FINANCIAL AND ECONOMIC ANALYSIS ESSENTIAL DURING THE DESIGN PHASE TO ENSURE OPTIMAL DESIGN OF A PROCESING CIRCUIT

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Overview

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- Decision Making Process
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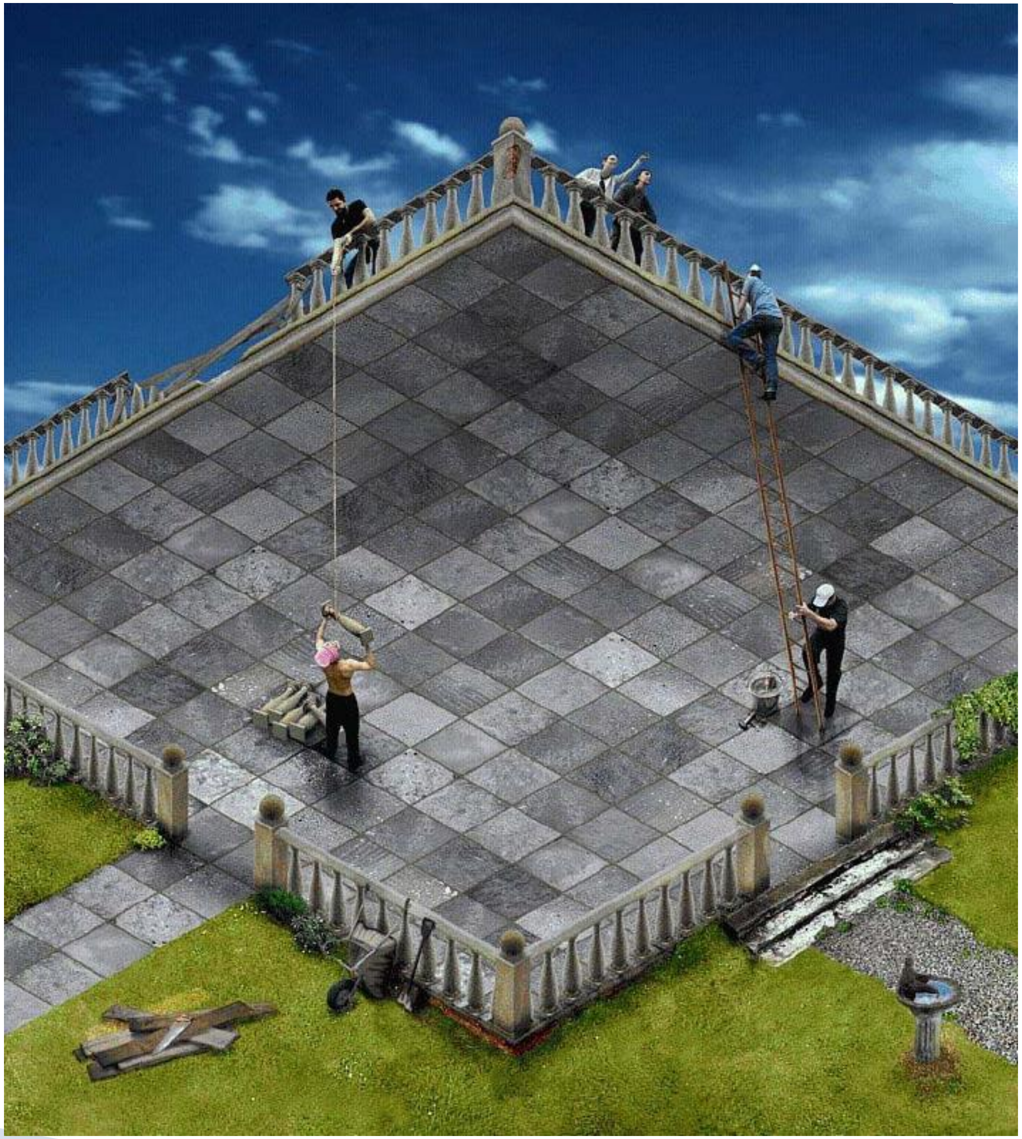
Introduction

This presentation will show that using geometallurgical information in various phases of a project or existing operation is of utmost importance to improve your mine value chain. A well planned and executed geometallurgical testwork programme during the early phases, will result in a more accurate decision making process during the selection phase.

Perception

Perception can be dangerous and costly



Decision Making Process

Understanding the response of variable material through a process

Allowing more effective decisions to be made at a planning AND operational stage

Enabling economics to be maximised

Economic Analysis

- Simplified financial models were developed based on:
  - the grind/recovery/energy data for three different case studies (ore bodies and commodities).

- Model incorporate various factors and assumptions such as:
  - capital cost multiplier of equipment capital,
  - capital cost payback period,
  - power cost (including power station if applicable), reagent cost,
  - operating hours,
  - consumable cost,
  - valuable metal grade, and
  - throughput rate.

Case Studies

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Case Study 1 - An average gold grade (2 to 6 g/t) free milling gold project with a conventional flowsheet (comminution, CIL, elution and electrowinning)

Case Study 2 - An low gold grade (0.8 to 2 g/t) free milling gold project with a conventional flowsheet (comminution, gravity, CIL, elution and electrowinning)

Case Study 3 - A low grade massive copper sulphide deposit (average about 0.5%) producing a copper concentrate (also some by-products which forms less than 10% of final copper metal value)

Case Study 1

- Deposit situated in Africa
- Gold Grade – 2 to 6 g/t (variable and spotty)
- Mineralogy of Ore Body
  - plagioclase feldspar (major)
  - carbonates (moderate)
  - quarts and pyrite (moderate to minor)
  - calcite and chlorites (minor)
- No real deleterious elements to be worried about (some pockets of cyanide soluble copper)

