HOME

Why Do Brownfields Exploration?

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ABSTRACT

The future of any mining company depends on maintaining and growing its access to high-quality mineral resources. Often the true size of a given resource is not fully recognised until after mining has commenced. Also, the strong desire to increase production puts pressure to expand the resource base of the mine to get maximum value out of the capital employed. This, plus diminishing M&A opportunities and declining world-class greenfield discovery rates, makes brownfields exploration a high priority activity in any operating company. For the success and long-term survival of the company it is critical that this is done well.

The primary aim of brownfields exploration is to find or acquire new deposits within economic transport distance of an existing mine that will add materially to shareholder value through:

- mine or capacity expansion,
- displacement of lower-margin ore from the mine plan,
- preserving and extending the mine life, and
- ensuring potential value is understood in order to maximise potential future mine development or exit.

A number of strategic principles are important in any program designed to achieve these aims:

- understanding the life of mine (LOM) production profile and the related key drivers for exploration,
- understanding the dynamic nature of the brownfields search space,
- understanding and measuring depletion of the brownfields search space,
- understanding the potential of the near-mine region,
- investing in exploration technology to expand the search space, and
- investing in a basic geological understanding of the ore-environment.

Examination of the LOM profile will highlight critical issues facing development plans for the mine including future grade and throughput issues, key technology requirements or innovations and scenarios for increased production. Exploration targets in the brownfields program should address these key issues. Often it is as 'simple' as keeping mine development sufficiently far ahead of extraction to allow time for the various phases of exploration and resource assessment drilling.

Because of the low additional capital costs required, expansion of the brownfields search space is strongly leveraged to:

- metal prices,
- development of new markets,
- incremental operating cost reductions,
- strategic changes in downstream requirements in integrated businesses,
- depletion of higher unit-value ores, and
- new technologies (both extraction and exploration).

Therefore the brownfields search space is likely to incrementally expand through time and must be *regularly* reviewed. This is also important as any given search space will be progressively exhausted, resulting in smaller and higher cost discoveries. It is therefore important to monitor and critically review sustained trends of increasing brownfields discovery cost.

The first wave of discoveries in any camp are usually empirically driven and do not need a strong geological understanding. However, an improved geological understanding is critical to making the next generation of hidden discoveries.

To illustrate these points, a case study was carried out on the exploration and development history of the Kambalda nickel camp. Over a period of 40 years, more than 40 deposits were found containing over 1.7 million tonnes of nickel metal.

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Efficient mines need to maintain reserves for operating flexibility. Consequently, the company needs to clearly understand the global resource in order to maximise its full potential. In addition, understanding the full brownfields potential earlier in the development of a deposit rather than later, creates optionality through the flexibility that this understanding brings to future development choices.

To ensure best practice in attaining this aim, the roles and responsibilities of the exploration team and the mine operation should be clearly understood. It is important for the explorers and the operators to have shared views about what needs to be done. Typically, mine operators would be accountable for identifying future resource requirements to support the life-of-mine production schedule whilst explorers would be accountable to ensure best-practice assessment of brownfields exploration opportunities. This would include an assessment of the global undiscovered endowment in the regional near-mine area. The balance between brownfield exploration drilling and resources to reserve conversion will need to be decided to ensure efficient operations are maintained. Both need to agree the optimum level of brownfields funding taking into account:

- urgency to replace or grow reserves, and
- quality of opportunities (relative to those elsewhere).

The ultimate cost of ignoring the full brownfields potential of an operating asset can be significant, ranging from inefficient and poorly planned operations, lost opportunity cost and resultant value through under-utilised resources and, in the worst case, early exit from the asset at the bottom of the commodity cycle – leaving behind huge amounts of shareholder value.

BACKGROUND

A quick review of the published literature indicates that a large body of knowledge exists on the various exploration techniques and methodologies available, as well as the strategic issues affecting the industry. However, most of these studies are either focused on specific deposits, or are directed towards grassroots exploration. In contrast, there are no current studies specifically dedicated to how to best manage brownfield exploration programs around an existing mining operation. This is rather surprising – especially as mine site exploration accounted for 20 per cent of all exploration expenditures in the Western world in 2005 (Metals Economics Group, 2005).

The purpose of this paper is to provide a practical overview of how to develop and manage a brownfields exploration program and to provide a framework for assessing its strategic importance to the company.

WHAT IS BROWNFIELDS EXPLORATION?

Definitions

For all practical purposes, the terms *brownfields exploration* and *mine site exploration* are interchangeable.

It should be noted that there is no universally agreed definition of what is exactly meant by these terms. For example, in its annual surveys of exploration expenditures the Metals Economics Group (MEG) defines mine site exploration as:

> *All exploration (regardless of stage) that is at or immediately around an existing mine site held by the company (not including step-out drilling on the orebody being mined), including the search for satellite orebodies that, if found, would feed an existing mill. [It] also includes exploration at*

> *or immediately around a project that has been committed to development* (Metals Economics Group, 2005).

Consistent with this, MEG define *grassroots exploration* as exploration from the earliest stage through perimeter drilling; which also includes reconnaissance and evaluative forays. And, for completeness, they define *advanced-stage exploration* as all activities involved in further quantifying and defining a previously identified orebody once the target outline stage has been completed. It also includes all feasibility work up to the point of a production decision.

