

NEWCREST TECHNOLOGY STEP CHANGE

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ABSTRACT

Newcrest has a strong history of growth over the past 20 years, yielding value from previously marginal ore bodies. We have grown regionally in Asia Pacific through our operations in Australia, Indonesia and Papua New Guinea, and also established a beachhead in West Africa. The company has a reputation of realizing value from large, low-grade deposits adopting step change approaches.

Newcrest is focused on an overall strategy of gold, low cost, long life and moderate growth. Capability step changes play a large delivery role. They transition from a business offline-to-online approach as opportunities mature. Newcrest believes in a) Knowing what 'good' looks like, b) An open innovation approach to actively working with others, c) The leap frogging leverage of making the 'old new again', d) An adopt-adapt-develop methodology enabled by rapid prototyping/piloting, e) Getting our hands dirty with test work and plant analysis, and f) Staying focused on a few high business leverage areas.

This paper describes Newcrest's approach and our experiences in establishing renewed metallurgical processes, specifically aimed at increasing innovation adoption. Some of our step changes discussed include: 1) Early waste rejection to avoid high energy processing downstream, 2) Broader gold product channels to reduce site based processing needs, 3) Lower energy processing, and 4) Geo-Metallurgy approaches.

Keywords: Newcrest, gold, step change, open innovation, adopt, adapt, develop, offline, online, prototyping, old new again, waste rejection, low energy, geo-metallurgy

INTRODUCTION

Newcrest Mining is the largest gold producer listed on the Australian Stock Exchange and one of the world's top 5 gold mining companies by production, reserves and market capitalization. Over the last five years the company has grown substantially by means of acquisition, Greenfields and Brownfield's projects. The company's core strength is low cost mining of gold and copper from low-grade resources. The operating mines at Telfer in Western Australia and Cadia in New South Wales are large low grade ore bodies, reporting copper at less than 0.3% and gold at less than 1 g/t. Newcrest, over the years, has developed mining and process technology for efficient extraction of copper as concentrate, and gold as bullion and in copper concentrate. The copper concentrate is then marketed as smelter feed.

In 2010, the company acquired The Lihir Gold Mine in Papua New Guinea, prompting a further capability step change. Unlike the resources at Telfer and Cadia, where the gold occurs as free particles and with copper minerals, Lihir is a refractory gold ore body where gold tends to occur inside pyrite grains. In addition to the conventional crushing and grinding facilities, autoclaves oxidize the sulphides to release the encapsulated gold for downstream extraction.

Newcrest remains focused on its overall strategy of gold, low cost, long life and moderate growth. In order to sustain this moderate growth strategy, it has also several Greenfields projects like the Wafi-Golpu copper gold project in Papua New Guinea and the large low grade Namosi copper/gold project in Fiji (as shown in Figure 1).

The mining industry overall is also facing changes. In spite of a substantial investment in exploration, major resource finds are few and far between. Ore grades are dropping and new finds are at considerable depth, resulting in a steep increase in unit cost. The increasing need for new regional infrastructure to support mine

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facilities, lower labor productivities, larger financial off-takes by development partners and elevated environmental management of deleterious elements are some of the heightened challenges that companies are addressing. The fact that the industry is a 'price taker' also makes it imperative that robust capabilities are in place to weather long term market variations. The industry has been slow in reacting to these challenges, with a linear rate innovation compared to exponential innovation elsewhere. It also suffers from the many common issues shown in Figure 2. These need to be addressed by approaches uncommon to the industry, otherwise we cannot move forward.

