2012 SEG Distinguished Lecture

Title: Crucial Challenges to Discovery and Mining – *Tomorrow's Deeper Ore Bodies*

Author: Dan Wood, W H Bryan Mining & Geology Research Centre, The University of Queensland, Australia

Introduction

It is stating the obvious to observe that there is no shortage of metal in the Earth's crust, only of known ore. Unfortunately, ore is becoming increasingly more difficult to define with any certainty. For many metals, what is now considered ore is trending to lower grade and it is becoming more deeply situated. Moreover, as the declining discovery rate over recent decades has shown, it is becoming more difficult to discover an ore body now than it was 30 – 50 years ago.

Compounding the problem for mining companies and their explorers, this is all happening at a time when the demands for many mineral commodities are at all-time highs, and increasing. Without doubt, the world's exploration teams will require a significantly improved future discovery performance if the present inventories of mineral-commodity ore reserves are not to be seriously depleted as the demand for mineral resources escalates over the coming decades, as seems likely.

This enhanced discovery performance will need to be achieved at a time when most of the supposedly 'easy-to-make' discoveries have probably been made and most future discoveries are expected to be much less 'obvious', prior to discovery, than in the past. It is becoming increasingly difficult to discover an ore body, partly because it is becoming more difficult to define what constitutes ore; for a variety of reasons, particularly as deeper mineralisation is discovered. The present trend in defining ore is towards lower grade, but whether this is sustainable and future ore bodies will have a lower, average ore grade than is presently accepted is probably a debatable point.

To satisfy the reserve-replacement and future production challenges, the mineral exploration industry will need to sharpen its focus, to target and discover extremely large ore bodies that can be mined using very large-scale (mass), open pit and underground mining techniques (Wood et al., 2010). Increasingly in mature exploration terranes, and possibly elsewhere in less explored areas, these ore bodies will be located in '*deep-earth'*, where mass mining is presently being contemplated at depths below surface down to 1,500 – 2,000 m; but probably extending to 3,000 m over time as underground mass mining technology advances.

Discovery Implications

An immediate implication of exploring in *deep earth* is the heightened importance of the surface area and geometry of a discovered mineral deposit, if it is to become an ore body. As the mining depth of an open pit increases, and panel-caving progressively replaces block-cave mining in order to mine lower grade mineralisation underground, the surface area of the ore body becomes a prime consideration in determining whether the mineralisation can be mined economically and is ore. Both *Ultra-deep* open pits and *Super-cave* underground mines require an ore body with a large surface area, in order to obtain the efficiencies of an acceptable waste:ore ratio for an open pit, and the plan-area (footprint) required for panel cave mining in a Super-cave mine.

Discovery Challenges

Whereas there are innumerable challenges to discovering an ore body, most can be classified as being of one of three important types: ***Geology-related, Mining-related,*** and ***Corporate and self-inflicted****.* Of these, while the *geology-related* challenges are extremely important, the *mining-related* and *self-inflicted corporate* challenges are those that probably will most determine whether a discovery is made and whether the discovered mineralisation will become an ore body, or remain mineralisation of possibly only curiosity interest – one of those 'technical successes' that doesn't have any present economic value.

Geology-related Challenges

Geology-related challenges include the obvious ones of subtle, unrecognizable, or absent, near-surface evidence of the presence of an ore body, and the related issue of obscuring, or poorly known, four-dimensional geology. The latter is a crucial consideration since exploring at *deep earth* depths requires a far better understanding, at the start of exploration, of the effect of time on the regional and local geology, than may need to be the case with a near-surface deposit, where there is often recognizable surface evidence of the presence of mineralisation.

To the best of my knowledge, Sigfried Muessig from Getty Mining is credited with observing many years ago that, "***where best to look***" for ore was in the "***shadow of the headframe"*** and this was a discovery model used with great success by many exploration geologists and old-time prospectors before, then and since. The reason for this is quite simple and was stated as "***the closer to ore, the lower the risk***". It worked in the past and in my day, still does, and should continue to do so for many years into the future. Discovery requires careful management of risk and exploring close to known ore is a simple way of initially managing risk. The key in using this approach is to think differently from all of the explorers who previously sought to make a discovery in the shadow of the headframe but, for various reasons, did not.