In practice, many companies define *mine site exploration* to include activities which extend the size of an existing orebody. Also, primarily for convenience, they may include all exploration activities on their mining leases as brownfields exploration – even if the ore associated with discovery is unlikely to be processed through an existing mill (for example gold exploration around an existing copper mine and vise versa, or drilling for sulfide ore underneath an existing oxide orebody).

Given the above, the authors have adopted a much broader definition for brownfields/mine site than that used by MEG. For the purposes of this paper the authors define *brownfields exploration* as:

> *All activities which aim to find or acquire new deposits within an economic transport distance of an operating mine that will add materially to shareholder value through:*
>
> - *mine expansion,*
> - *displacement of lower-margin ore from mine plan, and*
> - *extension of mine life.*

Again for the purposes of this paper, brownfields exploration does not include:

> *Production geology which ensures the mine continues to be supplied with ore at mine plan tonnages and grades. This may include activities such as grade control, geotechnical/rock engineering, reserve estimation and JORC reporting, hydrology, resource/reserve planning and scheduling.*

Similarly resource to reserve conversion is considered an interface between brownfields exploration and production geology and somewhat commodity dependent (eg coal versus base metals). The appropriate resource to reserve conversion ratios does need to be addressed. This involves deciding what proportion of the money and people should be allocated to converting existing resources into reserves versus adding to the known resources. The question of whether this activity is brownfields exploration is case dependent and should be resolved by team leaders consistent with an agreed brownfields charter.

Two key differences between brownfields and grassroots exploration

The first key difference between brownfields exploration and grassroots exploration is the level of risk involved. Brownfields exploration is inherently less risky because of its proximity to existing mines. This is due to two factors. Firstly, in the brownfields environment, one is exploring in an area of known mineral endowment. Secondly, due to the ability to piggyback off existing infrastructure, the minimum size threshold for an economic deposit is smaller. Given that the population of mineral deposit sizes generally follows a log-normal distribution, there are many more small deposits than big deposits. Consequently, brownfields exploration is much more likely to discover a deposit of economic interest.

Notwithstanding the above, brownfields exploration will start destroying value once all the substantial economic deposits in the area have been discovered. Consequently, it is vitally important for the mine manager to know when to stop exploring and start planning for mine closure. It should not be forgotten that all mines, both great and small, eventually run out of ore.

A second key difference between brownfields and grassroots exploration is the amount of data available – especially data in the third dimension. In the case of grassroots exploration, there is generally only broad-scale information available on the local geology and the structural setting. There will be few, if any, drill holes in the local area which contain economic mineralisation. In contrast, a mature mining camp will have extensive drill data (often numbering in the thousands of holes) as well as detailed geological models of how mineralisation occurs.

The challenge for the mine manager is to best take advantage of the available information – so as to make better decisions on where to explore in the area.

These twin challenges of deciding where to explore and when to stop work are discussed in more detail later in this paper.

WHY DO BROWNFIELDS EXPLORATION?

To help set the context of the importance of brownfields exploration it is worthwhile outlining the strategic drivers for exploration in general and brownfields/mine site exploration in particular. To help illustrate the key observations, the paper includes historical data on the discovery and production history of the Kambalda nickel camp in Western Australia.

Case study – Kambalda nickel camp

High-grade massive nickel sulfide ore was discovered by Western Mining Corporation at Kambalda in 1966. The initial discovery was called the Lunnon Shoot to honour the name of the driller in charge of the exploration program at the time. Mining commenced in late 1967, based on an initial resource of 38 kt of nickel metal at Lunnon. In the intervening years the resource grew to nearly 150 kt. In addition to extending the resource at Lunnon, brownfields exploration has led to the discovery of 39 other nickel deposits in the immediate area. As at end-2005, the mineral endowment of the world-class Kambalda camp had grown to over 1.7 million tonnes of nickel, of which over 1.34 Mt had been mined (see Figure 3). It should be noted that, for purposes of this paper, we have excluded discoveries and production associated with the nearby Widgiemooltha nickel camp – which also feeds into the central mill at Kambalda.

In 2000 - 2002, in the face of poor nickel prices and rising costs, and a perception that the camp was reaching the end of its life, WMC Resources Ltd progressively sold its mines to a number of small operators. Since then a combination of improved costs, higher prices and increased exploration activity have led to a renaissance of exploration and development activity.

Strategic drivers of brownfields exploration

The future of any mining company depends on maintaining and growing its access to high-quality mineral resources. The recent industry trend of rapidly increasing demand growth due to economic development within Brazil, Russia, India and China has had a very positive effect on commodity prices. In addition, massive ongoing consolidation within the mining industry has seen the top four companies leap from 27 per cent of total mining industry value in 1999 to in excess of 41 per cent in 2005. Although consolidation and increased demand has led to much speculation on whether we see a 'super-cycle' similar to the post-war era driving rising demand and sustainably higher commodity prices it has also had a number of other side effects. These include increased resource depletion rates due to capacity expansion at most existing operations and diminishing merger and acquisition opportunities for the very large mining companies. These trends, when coupled with what appear to be falling greenfield discovery rates, mean that extending the life of the existing mining operations through brownfields discovery has become even more important for the industry.