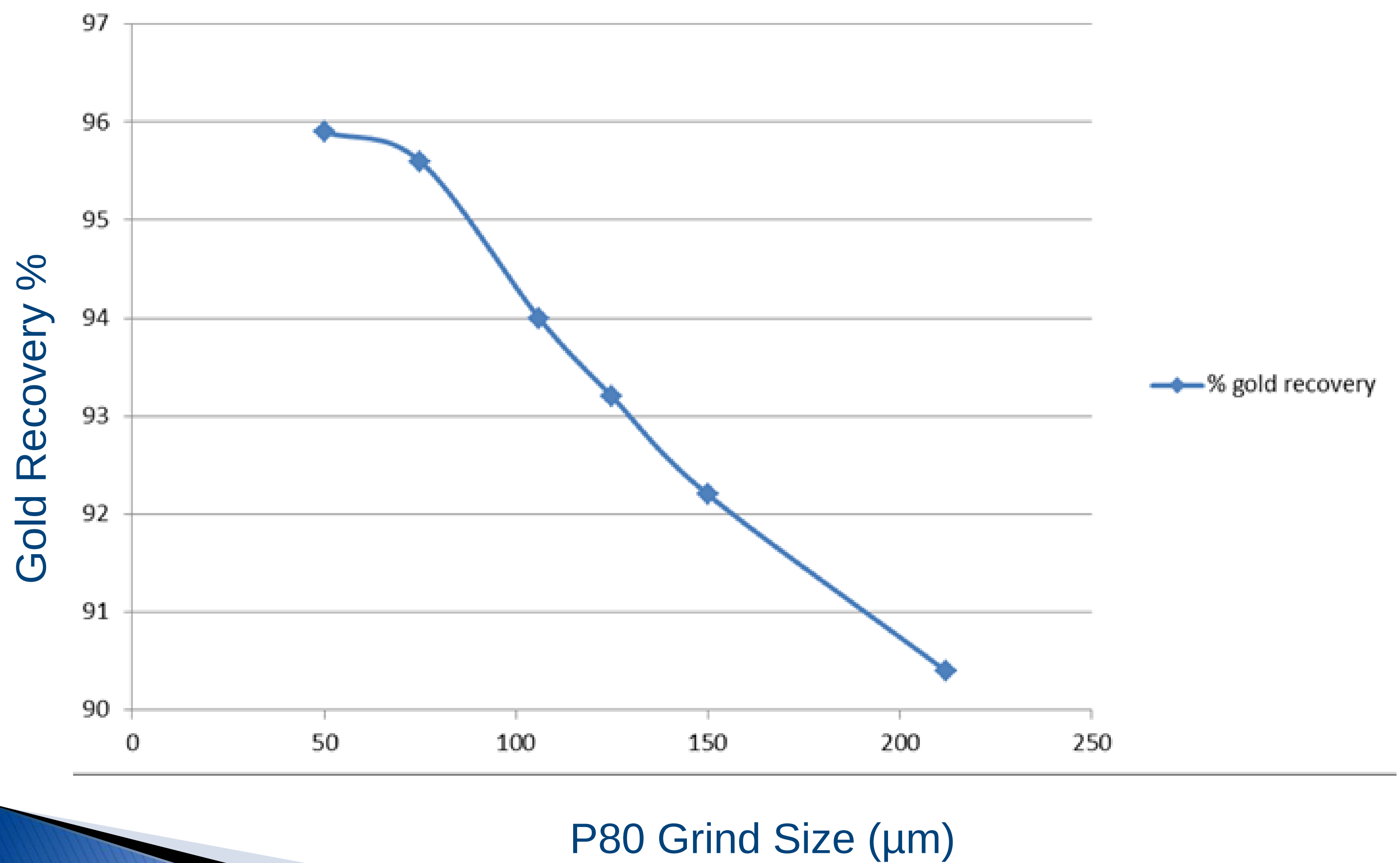
Metallurgical Testwork

Programme managed by owner:

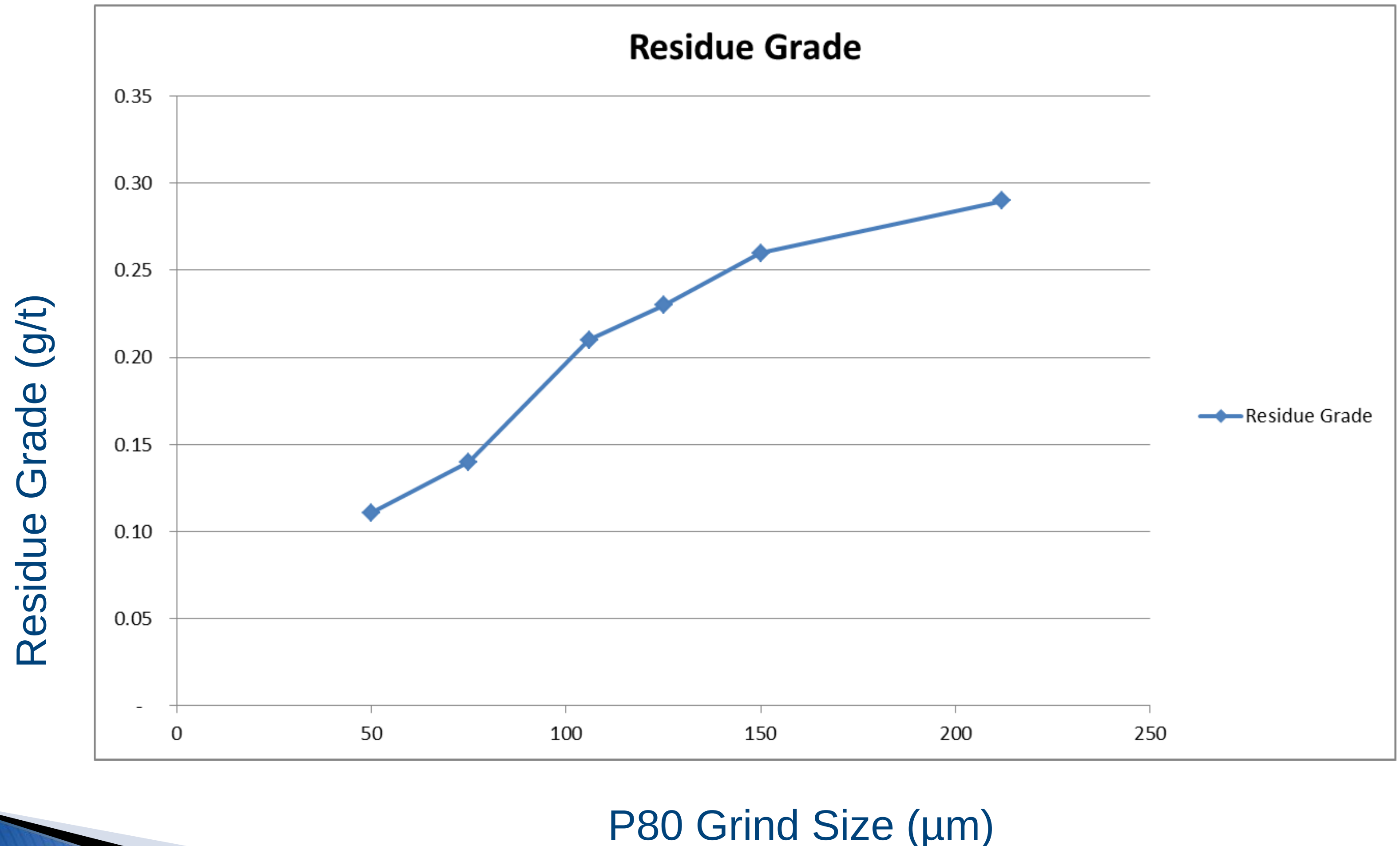
- Grind Establishment and Grind Optimisation (by Gravity and CIL Leach).
- Size-by-Size Analysis at selected optimum grind size.
- Sequential Triple Contact CIP and Equilibrium Carbon Loading.
- Oxygen Uptake and Viscosity Testing.
- Cyanide Optimisation.
- The Master Composite Samples were ground to nominal grind sizes of 212µm, 150µm, 125µm, 106µm, and 75µm, respectively.