A very simple example of using this approach, combined with informed conceptual thinking, is Newcrest Mining's discovery of the Cadia Hill, Ridgeway and Cadia Far East porphyry Au-Cu ore bodies in Australia (Wood, 2012). Collectively these and the other two porphyry deposits in the Cadia district contain an estimated mineral resource of >44 Moz Au and 7.5 Mt Cu. The three ore bodies also conveniently demonstrate the progression from discovering an ore body in outcrop (Cadia Hill), to *deep-earth* discoveries at Ridgeway and Cadia Far East.

At **Cadia Hill**, discovery involved no more than informed conceptual thinking, searching for evidence in the available public record of the possible presence of the target deposit, and doing the obvious. Doing the obvious was simply a matter of detailed geochemical sampling, in this instance of residual soil, to expand on two strongly anomalous, existing soil Au values. Previous explorers had been prevented from drilling over the main part of the Cadia Hill ore body by the presence of a degraded pine plantation, into which access had been denied. Fortunately, negotiating an option to purchase the pine plantation with a new owner cleared the way for detailed soil sampling and drilling, resulting in discovery. The ore body cropped out and there was considerable evidence of its possible presence available from public-record soil sampling and shallow drilling results.

The **Ridgeway** discovery was much more difficult to make and relied on informed geological intuition and a willingness to take risk, based on a good working understanding of a developing model of porphyry-style Au-Cu mineralisation in the Central Lachlan Volcanic Province of New South Wales. Exploration was focussed into the Ridgeway area by the use of wide-spaced dipole-dipole, Induced Polarisation electrical geophysics, which is interpreted, post-discovery, to have registered the induced polarisation chargeability effect of the disseminated pyrite in the weakly-developed hydrothermal alteration halo overlying the Ridgeway Au-Cu ore body. The top of the Ridgeway ore body is located 500 m below the present land surface where its overlying, weak hydrothermal-alteration envelope is obscured by post-mineral basalt cover, up to 80 m thick. This is a blind deposit where electrical geophysics was required to essentially detect the 'sulfur' anomaly, in the form of disseminated pyrite, overlying the tightly-confined porphyry, Au-Cu ore.

By comparison with the Ridgeway ore body, which is essentially located in the transitional zone between near-surface deposits and the very deep deposits that exploration geologists increasingly will be called upon to make in future years, the discovery of the **Cadia Far East** deposit, adjacent to the Cadia East deposit and Cadia Hill ore body, clearly falls into the category of a *deep-earth* discovery. The top of the Cadia Far East deposit is located 800 m below surface and is obscured by 100 – 200 m of post-mineral cover rocks. Testing of the overlying low-grade Au-Cu-mineralised hydrothermal alteration envelope, to a depth of up to 700 m below surface, had failed to discover the high-grade part of the deposit. Discovery eventually followed as a result of "**asking good questions**" and "**testing these**" (Tedder et al., 2001), with the technical key being the ability to think and reason simply about the local

Au:Cu ratio within the previously-intersected Au-Cu porphyry mineralisation. The combined Cadia East and Cadia Far East deposits are being developed for mining as the Cadia East Super-cave, using panel caving to reduce the initial capital investment.

Other ***Geology-related*** challenges include those related to the gradually increasing time that, for various reasons, is now taken in moving a deposit through from the discovery hole into mine development and production. Presently, it can take upwards of 10 years to progress a >5 M oz Au deposit to producing Au, and upwards of 20 years for a >5 M t Cu deposit. There are large Cu deposits, for example, where this time-frame has long been exceeded: the El Pachon deposit in Argentina is still in feasibility study stage after >48 years; as is the Frieda River deposit in Papua New Guinea after >42 years; the Galeno deposit in Peru after >20 years; the Tampakan deposit in the Philippines after >19 years; and the Resolution deposit in the USA after >16 years. The challenge with this delay for the exploration geologist is trying to gauge what will constitute ore in 10 – 20 years' time.