Evidence of the vital role brownfields exploration plays in sustaining the industry can be seen in Figure 1, from Schodde (2003) which shows the amount of gold found in Australia in three selected periods between 1985 and 2002. In detail it shows that a total of 56 million ounces of gold was found between 1985 and 1989. Over 41 million ounces of this were identified after mining had commenced. In other words, brownfields exploration had tripled the size of the initial (ie pre-mine start-up) known resource. To further emphasise the importance of these brownfields discoveries, total mine production of 25 million ounces (as at 2002) had exceeded the initial reported resource (as known in 1989)!

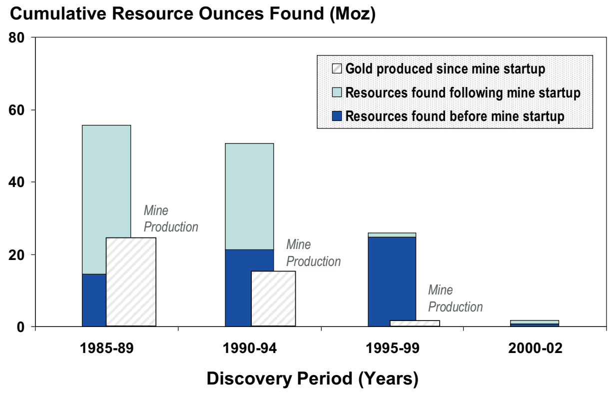


FIG 1 - Amount of gold discovered in Australia between 1985 and 2002, broken down into whether the gold was found before or after mine start-up. Note: mine production refers to only those deposits discovered in a given period.

Figure 1 also highlights an important characteristic of brownfields exploration – namely that it takes a long time to identify and delineate the full potential of a given district. This is evidenced by the relatively lower proportion of resources identified post-mine start-up in the later periods.

The resulting growth in resources from brownfields exploration not only extends mine lives, but also creates opportunities to increase mine throughput. This can create significant value, particularly for world-class mines (Figure 2). In particular, the huge resource base associated with world-class deposits creates options to leverage off new technologies and quickly, cheaply expand production. For example, at the time of writing, Escondida was into its sixth expansion phase. This was driven by production expansion and innovations in mineral processing technologies as well as brownfields discoveries such as Escondida Norte. However, such rapid production expansion increases the need for reserve replacement and hence another key strategic driver of brownfields exploration is preserving and extending asset life. This is increasingly relevant as closure costs are increasing at most mine sites and it is worth a lot of NPV if you can put off closure by a year or two.

Finally as the mine life draws to a close understanding the full brownfields potential of the asset ensures that full value will be realised if management decides to sell the asset before closure.

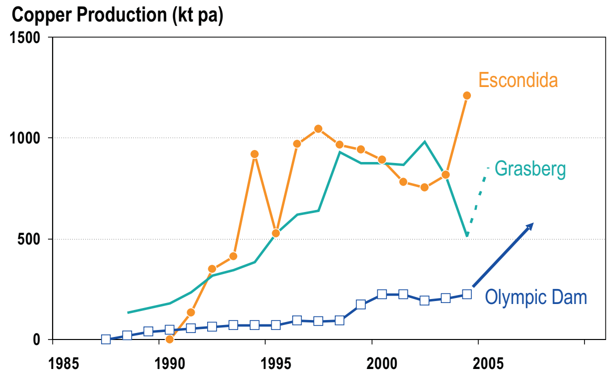


FIG 2 - Growth in production from three selected world-class copper mines.

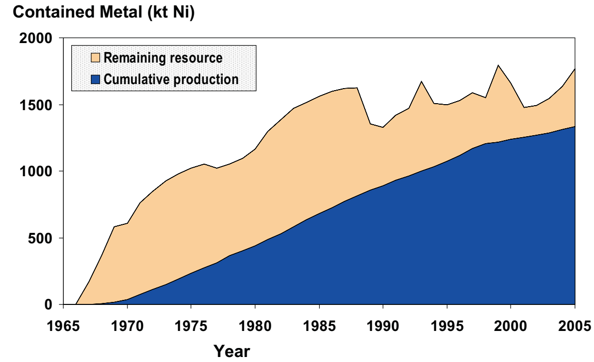


FIG 3 - Cumulative production and remaining resources at the Kambalda nickel camp.

GENERAL PRINCIPLES OF BROWNFIELDS EXPLORATION

Concept of the exploration search space

Brownfields exploration along with other business activities, notably greenfields exploration and pharmaceuticals, are basically a search through a defined parameter space (the '*search space*'). This search space is the given set of conditions which constrain economically-significant outcomes of the search process. These include:

- target ore-type (detectability, economics);
- cover conditions;
- detection technology;
- extraction technology; and
- political/commercial environment.

A key observation is that the largest deposits in any given prospective search space are usually found early because they have the most obvious signatures. This was certainly the case at Kambalda, with the four largest deposits there being found in the first six years following the initial discovery (see Figure 4).

Figure 4 also reinforces an earlier observation – namely that it can take many years of exploration to determine the true size of these discoveries (as evidenced by the increase in the reported initial and current resource size for each of the deposits).

Another general characteristic of any mining camp is that most of the ore (and value) is captured in a handful of discoveries. Figure 5 shows that at Kambalda, the five largest deposits collectively host over half of the contained metal.