Testwork (Recovery vs Grind Size)

Recoveries at 24 hr and varying grind size.



Testwork Results (Residue Grade vs Grind Size)



Comminution Circuit Modelling

Experts in comminution circuit design modelled 3 possible comminution circuits:

- Tertiary Crush and Ball Mill
- **Primary Crush SABC**
- Partially Secondary Crush SABC

Model Outputs

- Specific energy requirements for each circuit
- Major equipment list for each circuit
- Major consumable estimates for each circuit

Economic Model

Inputs

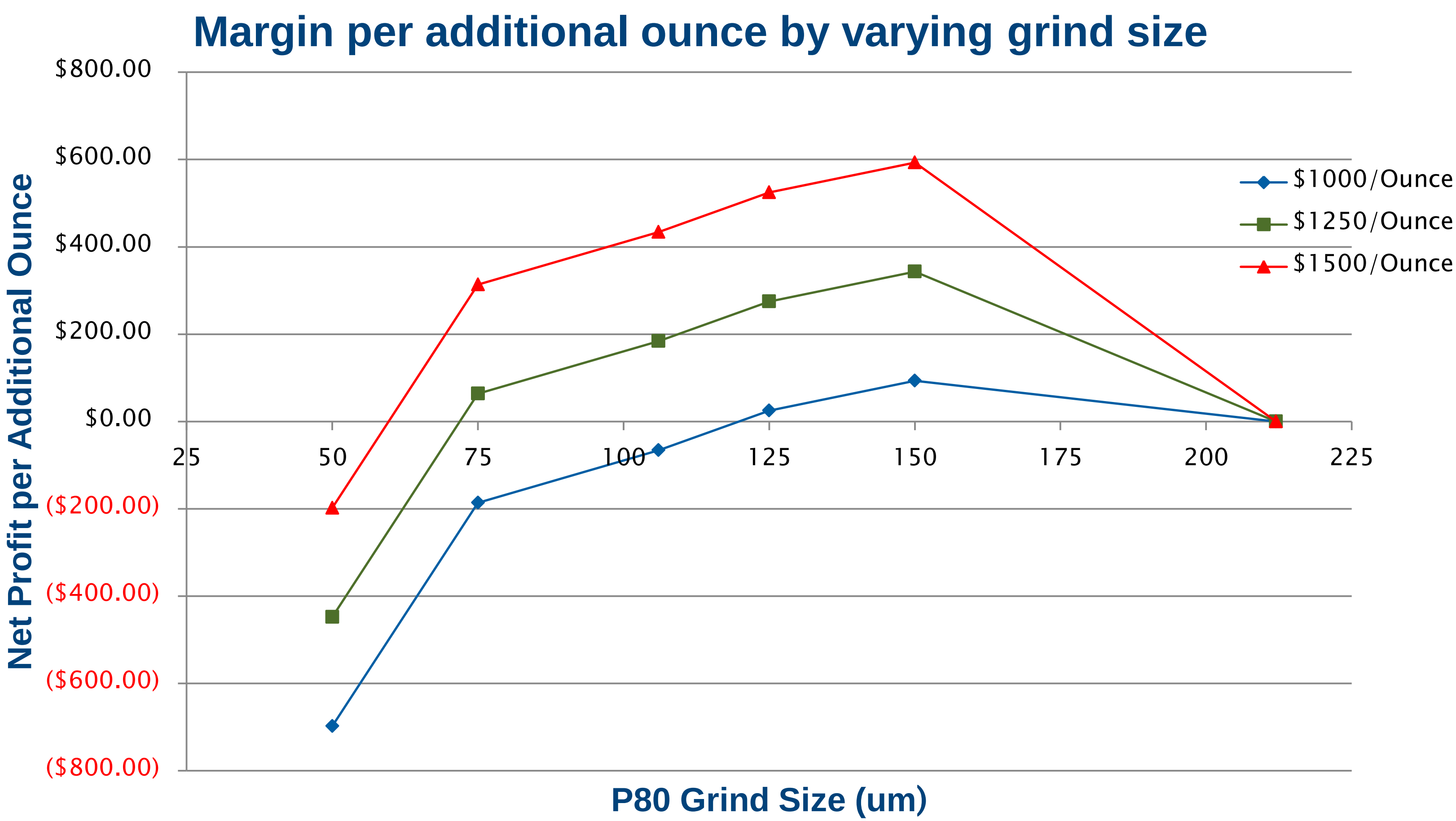
- Capital cost of major comminution equipment
- Cost of consumables based on similar projects in that area
- Cyanide and lime consumptions presented in the leach testwork at the grind sizes provided ambiguous reagent consumption results
- Plant throughput of 4 Mtpa
- Milling circuit configuration based on SABC
- 24 hours residence time (leaching)
- Milling circuit maintenance costs calculated as 4% of the mill supply capital cost (Lycopodium), and included in the operating
- ROM head grade of 2.60 g Au/t