A rarely considered ***geology-related*** challenge, but one that is a potentially significant issue, which is already causing concern for two possible deep mine developments, is that of thermal gradient. Rock temperatures of more than 80 degrees centigrade are reported to have been recorded at the Resolution porphyry Cu deposit, in Arizona, and at the Far South East porphyry Cu-Au deposit, in Northern Luzon in the Phillipines. Engineering research and solutions are required if high rock temperature is not to become a severely constraining physical issue with deep mine development, and it is not just physical discomfort to miners that is the issue. The effects of rock temperature within the 50 – 100 degree centigrade range on rock mechanical properties have to be understood and factored into engineering design; both for Super-cave and Ultra-deep open pit mines.

An additional and extremely important ***geology-related*** challenge is the inadequacy of present ore body models for the task of discovering ore bodies in *deep-earth*, where science-based risk-taking becomes a crucial part of the discovery process. Robust ore-body-halo models are required that describe the detectable effects of a large mineralising hydrothermal system, 1 – 3 km out from an ore body. Work on this aspect has started with several ore body types, but research clearly needs to be accelerated, as this information is urgently required in order to improve the effectiveness of deeply-targeted discovery drilling. An important guiding tool that could provide a district focus would be a deeply-penetrating electrical geophysical technique that is capable of detecting disseminated sulphide minerals at a depth of 500 – 1,000 m, or more; such as a much-deeper-sensing Induced Polarisation technique that, in effect, could regionally map in three dimensions the "sulfur anomaly" associated with a very large, hydrothermal alteration-mineralisation system.

Mining-related Challenges

Mining-related challenges with discovering ore bodies that will be mass mined include the present mass mining trend to much larger scale and depth to which an ore body will be mined (Chitombo, 2011). The mining industry is now developing ***Ultra-deep*** open pits that will be mined to a depth of 1,500 m, at least, and large-scale underground mines, ***Super-caves***, that will have the extraction level developed at a depth of up to 2,000 m, and probably deepening to 3,000 m over time as underground, mass mining technology develops with ongoing research.

Impacting on these mass mining trends, however, are some significant issues that the mining industry will have to meaningfully address if this vision of an Ultra-deep open pit and a Super-cave underground mine is to be realised. An obvious material movement/handling issue for a scaled-up, Ultra-deep open pit is the fact that there have been only incremental increases in equipment size over the past 30 – 40 years. Trucks are still restricted to carrying 300 – 340 tonnes of material, shovels haven't increased in size much beyond 50 – 55 cubic meters capacity. On the mineral processing front, the largest SAG mill is only a little over 40 ft in diameter.

The largest Cu mine in the World, in terms of annual Cu production, presently mines and transports about 440 million tonnes of combined ore and waste a year from two open pits, to produce about 1 million tonnes of Cu. It is possible to envisage a hypothetical open pit developed on the presently known ore bodies at this mine that will have a single final open pit measuring roughly 11.0 km in length, 5.5 km in width and 1.5 km deep. If developed, this open pit has the potential to mine and process between 800,000 and 1 million tonnes of ore and mine more than 3 million tonnes of waste a day.

As with many an open-pit mining operation this will be a waste-mine that produces ore. The increase in scale is challenging using presently available equipment; the amount of ore mined and processed will increase by up to three times, the amount of waste removed by more than four times, with the total material moved increasing to up to 1.8 billion tonnes per year. For many mining companies, mining an ore body containing an ore plus waste total of 1.8 billion tonnes is a significant mine, let alone contemplating moving this amount of material per year. The thought of mining this amount of material annually is a completely foreign concept, but will increasingly need to become the norm for the giant mines that will be needed to satisfy the world's increasing demand for Cu, for example.