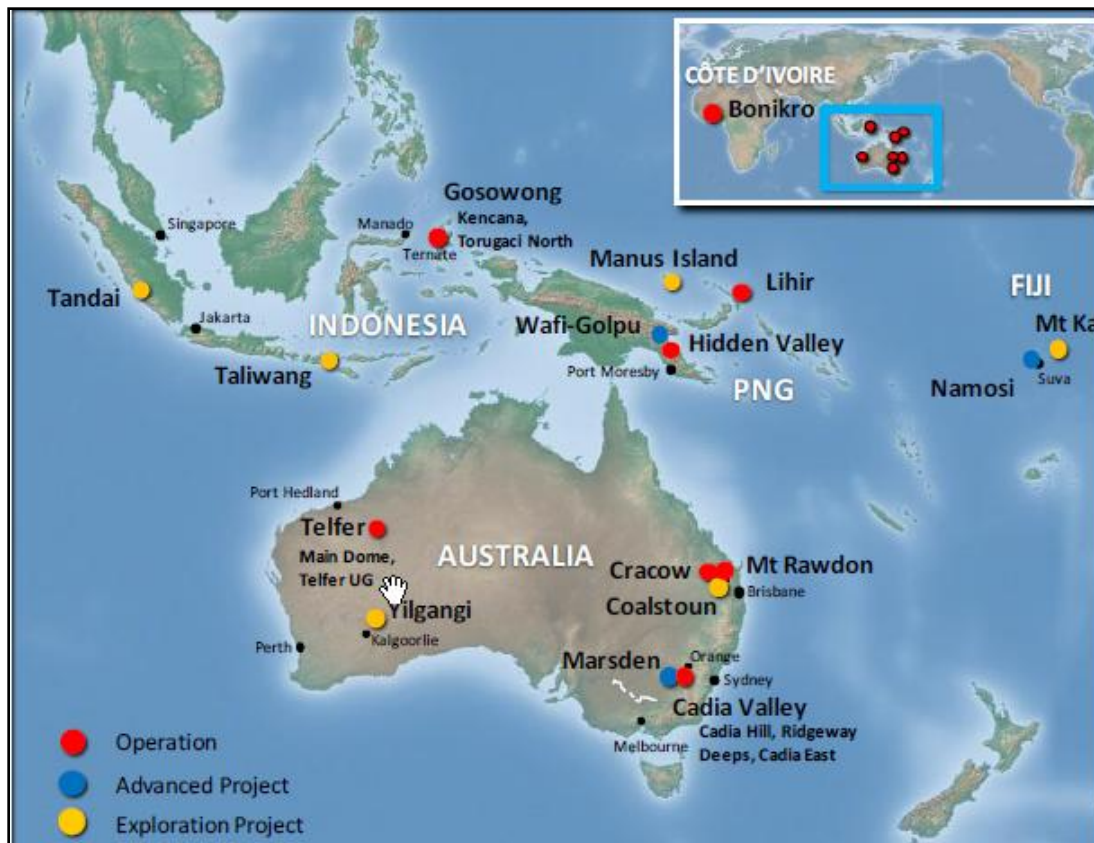


Figure 1. Newcrest Locations 2012

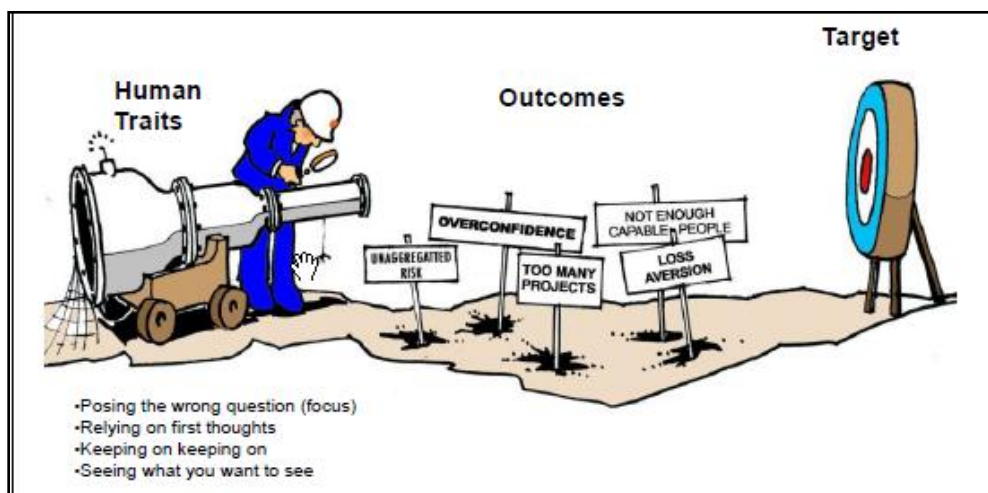


Figure 2. Common Issues in Innovative Projects

STEP CHANGE METHODOLOGY

Newcrest looks for step changes with the greatest margin, by considering new 'offline' paradigms. Often these are 'wicked' problems of the existing business, not conventionally solved. They need to have delivery within the company's five year plan, with a clear way forward. Deliverables must be clear and succinct enough for an "elevator speech" with two to three clear value propositions. It focuses on immediate benefit, 'no disruption' applications with a keenness to implement existing technologies through the use scientists, practical implementers, collaborations and relevant testing facilities. Newcrest has an obsession with simplicity, as reduced complexity increases speed of delivery, reduces workload and enables clear, open lines of communication. It seeks to work with other collaborators for mutual benefit. All these strategies then need to be taken deliberately from ideation, design and planning into adoption.

Newcrest follows a step change thinking process similar to De Bono's TO-LO-PO-SO-GO thinking framework. Designers in the mining industry, like other industries, have the habit to 'short cut' from the defined intent direct to action, by overly 'standing on the shoulders' of their previous experience (pattern recognition). Embedded in this experience are many paradigms that may or may not be relevant to the specific situation. By following the systematic design steps of 1) Declaring a new bold intent, 2) Looking at the broad perspectives, 3) Creating new possibilities, 4) Developing these into options then choosing, 5) Fast, disciplined execution, uncommon value can be created. This requires creative discontent to look from different perspectives and having the courage to do new things to redefine who you are (as shown in figure 3). Newcrest then chunks these bold innovation visions into digestible steps.