Economic Model

Inputs Continue

- Power requirements and comminution consumable usage rates were provided.
- Power, media and liner consumptions are based on the average of the available comminution results ores.
- A power unit cost of US$0.33 kWh based on a Heavy Fuel Oil (HFO) power station at 26 c/l
- Incremental change in power station capital cost: US$1.5M per Megawatt
- Incremental change in comminution circuit capital cost: US$1.2M per Megawatt
- Three gold prices used – US$1,000/oz, US$1,250/oz and US$1,500/oz
- Payback for capital items 3 years

Net Profit per Additional Ounces vs Grind Size



Case Study 1- Conclusions

These relationships/geometallurgical inputs into the pit optimisation process allowed the owner to make calls on what will be the best mining strategy, ie:

- Processing various ore domains separately;
- Processing blends of various ore domains;

to obtain the best possible economic outcome for the project.

Case Study 2

Free milling gold ore body with more than 50% gravity component with three domains, fresh, transitional and oxides – Australian Ore Body

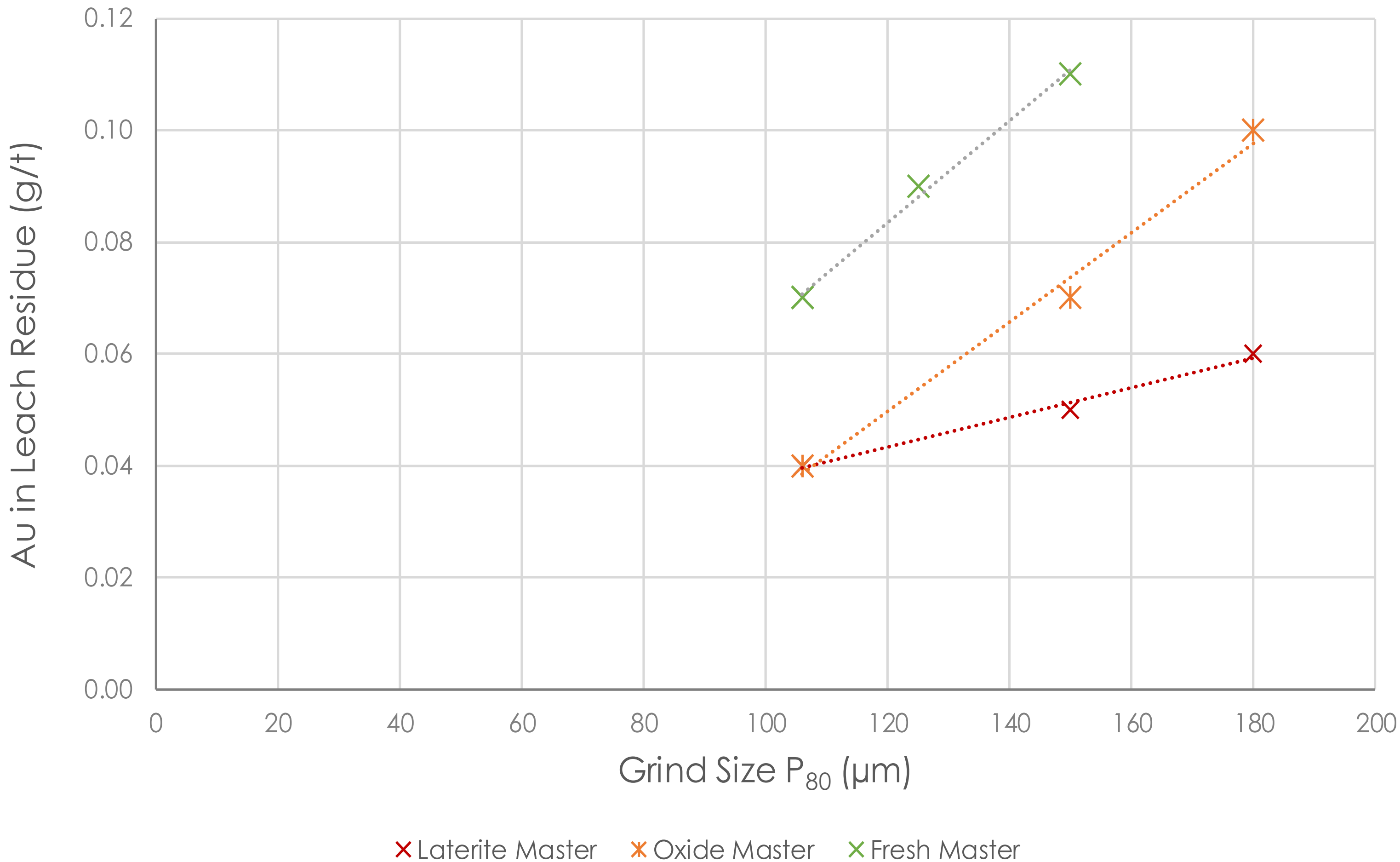
Inputs into financial analysis:

- Ore hardness at various grind sizes;
- Specific energy consumption and cost (confirmed by Orway Mineral Consultants);
- Grinding media and mill liners consumptions (calculated using Abrasion Indices and specific power inputs);
- Gold losses to leach tailings at various grind sizes;
- Estimated operating and capital cost for comminution circuit

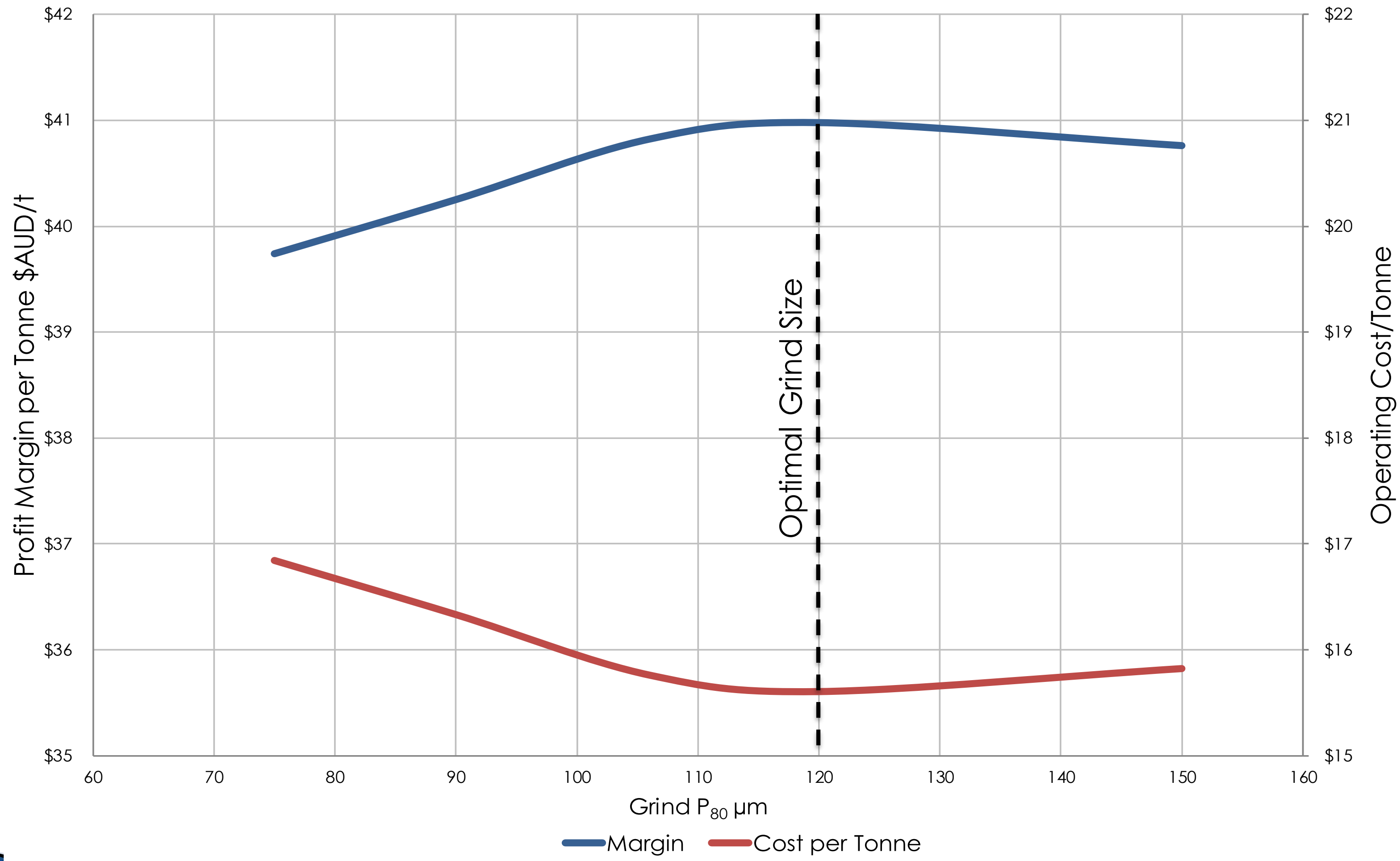
Summary of Parameters Inputs

Input	Value
Metal Price_Gold	$1,600/oz
Power Supply Cost	$0.20/kWh
Grinding Media Cost	$1,450/tonne
Grinding Mill Liner Cost	$3,400/tonne
Fixed Costs (G&A, Mine & Plant labour overheads)	$19M/a