With mass underground mining, caving technology has advanced significantly since the first block cave mine (Pewabic) was developed in 1898 to mine Fe ore in the USA. For many years cave mining was restricted to weak rock being mined from shallow depth. Mining rock-mechanics theory and technology eventually developed to the point where strong rock located at a moderate depth could be mined successfully, which is the position today with contemporary block cave mining. Cave mining is about to move into a new dimension with the arrival of the Super-cave mine (Chitombo, 2011). These mines are being developed in response to falling average metal grade in newly-discovered large Cu deposits and in existing Cu mines where the mineralisation is too deeply located to be mined by open pit, or by contemporary block caving because of the low grade of the mineralisation. To overcome the economic limitation of the block-caving mining technique employed in many contemporary cave mines, Super-cave mines will use the panel-cave style of mining to reduce the economic cost of mine development.

Panel caving will be employed as a means of reducing the upfront capital cost required to develop a large-scale underground mine. Capital cost is the one, obvious remaining area in cave mining where a significant cost reduction is possibly achievable. Up until now the focus in developing mass underground mining technology has been to reduce operating cost, where reductions of up to 50% in operating cost are separately achieved in moving from long-hole open-stope mining to sub-level cave mining to block cave mining. With panel cave mining, a lower initial capital cost is achievable because of the opportunity provided by the mining technique to delay complete development of the production level in the mine. Rather than installing all of the extraction-level draw-points before caving can be initiated, panel caving permits the ore extraction points to be developed only as required as the panel being caved progressively mines through the ore body.

Attending this new development in cave mining is a substantial increase in scale. Whereas a contemporary block cave mine will have a surface area (footprint) with dimensions of about 200 m by 200 m, a Super-cave mine will have a footprint of up to 2,000 m by 2,000 m, an increase of up to two orders of magnitude (Chitombo, 2011). The mining block height will more than double to up to 1000 m, increasing from less than 500 m in a single lift, or typically much less than this as occurs at the El Tenniente porphyry Cu mine in Chile where the block height is on the order of 250 m.

The undercut level in a contemporary block cave mine, from which caving is initiated, is typically located at a depth of less than 1,000 m below surface. In a Super-cave mine, the undercut level is expected to be 1,500 – 2,000 m deep, probably extending to 3,000 m deep over time as cave mining theory and technology advance. Daily production from a contemporary block cave mine is presently in the range of 10,000 – 40,000 tonnes. In a panel cave mine, which is expected to be mining several panels simultaneously, daily production from a single panel is expected to be in the 70,000 – 100,000 tonnes range.

Newcrest Mining's Cadia East ore body, which includes the Cadia Far East mineralisation, is the most advanced of the presently planned Super-cave mine developments. Other mines considered possible contenders to be developed, or extended, as a Super-cave mine include the Oyu Tolgoi deposit in Mongolia, the Grasberg mine in Indonesia, and the El Tenniente mine in Chile, amongst others.

Other ***Mining-related*** challenges include issues such as mine development capital intensity; ore grade and the increasing need in Cu mines, for example, of a by-product credit to increase the 'value' of the mined and processed ore; and the universal use of Net Present Value (NPV) in determining the mine size for an ore body that, realistically, will have a mine life extending for many decades. Of these, mine development capital intensity is probably the most pressing immediate issue facing the mining industry. Capital intensity is a simple measure of the amount of capital employed in developing a mine, measured in terms of money spent for some measure of metal production.

In the case of the Cu industry, where capital intensity has increased dramatically over the 2001 – 2010 period, and is still increasing, capital intensity is normally measured in terms of US$ of capital invested in mine development to produce an annual tonne of Cu. For a long time, capital intensity associated with developing a large open pit mine on a porphyry Cu deposit was less than US$3,000 per tonne of Cu produced each year. According to information provided by the Metals Economics Group (MEG) of Canada, the period 2001 – 2010 saw a three-fold increase in capital intensity for new Cu mines developed during this period, which has continued to rise since then.