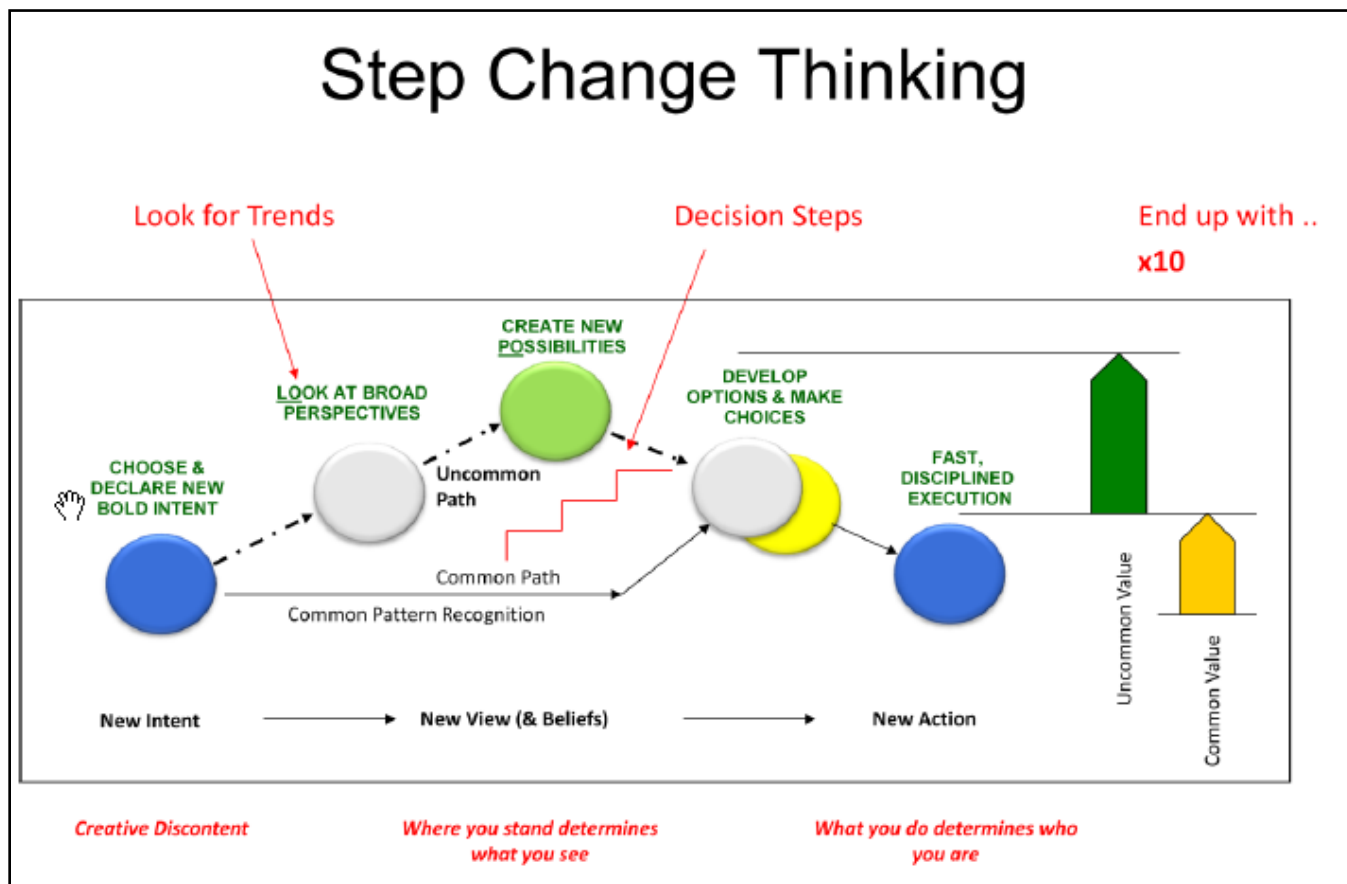


Figure 3. Newcrest Step Change Thinking

Starting with the end in mind, Newcrest has an adopt-adapt –develop philosophy. Innovation pipeline for new projects in other industries are actively managed as portfolios as projects progress, are stopped, or new advanced ones are added by standing on the shoulders of others work (figure 4). Mining exploration and projects

are also developed in a similar way, with clear 'toll-gating' through defined stages. From the author's experience though, mining innovation projects are often judged too early, before they are matured. They often need investment in experimenting/prototyping and an understanding a degree of attrition is expected. The adopt-adapt-develop approach reduces the number of innovation projects by focusing at the higher odds, delivery end.

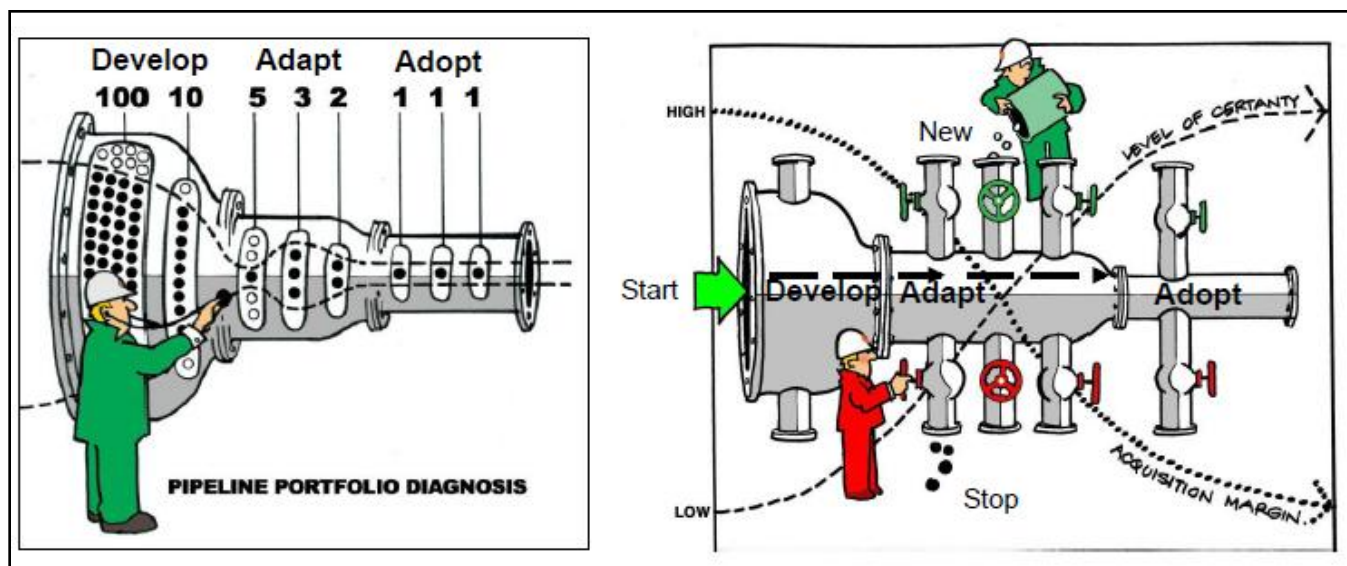


Figure 4. Innovation Pipelines Attrition and Trade In-Outs

Most of Newcrest's adopt-adapt-develop change design also involves human consideration rather than just technical factors. Simple processes to assist this, involve:

- **ASK:** Enlist people's participation to elicit information relevant to your project. Approaches include extreme user interviews and un-focus step change groups.
- **LOOK:** Observe people and situations to discover what they do rather than what they say they do. Approaches include a 'day in the life' behavior mapping, guided tours or shadowing.
- **LEARN:** Analyze the information you've collected to identify patterns and insights. Approaches include activity, decision task or error analysis: Lean Six Sigma tools help here too.
- **TRY:** Create simulations to help understand with people or situations to evaluate proposed designs. Approaches include body storming, role-playing, quick and dirty prototyping, predicting headlines, or scale modeling.

Applied Newcrest examples of these approaches are shown in figure 5.



Figure 5. Human Factors Design Examples

The world does not accord with our intuition either. Those who are successful at creating social change epidemics do not just do what they think is right; they deliberately test their intuitions. What must underlie successful step changes in the end, is a bedrock belief that lasting change is possible, and that people can radically transform

their paradigms in the face of the right kind of impetus. Tipping points are an affirmation of the potential for change and the power of intelligent action. With the slightest push, just in the right place, changes can be tipped.

For Newcrest, practical second adopters are the engine room of this change tipping. They are connected to the 'weirdo' innovators and 'gismo freak' first adopters on one side and majority who watch them on the other. Newcrest specifically targets this group to problem solve adaption practicalities and infect the majority's adoption. A part of this, rapid bench and field prototyping are adapted then adopted into full use. A bolder, venture capital type approach is considered with \$5-10M scale prototypes. Adoption is first supplementary and non disruptive to core production. This then flows into delivery into our 5 year business plan.