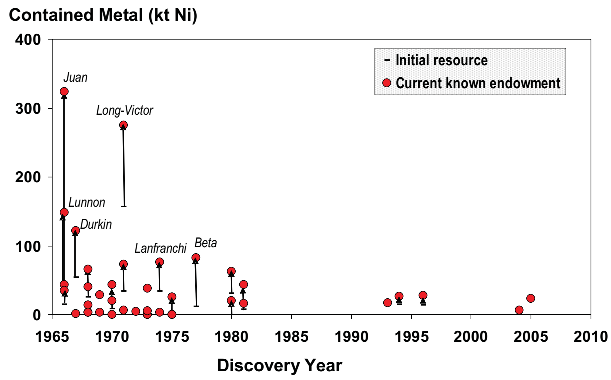


FIG 4 - Size and discovery date of nickel deposits found at Kambalda.

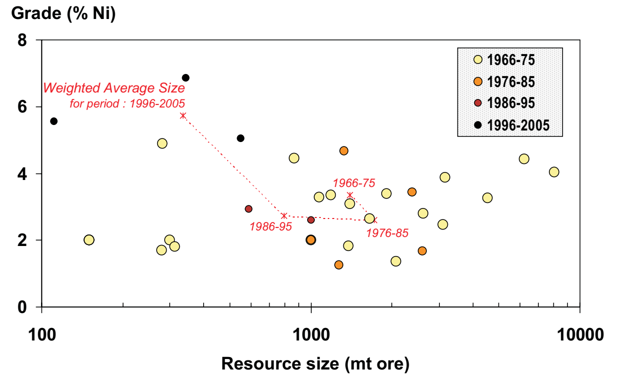


FIG 6 - Ore tonnes and grade of nickel deposits in the Kambalda camp (based on historic production plus remaining resource as at December 2005).

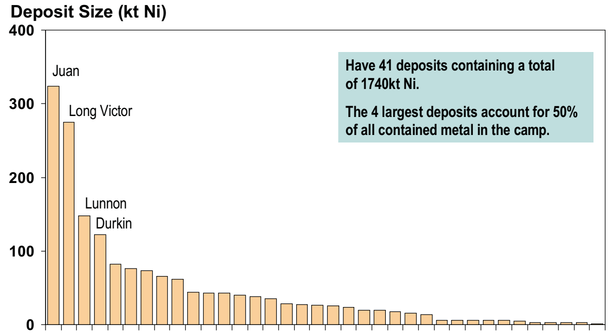


FIG 5 - Contained metal tonnes of nickel deposits in the Kambalda camp (based on historic production plus remaining resource as at December 2005).

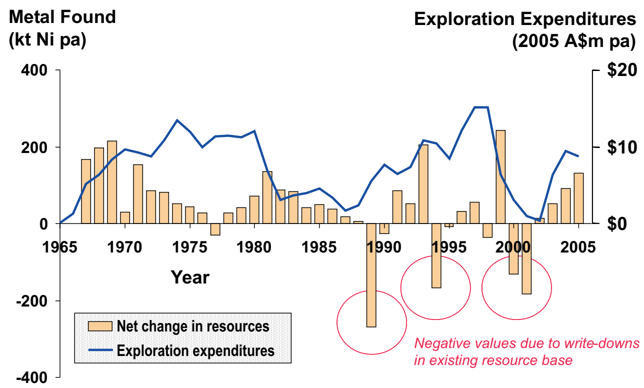


FIG 7 - Nickel metal found at Kambalda versus exploration expenditures from 1965 to 2005. Note: metal found is based on the net increase in the reported resource plus the ore mined (before milling losses) in the given year. Due to revisions in the resource base, the calculated figure was negative in some years.

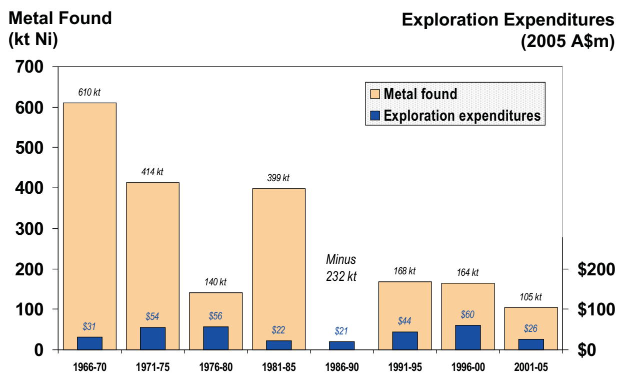


FIG 8 - Total amount of nickel metal found and brownfield exploration expenditures at Kambalda in five year increments between 1966 and 2005.

Figure 6 plots the tonnes and grade characteristics of the 40 nickel deposits found in the Kambalda camp. It shows that the weighted average size of deposit discovered in the first decade (1966-1975) of the camp's life was 1.40 Mt @ 3.34 per cent Ni containing 47 kt of nickel metal. In the second decade the average was 1.72 Mt @ 2.61 per cent Ni. While the overall metal content was similar (45 kt Ni) to the previous decade, the lower grades meant that these deposits were less profitable to mine. In the third decade the average size had deteriorated to 0.80 Mt @ 2.73 per cent, containing just 22 kt of nickel metal. Evidence of the mediocre profitability of these discoveries can be seen in the fact that many of them remain undeveloped (see Table 1). And, in the last decade (1996 - 2005) the apparent average size found was 0.34 Mt @ 5.72 per cent Ni for 19 kt of nickel metal. It should be cautioned that the reported numbers may increase in the future as ongoing brownfields exploration extends the current known mineralisation.

