting in strength gain. To date, a maximum deposition slope angle approximating five degrees has been achieved with progressive deposition. The higher bulk density of a paste and the stacked disposal scheme allow for a smaller footprint area.

6 Conclusions

Deposition of non-segregating thickened slurry allows improved water management, significant reductions in dam construction costs, and increased storage capacity of the impoundment area, and opens the possibility to allow progressive closure concurrent with deposition.

The technology for management of tailings facilities has evolved as needed by the mining industry since 1970, and since the first efforts to socialise sustainability concepts in 1992, started here in Brazil with the Earth Summit, but not too much has been implemented since then. The mining industry is committed to efforts to achieve long term socio-environmental sustainability. This paper has summarised the efforts of Golder to demonstrate that the technology to produce and deposit thickened, non-segregating tailings is feasible even in tropical countries with intense heavy rainfall, such as Brazil, and not only in the drier South American Andean region.

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