FUTURE MINE STEP CHANGES

Newcrest's Future Mine vision requires a set of specific strategies to significantly reduce operating costs across the asset portfolio and increase reliability of production, both of which are key to shareholder value. The key activity areas and bold targets include:

- Continuous underground and pit mining with business applications at Golpu, Cadia East, Lihir, and Telfer; with a bold vision of 10x labor productivity; and next steps to non disruptively adapt and test underground and pit systems at Cadia.
- Bulk pits with business applications as Lihir, Telfer and Namosi; with a bold vision to halve pit mining costs; and next steps to adopt bulk copper pit practices in five year plans.
- Low energy processing with business applications at Lihir, Cadia and Telfer; with bold vision to halve energy use to liberate gold; and next steps to adapt and adopt mine to mill waste rejection.
- Future geo-metallurgy ore testing capabilities across all our mines; with a bold vision of systematic future ores and systems testing; and next steps to set up systematic testing for ores, mining and geology.
- Modern decision workflows with business applications at Brisbane, Telfer and Lihir; with a bold vision of >30% productivity improvement from more efficient operational problems solving and decision making; and next steps to set up operating centres, data fusion, 'one views', and new workflow designs.

Newcrest has established open relationships with key players like Australian CRCs (Mining, Ore, and Hydromet), CSIRO, Joy Mining, JX Nippon, Selfrag AG and Codelco, to define technologies, field test and apply high leverage capabilities earlier than a sequential Research and Development approach. Opportunities are often advanced by leap frogging established concepts that have been stalled in execution or commercial traps by others. This has often meant we have made the 'old new again'.

Mining

Newcrest has a range of mining innovation and step changes. An example is bulk cave mining. Newcrest's caving strategy has been developed through growing a base knowledge and capability. In the past, Sublevel Caving at Ridgeway and Telfer mines have shown strong results. In moving forward, Newcrest aims to expand on this developed knowledge by increasing Block and Panel Caving expertise. As industry co-leaders in these techniques, Newcrest can leverage this capability with potential opportunities in JVs and other partnerships. Newcrest is now adopting Panel Caving at Cadia East and is moving in steps towards applying a continuous mining system for the Wafi-Golpu Project (as shown in figure 6).

The industry trend towards underground is also set to continue, particularly for copper-gold deposits, as giant open-pits become deeper and underground mines becoming larger, reducing open-pits cost advantage. Rio Tinto has stated that its current 80/20 open pit - underground split will be moving towards 20/80 over the coming decades, thus putting Newcrest in a vantage position in terms of underground capabilities.

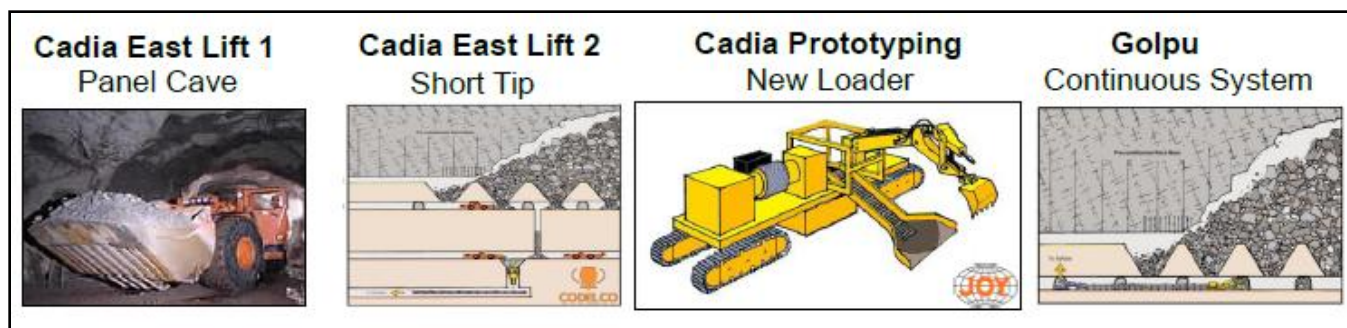


Figure 6. Newcrest's Current and Future Progression of Caving Techniques

Processing

Newcrest has a range of processing innovation and step changes also. Examples include waste rejection, broader product channels, lower energy comminution and geo-metallurgy approaches.

The current processing paradigm takes a feed from the mine as blasted rock. Rock types determined through geological modeling are then considered to be either ore or waste, at the smallest mineable unit or block. Within this unit is the potential for significant variance, or "nugget-effect" on a much smaller scale. This means that within any bucket, truck or conveyor segment, there may only be 10% of the volume, which is true 'ore', and the rest may be barren waste. However, this all goes to the mill.

Waste Rejection

Newcrest is targeting a bold intent to reject greater than 20% of waste from ore stream to be processed, materially reducing power & water use (>20%), increasing gold & copper recoveries (1-2%), adopting waste disposal at mine source, increasing tailing dam life, and increasing (>10%) metal production capability.

Newcrest is adopting mine to mill waste rejection at Telfer, Lihir and other sites. These mines carry a substantial amount of lower grade of ore. The ore grade at the Cadia mine is also low by current standards and is expected to fall considerably in future. In order to maintain the cost structure and business viability, it is necessary to introduce a low cost intermediate stage of concentration, by rejecting a significant amount of barren gangue material.(as shown in figure 7).