Grind Size Dependance

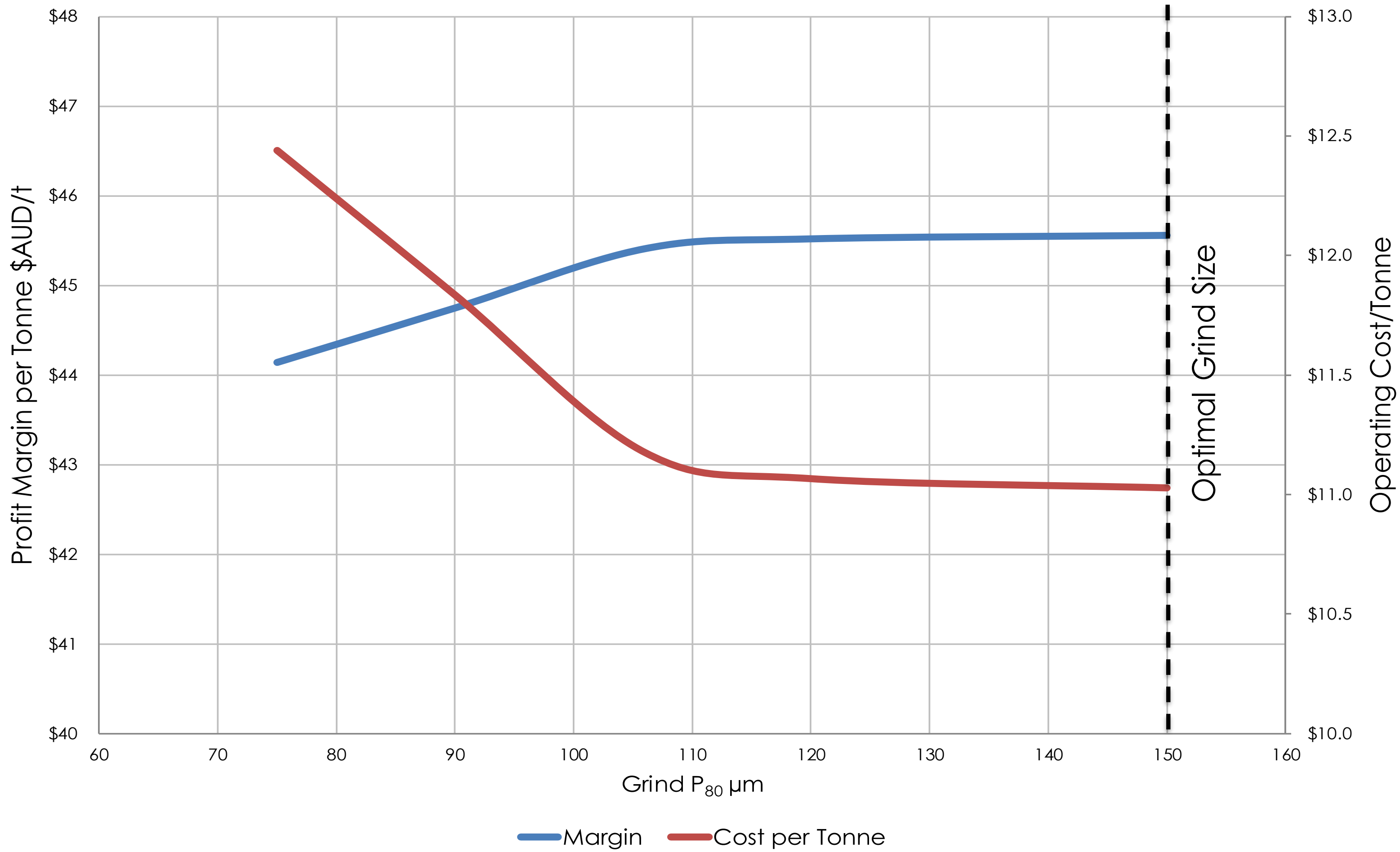


Fresh Ore



$42
$41
$40
$39
$38
$37
$36
$35
$22
$21
$20
$19
$18
$17
$16
$15
Profit Margin per Tonne $AUD/t
Operating Cost/Tonne
Optimal Grind Size
60
70
80
90
100
110
120
130
140
150
160
Grind P80 µm
Margin
Cost per Tonne

Oxide and Transition Ore



Case Study 2- Conclusions

For the different metallurgical ore types, the outcomes of the financial analysis for optimising grind are different. For the fresh ore, a primary grind of 80% passing 120 µm offers the greatest revenue benefit. For the laterite, oxide and transition ore a primary grind of 80% passing 150 µm is recommended.

Case Study 3

- Copper Oxide and Copper Sulphide Deposit (with recoverable molybdenum)
- Determine the effect of grind size (P80) on copper sulphide flotation response
- Best grind size for optimal copper recovery (taking into account molybdenum recovery)?
- Deposit in the Americas
- Escolme, et al. (2016) developed some predictive geometallurgical models to develop the Cu-Au-Mo deposit based on geochemistry to reflect the variability in Cu sequential leach data (ie oxide, transitional-oxide, transitional sulphide, sulphide and non-recoverable Cu).

Assumptions

- Recoveries from the grind series testwork - only from the main pit. Data equalized for grade.
- Actual comminution testwork results used.
- Ball mill capital costs – from quotation.
- Power cost US$0.10/kWh – from client.
- The marginal operating cost includes ball mill power, grinding media and liners.
- Initially only ball mill capital and operating costs varied with grind size.