Curiously, the MEG data on capital intensity indicate that the rise in Cu capital intensity in this period paralleled the rise in Cu price, with capital intensity rising from a little over US$2,000 per tonne of Cu metal produced for a new mine development in 2004 to about US$8,000 per tonne in 2010; while the Cu price rose from a little under US$2,000 per tonne in 2003 to almost US$8,000 per tonne in 2010 – an unexplained coincidence. This occurred at a time when the average Cu head grade fell from about 1.1 % to about 0.9 %. Disappointingly, the more than doubling of Cu production capacity that accompanied these mine developments failed to arrest the rapidly escalating capital intensity, and the economies of scale that would be expected to have attended this increase in production capacity are not obvious in the capital intensity value but, presumably, lessened the size of the increase.

The issue with increasing capital intensity for exploration and mine geologists is the impact it has on the cut-off grade for ore, now and in the future. A large capital intensity value, in the absence of a compensating increase in metal price, has the effect of extending the pay-back period required to recover the capital invested in developing a mine. Typically, a pay-back period of five years, or less, is expected with mine development, given the various risks to which the capital is exposed. With the level of capital intensity being considered as part of the feasibility study-stage evaluation of many undeveloped porphyry Cu deposits now exceeding US$10,000 per annual tonne of Cu produced, to approve development of these deposits into mines, mining company boards will need to be anticipating at least a doubling, if not a trebling, of the future Cu price in order to have an economically-viable project and justify developing a mine; or the financiers of new large-scale Cu mines will need to be prepared to invest with the understanding that the payback period will almost certainly extend beyond ten years.

As part of this dilemma for the mining industry, of expanding demand coupled with increasing development cost, it is useful to briefly consider the Cu mining industry. This is mainly developed on porphyry-style mineralisation, in the sense that porphyry-style deposits are by far the single largest producers of Cu. World Cu demand has been increasing at a consistently annually-compounding rate of 3 – 4 % over the past 110 ten years. In 1900, world Cu demand was 0.5 Mt; by 1930 demand had increased to 1.9 Mt; by 1960 it had reached 3.2 Mt; in 1990 it was 8.1 Mt; and in 2009 it had reached the somewhat alarming figure of 16.0 Mt. If the trend of the past 110 years continues, world Cu demand in 18 years time, in 2030, is likely to be at least 30 Mt; but could be larger.

Where is all of the Cu going to come from? Unfortunately, at a time when demand is doubling every 18 – 24 years, about 60 % is presently coming from relatively small mines, in terms of Cu production; with the behemoths of the Cu industry collectively producing only about 40 % of demand. In 2010, for example, the ten largest open-pit Cu-producing mines contributed 4.5 Mt of Cu, collectively, to demand. The ten largest underground mines produced about half of this amount, at 2.2 Mt combined. Collectively, the top 10 open pit and 10 underground Cu mines produced only 6.7 Mt of Cu.

Individually, the size of these mines highlights a further issue for the industry. The largest open pit mine produced 1.0 Mt of Cu in 2010; the next largest mine produced a little over 0.6 Mt of Cu, with the production range of the top 10 open pit mines being 0.24 – 1.0 Mt. The situation with large-scale underground Cu mines is worse; the largest underground mine produced only 0.42 Mt of Cu, with the production range of the top 10 underground mining operations in 2010 being 0.08 – 0.42 Mt. Clearly, these mines are too small if Cu demand in 2030 is to be satisfactorily met, predominantly, from mine production.

A possible "wild card" in the Cu supply mix is the concept of "**State Capitalism**", which is different from resource nationalism. The latter is a sovereign-risk issue, whereas state capitalism is very much a potential economic issue for non-state-owned mining companies. According to *The Economist* (January, 2012), "The world's ten biggest oil-and-gas firms, measured by reserves, are all state-owned". The Cu mining industry is so far similarly unchallenged, but so was the oil-and-gas industry not so long ago.