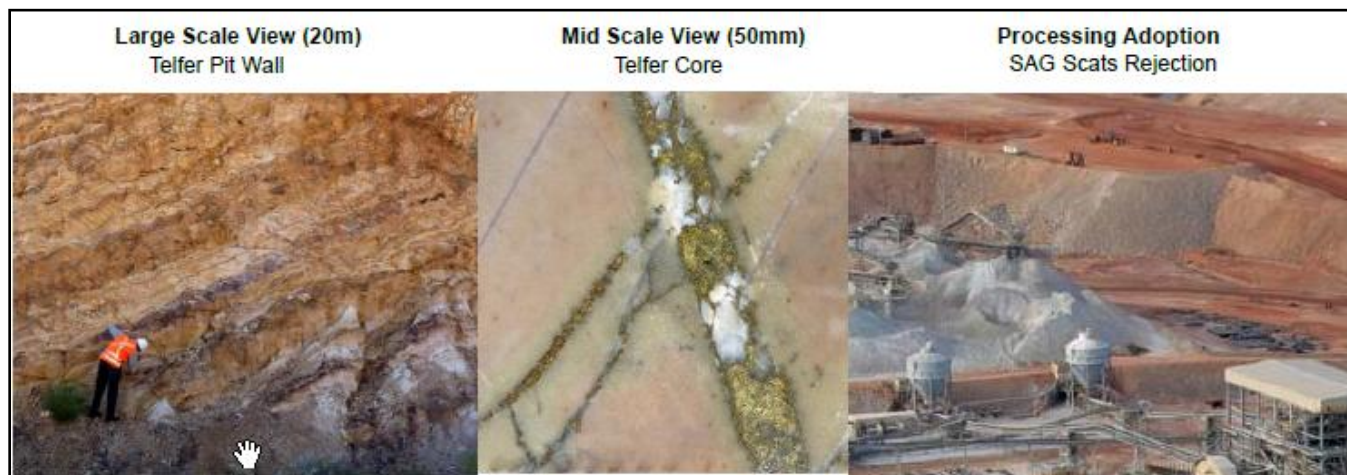


Figure 7. Telfer - Using Scale Knowledge to Adopt Waste Rejection

Ore is generally considered and defined by geologists at a 20m x 20m scale. Sometimes this goes down to 5m x 5m, with a statistical confidence fall. Metallurgists then consider liberation below 300 microns. This leaves a big gap in the middle. Newcrest is finding that gold-copper ores often exists as 'mortar' within a 'bricks and mortar'

rock fabric. We now systematically investigating how the brick fabric scale and differential brick-mortar properties varies for each ore type.



Figure 8. Telfer ROM and COS Belt Sampling

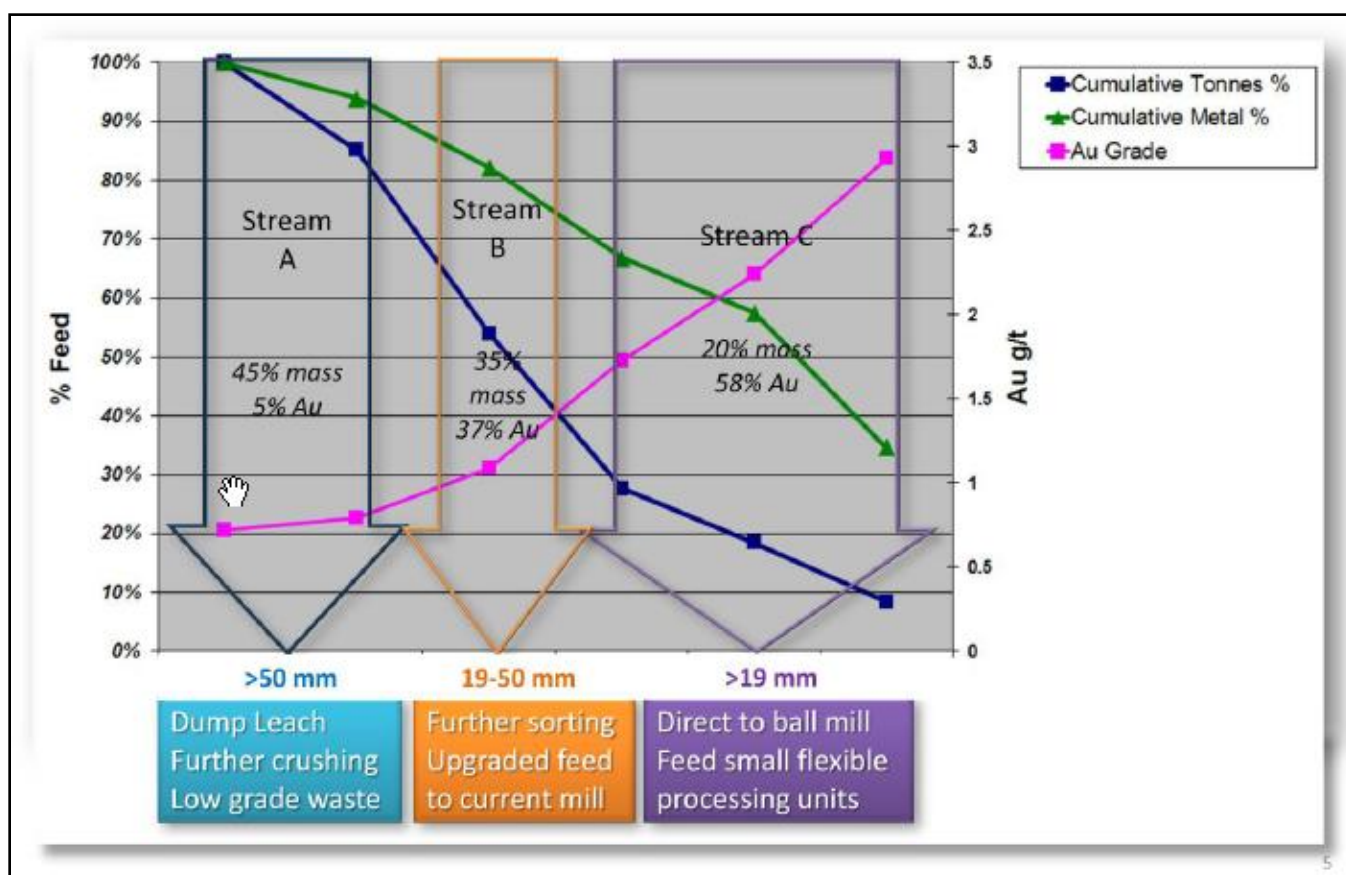


Figure 9. Example Gold Yield from ROM Size Testing Sample

Large scale screening tests conducted at Telfer on selected underground and open pit stockpiled ore, indicated a strong potential for an efficient upgrade. Two major test programs have been conducted recently. 17 run of mine (ROM) bulk samples were split into size groups then grade estimated. Over 130 belt cuts were also taken between the primary crusher and crushed ore stockpile (COS). The second method was found easier to conduct (as shown in figures 8 and 9). The test work indicated a discernable response of more gold and copper minerals reporting to the fines (<19mm), than the middle (19-50mm) and coarse (<50mm). Findings also indicate an improved performance after primary crushing for many ore types with >90% of the metal in the less than 50mm mass (shown in red in figure 10).