Assumptions

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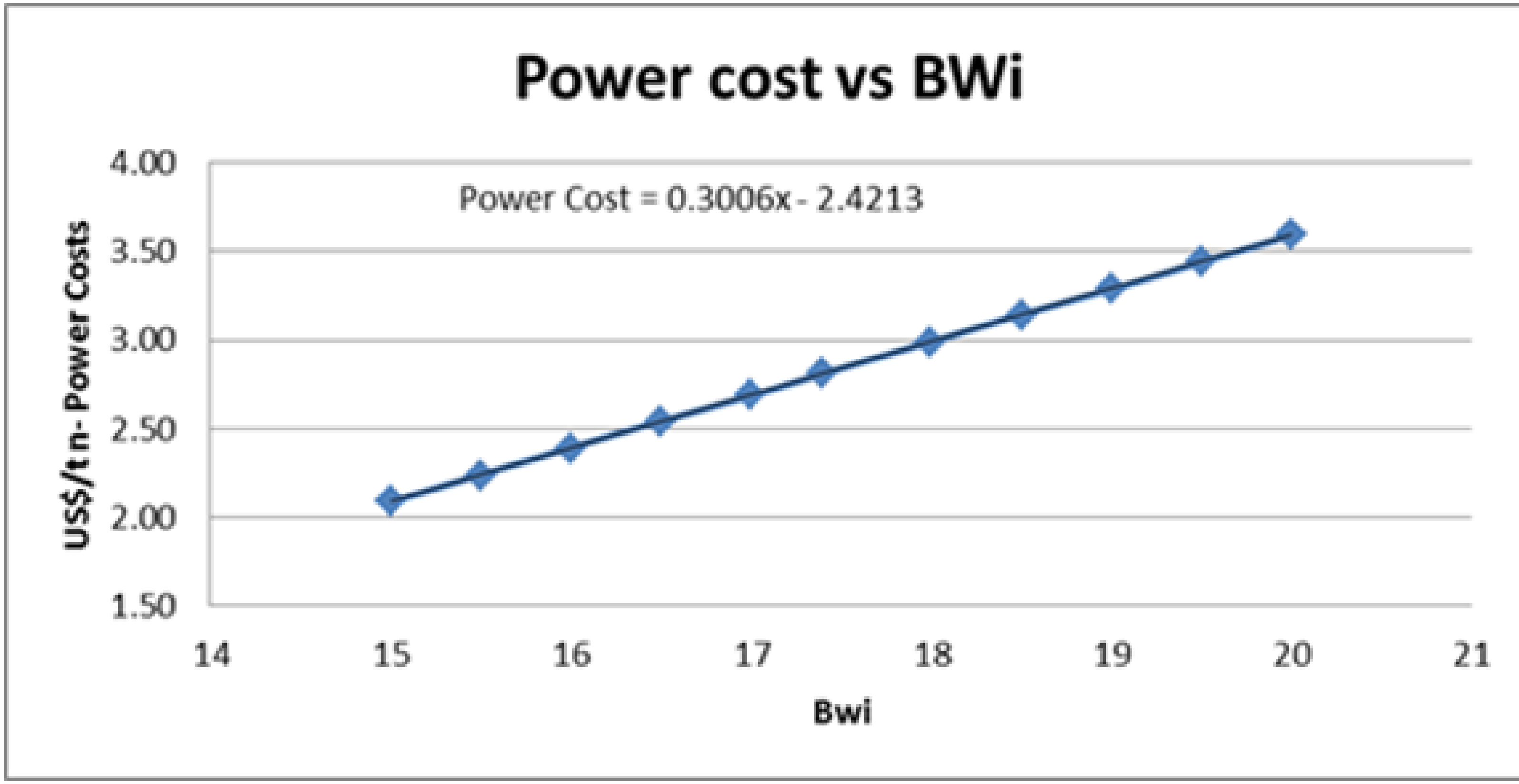
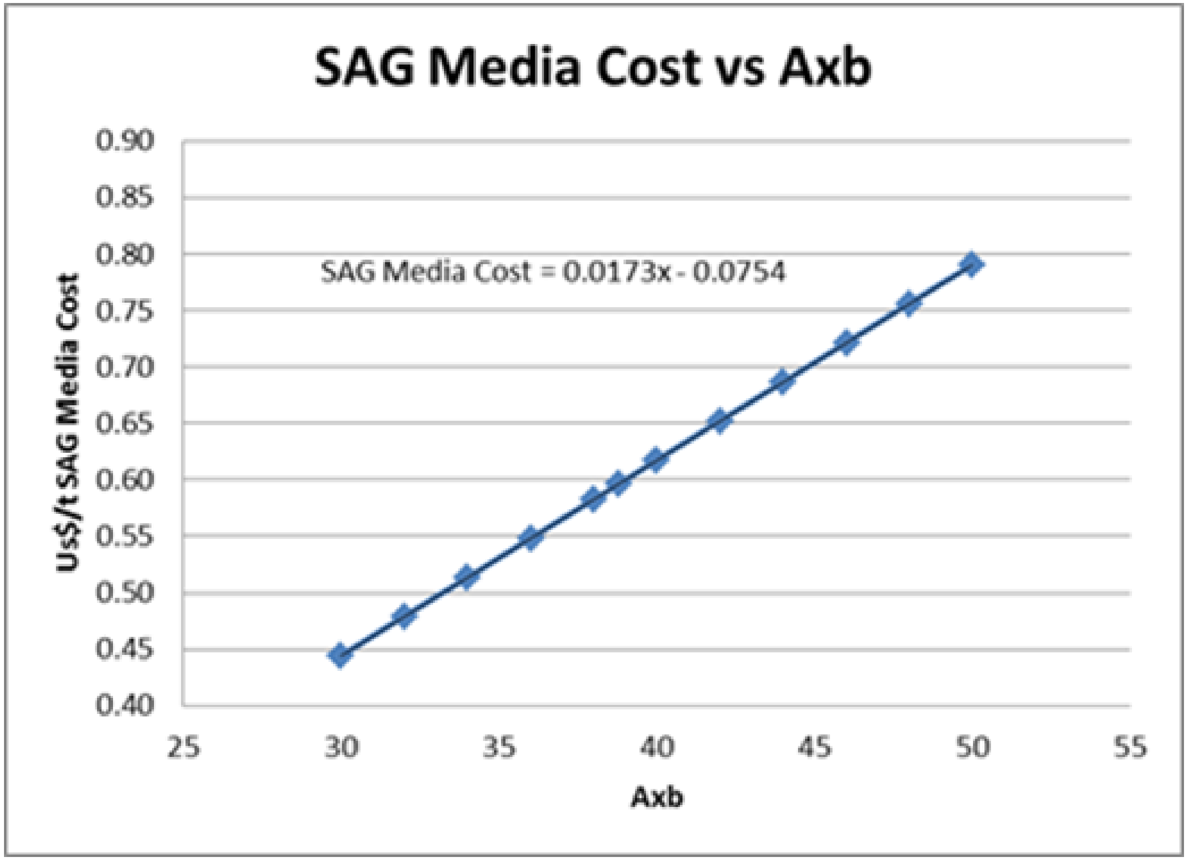
- Copper price used (US$ 6,000 /t Cu) is net of TC-RCs.
- Net revenue calculation: (Copper Price -TC-RCs) - marginal operating cost - marginal capital cost.
- Marginal operating cost includes ball mill power, grinding media and liners.
- Marginal capital cost is the installed ball mill cost divided by a nominal payback period of 5 years.
- The emphasis of this analysis is to define a design point for the Ball Mill:
  - In operation, actual grind size and throughput can be varied.