Corporate or Self-inflicted Challenges

Turning to the third of the three suggested categories of challenges to discovery, the **Corporate or self-inflicted** challenge; this has the capacity to destroy creative thinking and, in the process, severely reduce the number of expected discoveries in future years. It is a challenge that is extremely difficult to know how to combat. Essentially technical challenges, such as those outlined as **geology-related** and **mining-related**, are by far easier challenges to overcome. There is an almost insidious aspect to **corporate-related** challenges that, instinctively, every geologist will be aware of and can easily identify, both in terms of how it derives and manifests, and how it can easily be removed, if only the corporate world saw and treated the issue appropriately.

It would seem that a major starting point for corporate-related discovery challenges is the almost manic desire in most of the corporate world, and certainly within the mining industry corporate world, to grow. This desire for growth in the mining world often seems to have size as its only objective, as measured in terms of metal produced, almost irrespective of margin, although the case for growth will inevitably be demonstrated by a model that predicts increased margin accompanying increased production. As with mine performance versus feasibility study prediction, where about 70% of mine developments never meet feasibility study forecasts, let alone over-achieve; anecdotally it would seem that growth projections suffer a similar fate.

Unfortunately for exploration geologists, there are only two ways in which to grow in the mining industry; ore bodies are either discovered the old-fashioned way, or they are acquired through a merger or acquisition (M&A). For most larger-mining-company corporate management discovery is considered too high risk, although for successful explorers discovery is by far the most efficient way to create wealth; and a merger or acquisition is inevitably favoured as the way to grow. Compounding the issue insofar as creating opportunity for discovery, growth through M&A and sometimes even through discovery usually leads to increased management, as a larger business is typically considered to require more management.

Typically, there is a fairly predictable path that companies follow as they grow, irrespective of whether the company is in the mining sector or not. When a company is relatively small, its strengths are to be found in strong leadership and an entrepreneurial approach to business. As it grows into a large company, the composition of the company changes to one that has strong management and an increased bureaucracy, or at least bureaucratic tendencies, with a much reduced capacity to tolerate and accommodate entrepreneurial flair; which is the hallmark of a successful exploration team. Sadly for the discovery process, increased management almost inescapably leads to more bureaucracy, and the one certainty in the discovery business is that bureaucracy is bad for discovery – the two cannot co-exist. To the best of my knowledge, **bureaucrats don't find ore bodies.**

Continuing with the **corporate-related or self-inflicted** discovery-challenge theme, there is complete bewilderment at the corporate management level of most mining companies with the discovery process. Not only is there bewilderment with the process, there is often a lack of knowledge of where wealth is created in the mining value-chain. The oil and gas industry worked this out a long time ago, but it is still common in the mining industry for wealth-creation to somehow be attached to the mining-processing part of the mining chain, rather than at the pointy-end with discovery. Mining and ore-processing are, in essence, activities charged with minimizing wealth destruction, whereas the only role of exploration and discovery is wealth creation.

Not only is the discovery process poorly understood at best but, in reality, generally not understood at all; neither is discovery risk. It is pointless trying to explain a chance of success of one in one hundred, let alone one in one thousand or one in ten thousand, to corporate management and expecting to be showered with money to 'go out and explore'.

Compound this with the desire of management to 'manage', rather than lead discovery, and the magnitude of the **corporate-related and self-inflicted** challenge to discovery is apparent.

There is an obvious need for a "**discovery business model**", but this is easier said than done. The issue with trying to promote a discovery business model to a corporate management schooled in the latest management theory is that the 'discovery business' is completely different to the business of running a factory or a mine. One can forget most conventional management theory as is taught in business graduate-school; the edict of "if it can be measured it can be managed" needs to be mostly thrown out of the window, the 'discovery business' is essentially the antithesis of the 'need to measure'. The reason for all of this is quite simple, the **business of discovery is to encourage creativity**; there are no rules in this business, every ore body is different, as is the discovery process – there is no formula, or blueprint, for discovery.