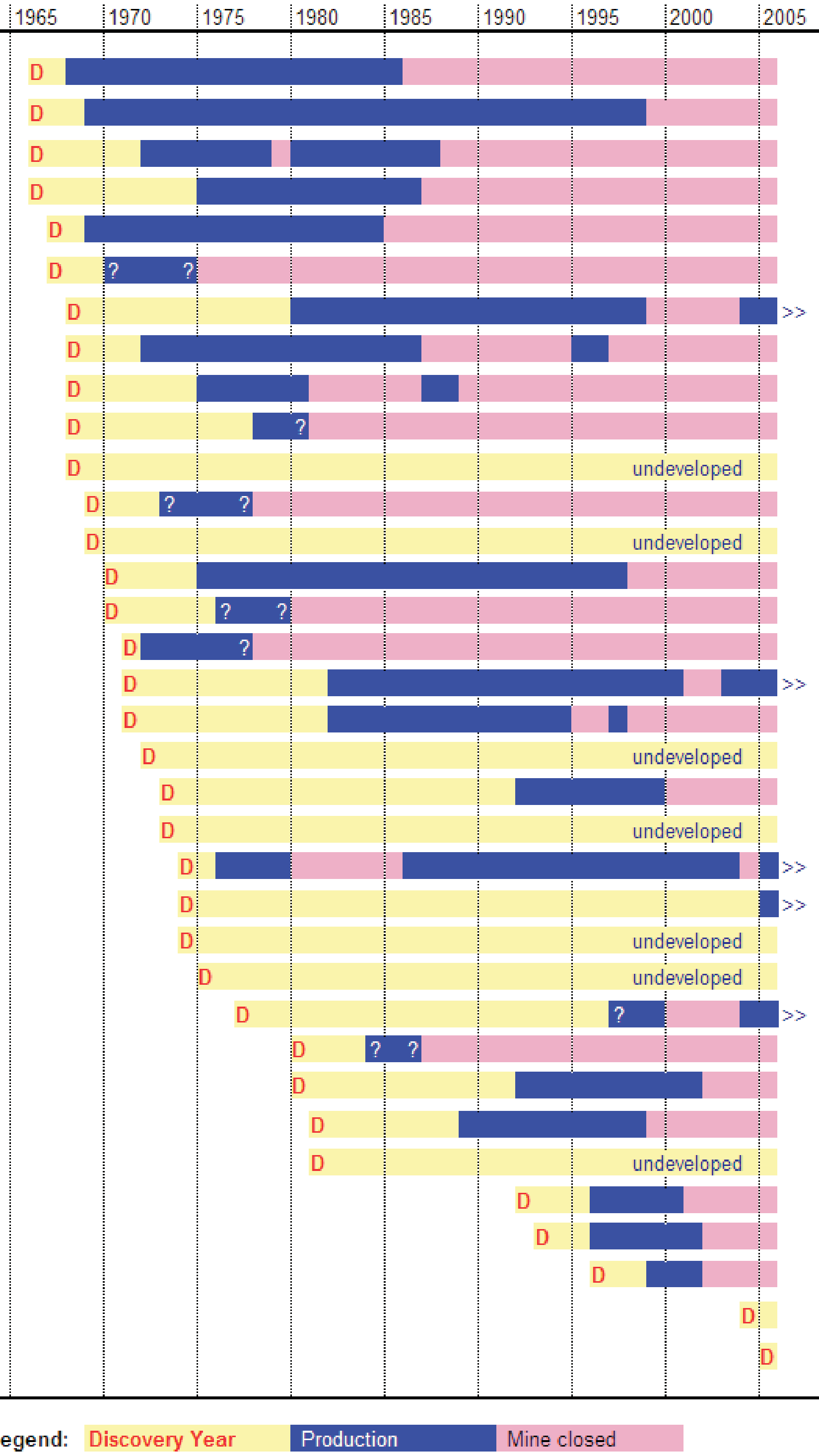
As a generalisation larger/higher grade deposits tend to be more valuable. Given that these types of deposits are often found early in the camp's life, this means that declining returns set in over time. In other words, a key characteristic of brownfields exploration is that with time the search space is progressively exhausted, resulting in smaller discoveries and often associated higher cost and lower value.

Evidence of this can be seen at Kambalda. Figures 7 and 8 show the trends in the amount of money spent on brownfields exploration and the net increase in resources at Kambalda. Data for 1965 - 2000 came from internal reports from WMC Resources Ltd (now BHP Billiton Ltd) and post-2000 data are the authors' estimates based on an analysis of public reports for the various companies now operating in Kambalda. After adjusting for the period in the 1980s and 1990s, when there some major downwards revisions in the resource base (see Figure 3), there is a clear trend towards rising unit exploration costs. Figure 9 shows that in the early years of the Kambalda camp, the average discovery cost was only 2.3 cents/lb in 2005 A$. Over the following 30 years this progressively rose to around 12 to 18 cents/lb. In recent years, following the sale of the mines, the average discovery cost has dropped back to around 11 cents/lb in 2001 - 2005. This illustrates the significant opportunity to re-invigorate a mature camp through the introduction of new approaches for exploration.

TABLE 1

Discovery dates and production history of nickel deposits found at Kambalda.