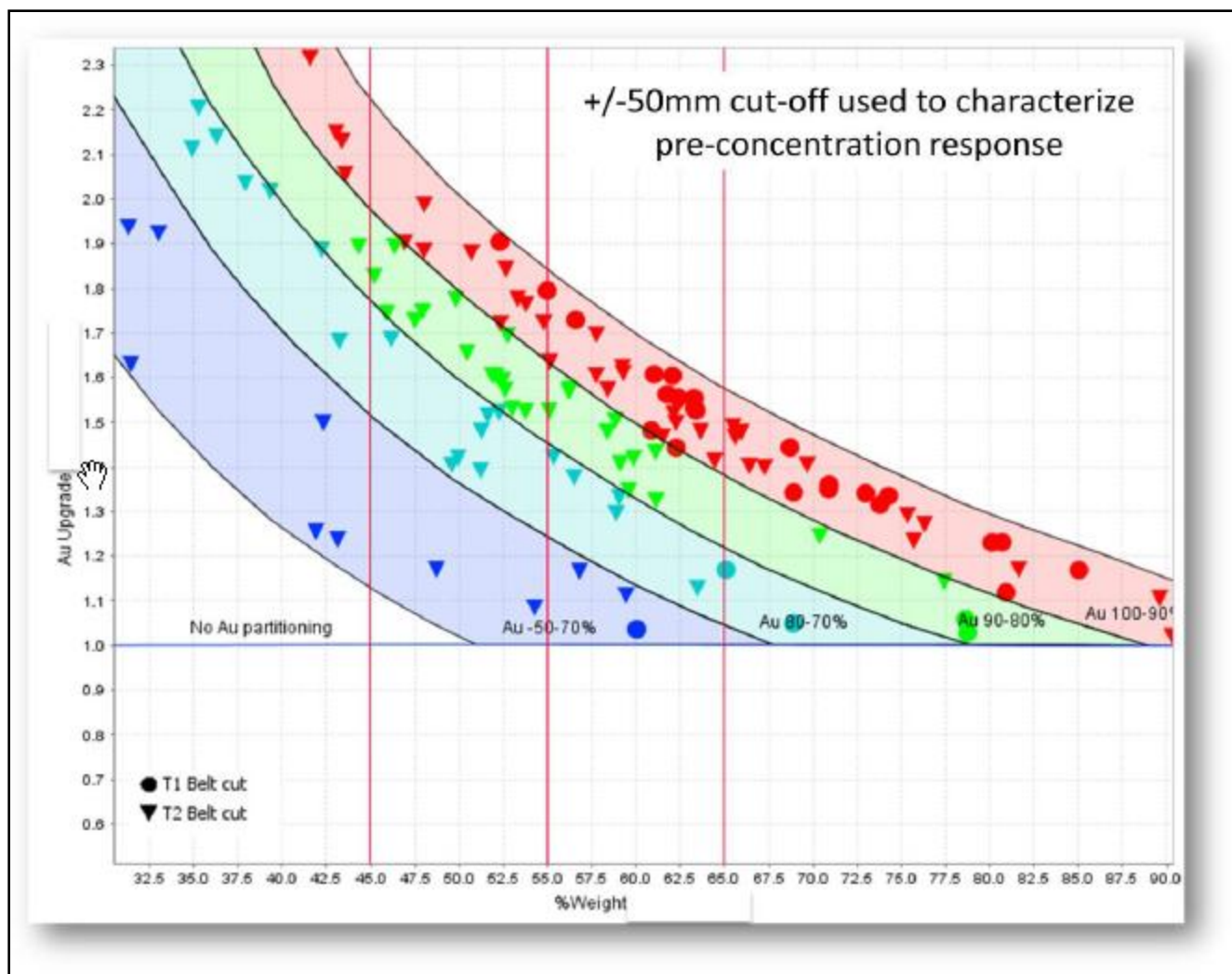


Figure 10. COS Belt Gold Upgrade Range After 50mm Top Cut (>130 Samples)

New flexible processing strategies are being adapted and developed to use these coarse size-metal deportment responses. Telfer has been using SAG mill scats rejection since 2009, where 5-15% of the feed mass is rejected at less than 20% the feed grade. Energy savings have been made, by discarding the tougher rock. Other field prototypes like scalping after the primary crusher or inline pressure jigging before the ball mill, are being explored.

Broader Gold Product Channels

Newcrest is also developing techniques to broader gold product channels at Cadia, Lihir and other sites.

In excess of 80% of the total gold output from the company's Telfer and Cadia operations is as copper concentrate. The concentrate produced is then marketed as copper smelter feed. Though gold accounts for in excess of 70% of the net value of the concentrate, the marketability of the product is set by the grade of copper. As the ore grade decreases, the associated economic grade of the copper concentrate produced tends to fall. A gold may also occur in association with arsenic, the concentrate may report amounts of arsenic. Lower grade copper concentrates with arsenic are not favored as a smelter feed though, even though the value of gold in this product could be two or three times the net value of copper.

In order to examine alternative process options, a review was conducted. The Nikko Chloride leach process developed by JX Nippon Mining and Metals Corporation (Nippon) was found to be a unique technology suitable for the efficient extraction of copper and gold in sequence, under ambient pressure. In order to maintain the long time viability of realizing value from low grade resources, Newcrest is now working with Nippon. Together we are

adapting and developing the Nikko process for low grade copper concentrates, that is leap frogging Nippon's application for recovery of precious metals from their smelter anode slimes. Nippon has installed a pilot circuit in Perth for the testing of low grade copper, gold silver concentrate (figure 11).

Table 1. Revolutionary changes within the mining sector since 1900 (After Bartos, 2007)

Commodity/Procedure	Innovation
Copper	Flotation
	SX-EW SAG mill circuits
Grade Control	Kriging
	Computer modeling
Gold	Heap leaching
	Autoclaving
Scheduling	Operations research
	GPS truck location
Mining	Open pit mining
	Ammonium nitrate explosives
	Electric and carbide mine lamps
	Rock bolts

The plant has successfully treated concentrate from Telfer. Successful bench scale testing of low grade copper/gold concentrate from the Newcrest's Cadia operations has also been completed. Indicative results are listed in table 2. A systematic investigation and piloting program for a range of potential materials has commenced, including Cadia, Lihir, Telfer and Wafi-Golpu ores.