Corporate challenges are mostly self-inflicted, which means that there is scope to ameliorate their effects through an enlightened approach to the discovery challenge. Unfortunately, there is little or no sign that the problem is identified as a significant issue by the mining industry.

Crucial Challenges

In essence, this essay has developed a theme that is best summarized as identifying four broad families of crucial challenges to discovering *tomorrow's deeper ore bodies*. These are:

- The absence almost everywhere of good quality 4-dimensional geology of the upper 0.5 – 3 km of the earth's crust; and the inadequacy for assisting discovery of present ore body models, which are invariably focussed predominantly on the ore body and its immediate surrounds rather than on the expression of the ore body 1 – 3 km beyond the boundary of the ore.
- The increased importance of discovering a body of mineralisation of an appropriate geometry, size and grade to be developed either as an Ultra-deep open pit or as a Super-cave underground mine.
- A relentlessly increasing mine capital intensity, at least in the Cu industry, that will require a many-fold increase in Cu price, or counteracting increase in ore grade and reduction in operating cost, for future ore body discovery.
- A corporate management style in larger mining companies that is counterproductive to discovery, and a major diverting influence on the discovery process.

Some Reflections

These are best summed up as:

- Discovery is a business and needs to be practised as such in order to succeed.
- Science-based risk-taking is an essential part of the discovery process and needs to be encouraged.
- Discovery is about managing risk and risk needs to be reduced as quickly as is possible.
- Commonsense dictates that discovery is more likely if low risk.
- There are many lessons to be learned from past discovery histories, and many future discoveries will inevitably reflect these lessons, whether learned or not.
- There is an immediate need to research and develop more comprehensive ore body models, where the focus will be on the host rocks to ore and the effects of the mineralizing process on these.
- *'*Deep-*earth'* isn't scary, it's just harder.

Final thoughts

- Large deposits, as are required in the Cu industry to meet projected metal demand, are easier to find than small deposits and obviously should be the primary target of a Cu search program.
- Discovery is random and unscripted.
- Correct exploration decisions are not always MBA material and require a degree of intestinal fortitude to make – they are not easy decisions.
- At least challenge, if not forget, conventional wisdom.
- **Think then act** – thinking without acting is something of a wasted effort in exploration, whereas acting without thinking can be a large waste of money.
- The final words are again credited to Sigfried Muessig who proposed that "**IQ gets you there ...... but NQ finds it**". He was incorrect on one point, **HQ triple-tube** is better than **NQ**.

Acknowledgements

My thanks to the SEG for providing the opportunity to present this lecture and to have a written version of it published in the SEG Newsletter; and to Newcrest Mining Limited, the W H Bryan Mining and Geology Research Centre at The University of Queensland, the Metals Economics Group of Canada, and BHP Billiton for providing some of the material used in the lecture.

References

Tedder, I. J., Holliday, J., and Hayward, S., 2001, Discovery and evaluation drilling of the Cadia Far East gold-copper deposit: Boart Longyear, NewGenGold 2001, Perth, Western Australia, 26-27 November 2001, Proceedings, p. 171-184.

Chitombo, G., 2011, Total Deposit Knowledge – Geology, Underground Mass Mining and the Future – A Mining Engineer's Perspective: Eighth International Mining Geology Conference, Queenstown, New Zealand, 22-24 August 2011, Proceedings, p. 11-14.

Wood, D., 2012, Discovery of the Cadia Deposits, NSW, Australia (Part 1): SEG Newsletter, January 2012, p. 1, 13-18.

Wood, D., 2012, Discovery of the Cadia Deposits, NSW, Australia (Part 2): SEG Newsletter, April 2012, p. 1, 17-22.

Wood, D., Chitombo, G., and Bryan, S., 2010, Mass underground mining and the role of the exploration geologist: SEG Newsletter, October 2010, p. 1, 22-24.