DEPOSIT	*Discovery Year*
Lunnon	1966
Juan	1966
Fisher	1966
Jan	1966
Durkin	1967
Gibb	1967
Carnilya Hill	1968
McMahon	1968
Edwin	1968
Gellatly	1968
John	1968
Gordon	1969
Cruickshank	1969
Hunt	1970
Loreto	1970
Ken	1971
Long-Victor	1971
Foster	1971
Cameron	1972
Victor	1973
East Cooee	1973
Lanfranchi	1974
Alpha Island	1974
Duke	1974
Stockwell	1975
Beta Island	1977
NW Foster	1980
Schmitz	1980
Blair	1981
McComish	1981
Coronet	1993
Helmut	1994
Skinner	1996
Winner	2004
McLeay	2005



The various reasons behind the downgrades in Kambalda's resources in the 1980s and 1990s (Figures 3 and 7) are of interest – and provide useful learnings for other operations. The first round of downgrades at Kambalda was due to the introduction of the JORC Code which provided a more rigorous definition of reserves and resources than that previously used by the company. Subsequent to this, a sudden drop in nickel prices in the early 1990s, caused management to increase the cut-off grades for some of the deposits – resulting in a reduction in the metal tonnes reported. Concurrent with this, several mines permanently closed down and the remaining resources were written off. Finally, in the late 1990s, in response to concerns regarding mine safety, the company took a very conservative view on underground stope designs. This effectively sterilised significant amounts of pre-existing reserves and resources in high-stress areas. In recent years, through higher nickel prices, better mine design and additional drilling, some of these resources have been written back-in (Reeve, 2006).

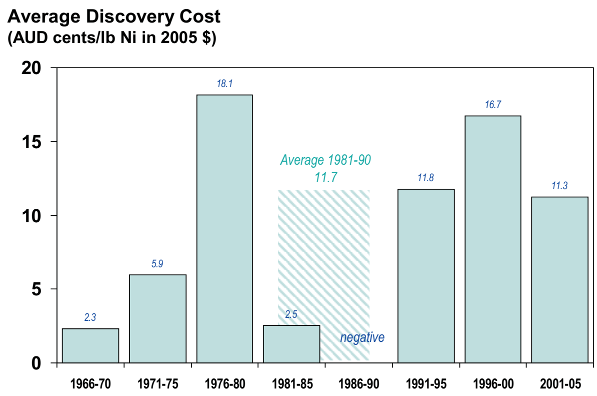


FIG 9 - Estimated average discovery cost for nickel at Kambalda (Australian cents per pound of nickel in constant 2005 dollars).

Benefit from developing new exploration search spaces

New exploration targets creates the opportunity for a step-change increase in the size of the known resource. As a general rule, the bigger the discontinuity, the bigger the potential pay-off. For the mining exploration business (both brownfields and greenfields) the most important business discontinuities are those which significantly expand the search space. These include entry into new geographies, higher commodity prices and introduction of new exploration concepts, exploration technologies or extraction technologies.

A good example of how technology expands the search space is provided by the petroleum industry in the Gulf of Mexico (Figures 10 and 11). Appenzeller (2004) shows that over the last 40 years massive new reserves have been found by developing drilling and extraction technology that enabled a move into an extension of a known prospective terrane, that is, the deep-water Gulf of Mexico. These developments were in turn driven by new exploration concepts on the genesis, migration and entrapment of oil in the Gulf of Mexico.

This example illustrates how the search space is very dynamic through time being sensitive to the business discontinuities already mentioned above. This means the brownfields potential around operating sites can change over time with changes in geological concepts, technology or business conditions and must therefore be regularly reviewed. The following is a list of principles that are a guide to what should be considered in such brownfields reviews and are discussed in more detail below:

- understand the life of mine (LOM) production profiles for each asset and the related key drivers for exploration,
- understand the dynamic nature of the brownfields search-space,
- understand and measure the depletion of the brownfields search space:
  - discovery cost metrics; the need to sterilise for threshold sized deposits, and
  - determine when is the best time to cease any further exploration,
- understand the potential of the near-mine region and identify the size of the catchment area for potential satellite mines feeding into the existing mill,
- invest in exploration technology to expand the search space, and
- invest in a basic geological understanding of the ore-environment.

These principles are discussed more fully below.

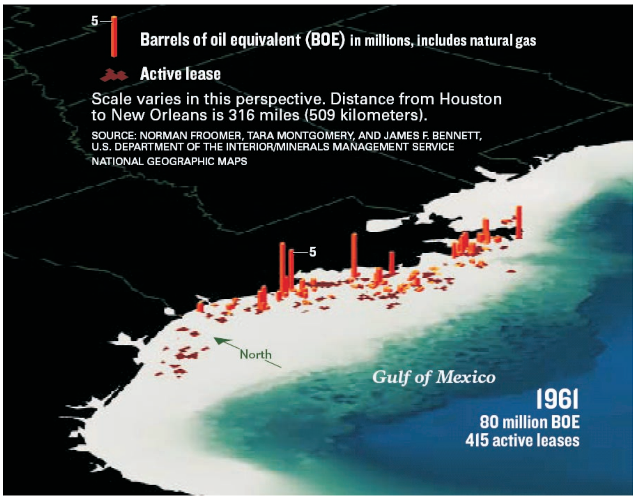


FIG 10 - Size and distribution of exploration leases and known oil fields in the Gulf of Mexico in 1961.