Table 2. Cadia High Gold Low Copper Concentrate Leach At JX Nippon Laboratory in Japan

	Retention Time (Hrs)	Ratio of Residue to Feed (%)	Au (g/t)	Cu (%)	Au Extraction (%)	Cu Extraction (%)
Start	0		58.1	3.47		
After Cu Leaching	14	94	36.4	0.15	41.2	95.9
After Au Leaching	19	88	3.9	0.08	94.1	98.0
	24	85	3.6	0.07	94.7	98.3
	29	84	4.7	0.06	93.2	98.5
	34	82	4.4	0.06	93.8	98.6
	39	80	3.3	0.05	9.5	98.9

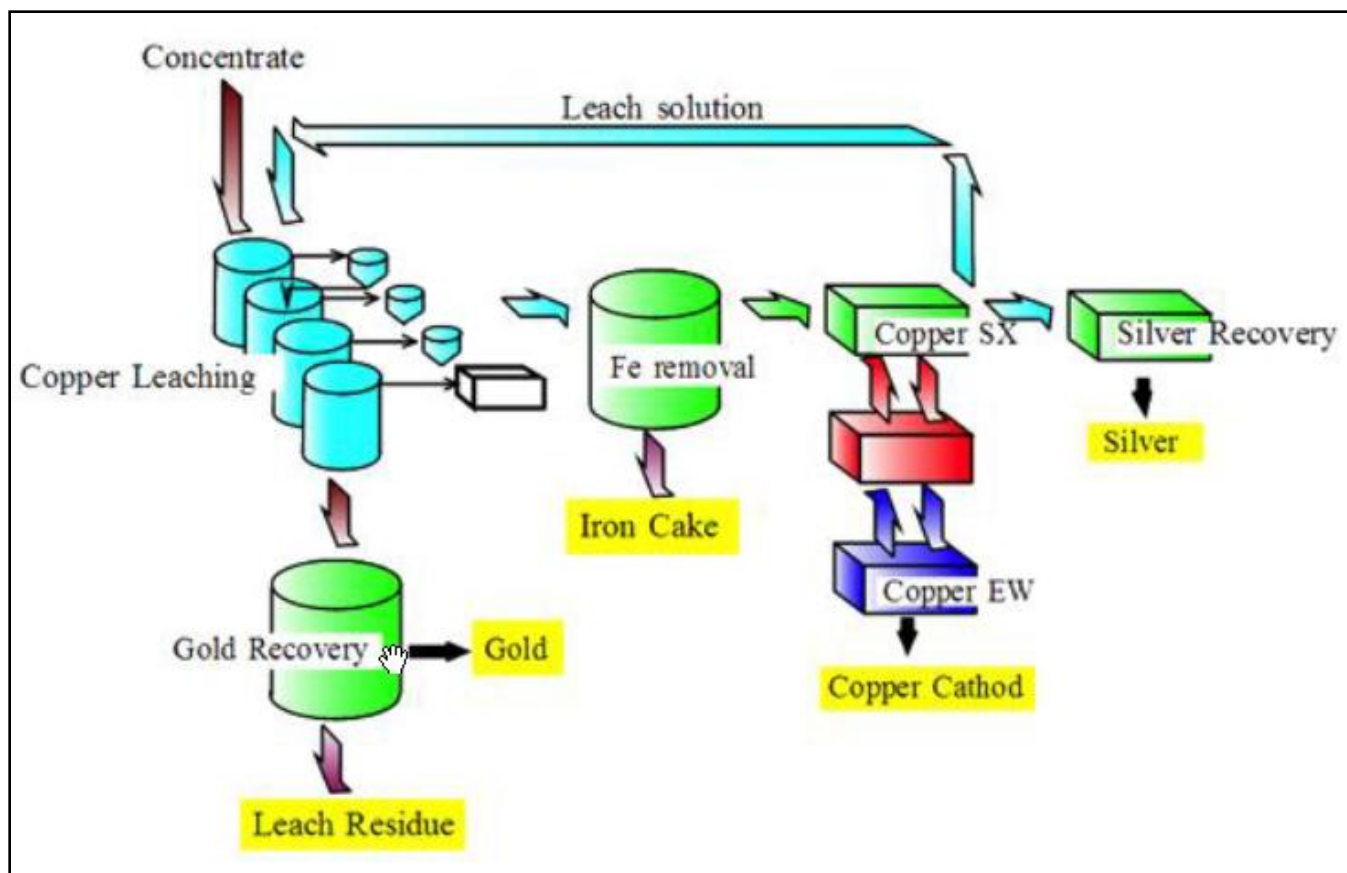


Figure 11. JX Nippon Chloride leach Pilot Circuit in Perth Australia

Energy Efficient Processing

Newcrest is also developing a range of techniques to reduce overall processing energy intensity. An example includes electro pretreatment of ore.

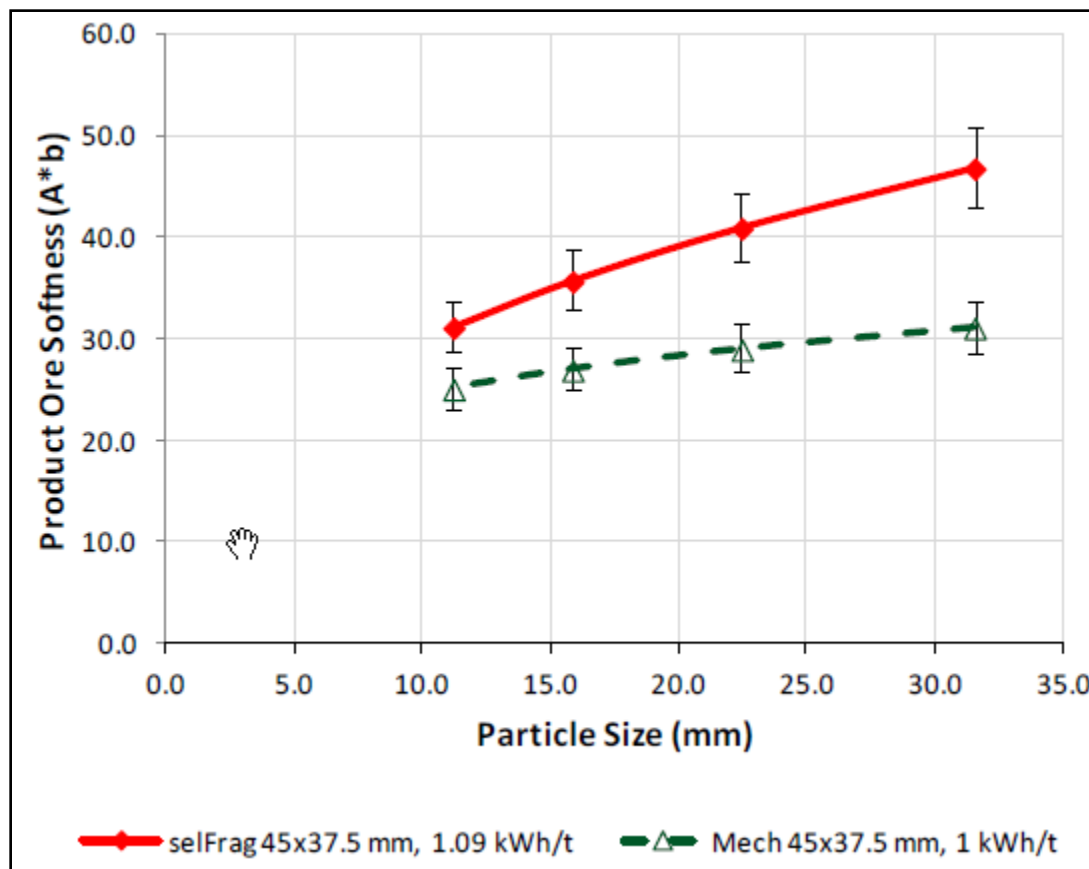
There is a consensus among forecasters that energy prices must increase in the long term. Newcrest's current energy sources include natural gas, coal, and diesel, of which Telfer and Cadia consume over 75% in total. Cadia receives the majority of power from black coal via the State grid and consequently has greater intensity than Telfer's supply, which utilizes natural gas open cycle gas turbines and diesel generators.