Power Cost as a Function of BWi



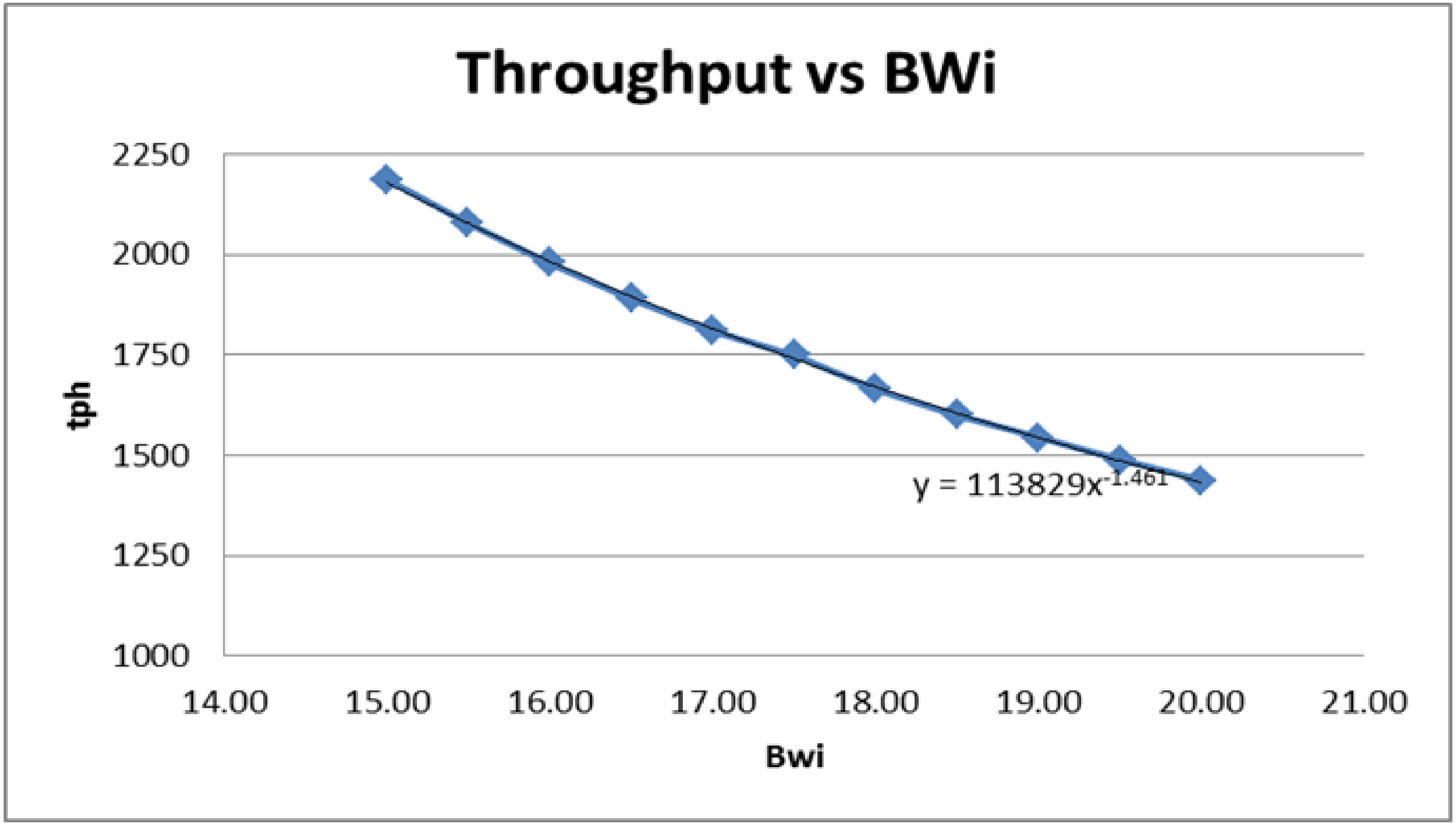
BWi = 0.9796 AI+1.5071 K+3.3686
Power Cost = 0.2067 BWi - 1.6051
Ball Mill Media Cost = $(0.0794\ Ai^{0.498})$ (1.667 BWi - 19.367)

SAG Mill Grinding Media Cost as a Function of Axb



SAG Mill Media Cost = 0.01733 x (700/BWi) – 0.07542

Throughput vs BWi



$$\text{Throughput} = 113829\ \text{BWi}^{-1.461}$$

Predictive Geometallurgical Model

King and Macdonald (2016) then developed a predictive geometallurgical model with the authors by using both discovery and integration aspects. In their paper they discussed the concepts of geometallurgical modelling in terms of the underlying relationships that are used in geology, metallurgy and economic value, and how the early-stage preparation of spatial geometallurgical models enhances project value and provides for a sound basis for further studies.

Case Study 3 - Conclusions

Using Bond Work index and Abrasion Index proxies in the geometallurgical model, the model could predict the variability of sulphide ore throughput and comminution costs for example. Heap leach acid consumption in oxide ore was estimated from results and drill hole calcium concentrations. This model was then used in the mine scheduling to identify high and low throughput in sulphide plant and high and low acid ore zones for processing in oxide heap leach.

The development of these four relationships allows the geometallurgical model to become a tool for economic analysis. The application of the proxy to the deposit to estimate the BWi in turn allows the estimation of the variable processing costs. Certain high or low processing cost ores can be brought forward or deferred in the mining schedule to improve the overall NPV of the project.

Conclusions

This presentation describes the use of various geometallurgical parameters using three case studies from different ore bodies to model the performance of a processing plant. The presentation shows that it is of utmost importance to understand the response of variables throughout the process. Using relationships between these variables (geometallurgical variables), geological models as well as economic models allow the authors to make effective decisions at both a planning and operational stage. That enables the authors to maximise economics and thus viability of the project.

Conclusions

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The results from a well-designed geometallurgical programme can thus be used for:

- Better flowsheet design (more flexible);
- Better use of algorithms for throughput and recovery in resource and reserve models;
- Better use of the mining schedule to optimise plant performance;
- Better plant and equipment design and sizing;
- Optimise plant performance and forecasting;
- Reduce risk in subsequent phases; and,
- Enable economics to be maximised.

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QUESTIONS