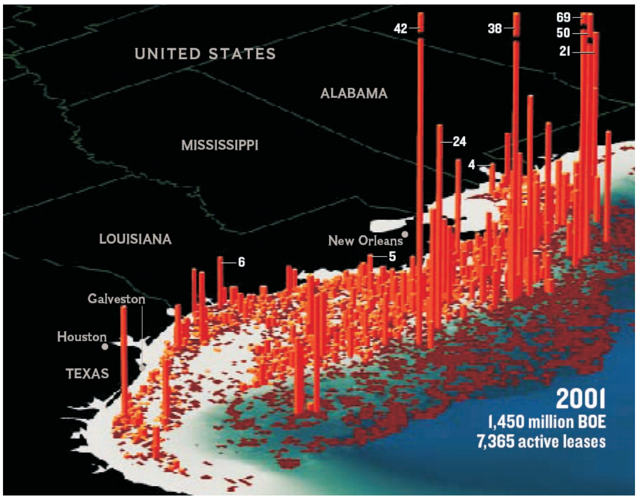


FIG 11 - Size and distribution of exploration leases and known oil fields in the Gulf of Mexico in 2001.

The importance of fully *understanding the life of mine (LOM) production profile* lies in its ability to highlight critical issues facing development plans for the mine (eg grade and throughput issues) thus identifying looming 'cliffs' in the production profile (Figure 12). Targets in the brownfields program should address these key issues including scenarios for increased production or any present technology issues or potential future innovations that could expand the search space.

When developing the strategy for brownfields exploration, it is important to set some objectives with regard to the size and quality of the exploration target. These criteria will change over the life of the mine. In particular, in the early years, focus should be on finding large (and preferably high-grade) deposits – as finding large deposits can enable the operator to invest in expanding the processing capacity and reap the benefits of economies of scale. This works best while the mine still has a long life ahead of it.

During the early period, finding a small deposit may not create much value – as, unless there is an associated increase in milling capacity, ore from the new deposit will displace ore from existing operations. In practice, this will only happen if processing the new ore gives the operator better profit margins. In other words the

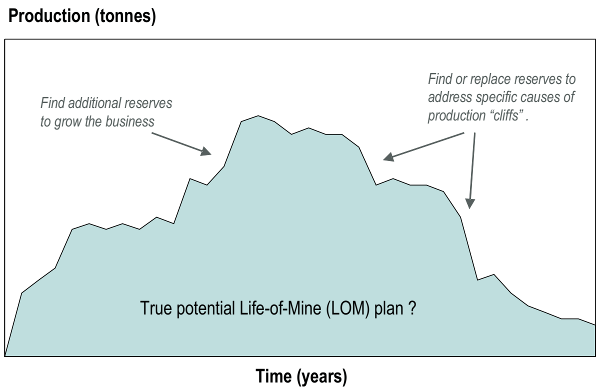


FIG 12 - Production rate profile over the life of a typical mine.

small new discovery needs to have higher grade and/or lower mining costs. If it doesn't, then the deposit will only get developed towards the end of the camp's life. Given that this may be several years away, the net present value of this type of discovery is small.

The above situation changes as the camp matures. In the later years, as the existing mines are exhausted, spare milling capacity will become available. In this situation there is a strong economic incentive to find low-grade and small deposits to fill the looming 'cliff' in the LOM production profile.

LOM profiles are also important in understanding the potential value of the mine under a range of different production scenarios. This is because value can be created in different ways across the asset's life cycle (Figure 13). At discovery, value can be quick or slow to realise depending on deposit size and commodity (eg base metals versus gold). Value can be added through expansion of brownfields reserves or identifying other companies projects that add value to your operation. Similarly, value can be destroyed by overspending on brownfields exploration once the search space is exhausted or by not exiting an asset at the end of its life at the right time.

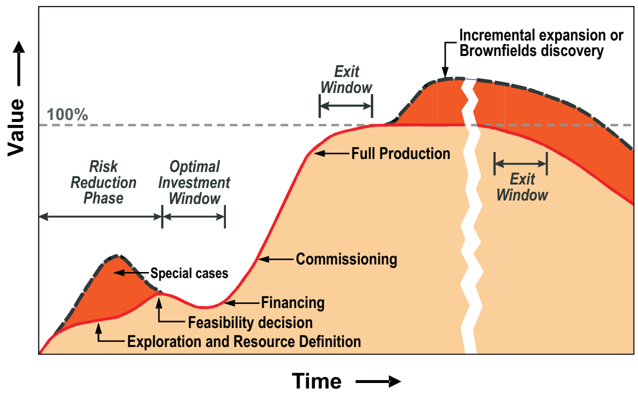


FIG 13 - Changes in asset value over the life of a typical mining project.

How value is calculated can also play an important role in subsequent development of the asset and the subsequent aims of brownfields exploration. For example, the effect of discounting factors are often not fully understood – an additional 15 years of reserves at the end of an existing 15 year mine life are not worth as much as the same reserves used to double a mines production within the same life.

It should be recognised that the *brownfields search space is dynamic* because low additional capital expenditures are required for expanding an existing operation. Consequently, it is strongly leveraged to:

- metal prices,
- development of new markets (eg higher phosphorus content iron ore),
- incremental operating cost reductions,
- strategic changes in downstream requirements in integrated businesses (eg lumpy iron ore versus fines), and
- depletion of higher unit-value ores which creates a production gap for poorer ores through elimination of the 'crowding out' effect.