Particle size reduction is the biggest consumer of energy at a mine site. The Swiss company SelFrag AG developed the technology of electro-dynamic fragmentation of rocks. It uses short term electrical discharges, introduced in to a material surrounded by a media with high breakdown field strength, to selectively liberate components along interfaces. The technology's potential mining application leap frogs its use to produce high purity products for specialist requirements. Newcrest is currently in collaboration with SelFrag AG and University of Queensland to systematically investigate a system for the pre-weakening of rocks prior to SAG milling. The aim is to achieve a step improvement in power efficiency.

A series of electro treatment bench tests were conducted at the University of Queensland JKMRC electro fragmentation facility in Brisbane. The encouraging results are summarized in figure 12 and table 3. Figure 12 indicates Ridgeway ore competency as measured by A^*B value (higher means less energy consumed in grinding) after subjecting 45 X 37.5mm feed particles to SelFrag and mechanical breakage at an equivalent 1kWh/t respectively. The coarse progeny (37 x 26.5mm) shows 52% change in A^*B , and the fine progeny (13.2 x 9.2mm) 24%. Table 3 is also a comparison of the product A^*B of Cadia East ore, 12.5 x 26.5mm particles electro-preconditioned using the above laboratory unit using a specific energy of 2 kWh/T. The treated product is about 36% weaker as indicated by A^*b values, than the untreated particles.

Table 3. Summary of the testing of Cadia East ore in the JKMRC laboratory scale SelfFrag unit

Size (mm)	9.5-11.2	5.6-8.0
Feed A*bValue	25.1	19.3
Product A*b Value	33.8	26.5
% Change	34.9	37.3

**Figure 12.** Ridgeway Ore Bench Scale Pre-Weakening Using A Selfrag Electro Unit

There are also potential liberation benefits by pre-weakening on interface boundaries rather than across from convention crushing and grinding. The hypothesis is that the pre-weakening process may not create as many mineral-waste composites that are more difficult to recover. Further testing is required to pursue this opportunity.

Geo-Metallurgy

Newcrest is adopting, adapting and developing geo-metallurgy capabilities to improve processing performance. In many ways this is about making the old new again as well as adopting new approaches.

Gold is generally sparse in the large low grade deposits and in the rock samples taken. In order to develop a process flow sheet for efficient extraction of gold, it is necessary to have a reliable quantitative estimate of gold deportation. In case of free milling gold, this requires the assessment of the amount of free and exposed gold, sulphide associated gold and gold in silicates. In case of refractory gold, this becomes complex. Detailed quantitative deportation will require the identification of sparse minerals and the gold associations. In general the 'key' minerals normally associated with quantifiable gold are pyrite, arsenopyrite, iron oxide and silicates.

Geo-metallurgy overall, seeks to quantify variability of an ore deposit in terms of process parameters such as ore hardness, flotation, leach response, environmental impact and impurities. The data is then applied back to the block model or mine plan. Once included, the model is able to generate economic parameters such as throughput rate, grind size, grade and recovery for use in further economic and mine plan modeling. Applying geo-metallurgy to Newcrest operations to augment traditional metallurgical techniques leads to more accurate data for development and operation of mines. The information can be used to: inform flow sheet design; better size equipment; assist in plant design; optimize plant performance; forecast production; and reduce risk during feasibility, production and operation. By understanding the linkages between geology, mineralogy and metallurgical performance, greater efficiency can be achieved. Newcrest is seeking to continue relationships with other industry partners to further research in this area.

The mechanics of determining the gold associations in these minerals are complex and often outside the operating range of conventional electron probe units. Gold determination in some low grade samples will require analytical techniques using proton probes, Secondary Ion Mass spectrometry or the laser ablation techniques. Newcrest is a developing partner in AMIRA International's study into new Laser Ablation Inductively Coupled Plasma Mass Spectrometry to rocks and ores. It offers extremely high sensitivity to a wide range of elements and consequently has applications to mineral sample analysis.

Mineralogy Based Process Control (MBPC) is also a critical capability due to the increased processing of refractory ores. MBPC is needed to support these new low-grade projects through maximizing the recovery rates. The main objectives is to predict the response of a gold ore and other minerals to the various candidate processes and periodic mineralogical analyses of ore feed and mill products to determine the nature of the problem if gold recovery is lower than expected. The extraction of gold is driven by mineralogical factors such as gold particle size, association with other minerals, coatings, presence of cyanides, oxygen consumers and preg-robbbers, presence of refractory gold minerals and locking of sub microscopic gold in minerals structures.

CONCLUSIONS

Newcrest has a strong history of growth over the past 20 years, yielding value from previously marginal ore bodies. Newcrest is focused on an overall strategy of gold, low cost, long life and moderate growth. Capability step changes play a large delivery role. They transition from a business offline to online adoption approach as opportunities mature. Newcrest believes in a) An open innovation approach to actively work with others, b) The leap frogging leverage of making the 'old new again', and c) An adopt-adapt-develop methodology enabled by rapid prototyping.

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