Therefore the brownfields search space is likely to incrementally expand with time and must be regularly reviewed. Good examples include the progressive change in Australian iron ore specifications over time from lump hematite ores to Channel Iron deposits to Marra Mamba style ores and recently to acceptance of high phosphorous Brockman ores. Similarly, in the copper industry there has been the evolution in copper processing technology with time from sulfide concentrates to oxide leach to chalcocite leach to bio-leach and into the future of chalcopyrite leach. Such changes significantly effect resource development options and brownfields search strategies.

The option-value embedded within world-class deposits is often poorly understood because these dynamic changes lie in a future which is often difficult to envisage. The option-value is also not only present in the deposit itself but also in the surrounding land packages required for capacity expansion and in infrastructure such water, power, rail, etc. There are many examples from history that show that if a regular review of brownfields potential does not happen the brownfields option-value can be (and often is) lost. The underlying problem is often due to a lack of strategic vision during periods of cyclic downturn.

As has already been discussed for the Kambalda nickel camp, depletion issues eventually become significant. Consequently, it is important to *understand and measure the rate of depletion of the brownfields search space*. This can be achieved by monitoring and critically reviewing the trends in brownfields discovery costs. An example such an analysis for the Kambalda camp can be seen in Figure 9. If there is a sustained increase in discovery cost over time, options need to be canvassed, including whether there are technology related opportunities to expand the exploration search space or whether it is better to bring in a third party (with fresh ideas and extra funding) to assess the remaining potential of the area. These decisions need to consider whether the fundamental geology of the deposit type typically results in clustered deposits and whether they have obvious exploration signatures. At some point it will be appropriate to stop brownfields exploration.

It should be noted that, even if the decision is made to stop exploration but continue mining, the brownfields potential should still be regularly reviewed. If depletion seems inevitable this knowledge will be a key influence on any consideration of selling the mine to a more appropriate owner who may place a higher value on the remaining production.

It is possible for companies to get overly-focussed on the operating leases around the mine (immediate near-mine) without fully *understanding the potential of the regional near-mine area* to deliver to the strategic plan. The potential of the surrounding area needs to be assessed in terms of both geological and economic factors (eg distance from the processing plant). For the purposes of this paper the *immediate near-mine* is usually the mine leases for which the mine management is responsible. The target size in this area will be reduced due to proximity to the operations. Target sizes in the *regional near-mine* area will be larger, although still smaller than a stand-alone greenfield target due to the potential synergies with existing infrastructure. In other words, the mine manager needs to determine what is the size of the natural 'catchment' area for satellite mines feeding into the existing operation. This will help clarify the roles and responsibilities of the brownfields and grassroots exploration teams.

Technologies and research underpin innovative strategies for extraction from the existing global resource and improving effective exploration in the brownfields search space. Tools to see deeper with more accuracy and discrimination capability are key and therefore it is critical to *invest in exploration technology to expand the search space*. Geophysical inversion and 3D GIS systems are becoming increasingly important in assessing exploration potential – especially given that the targets are often under deep cover. A good example of such an approach can be found in a paper by Stone, Beresford and Archibald (2005) which outlines the various exploration methods used to discover recent ore shoots at Kambalda.

The first wave of discoveries in any prospective camp are usually empirically driven and do not need a strong geological understanding. However, geological understanding is critical in making the next generation of hidden discoveries and it can be important to *invest in a basic geological understanding of the ore-environment* in these cases. Lots of geological data are routinely collected at an operating asset. Elucidating key guides to finding further ore may simply require a synthesis of these data. Geological studies of the ore-environment usually have low cost but relatively long lead times so they should be proactively implemented. Examples include the Kambalda geological work of the early 1970s and the subsequent nickel and gold discoveries by WMC Resources Ltd.

BROWNFIELDS REVIEW PROCESS

As the camp matures it is important that regular and thorough reviews of the remaining exploration potential be carried out. As the mine nears the end of its life a decision needs to be made on when to cease further brownfields exploration and to start planning for the mine's closure.

The general aim of the exploration review should be to realise the full value of the residual potential of tenements within economic distance of existing infrastructure. A key outcome would be the identification of possible LOM options for the asset. At the end of the review there should be confidence that completion of the proposed brownfields program would mean that *negligible potential will remain* for discovery of additional significant value-adding mineral deposits in the regional near-mine area.

The review team should be multi-disciplinary and include key exploration personnel together with appropriate representatives from the mine operations. The key is to have the right mix of skills to address strategic drivers including geology, structural geology, geophysics, geochemistry, database management, engineering and mine planning.

Specific review outcomes will come from identification of critical issues from the LOM production profile, which as already discussed, will highlight key issues facing development plans for the asset.

Targets that will address these key issues should then be identified. Target criteria should be agreed (eg X Mt deposit of Y grade within Z km of infrastructure). Specific priority ore types (and processing characteristics) should also be identified.

Generally the team will first focus on the near-mine potential by reviewing the target economic model and how this affects the exploration search space, particularly the economic depth limit. The desired target net present value (NPV) which will make a meaningful impact on the mine operations should be agreed. All relevant data should be consolidated into a 3D model which includes the current orebody mine model/plans and potential extensions as outlined by drilling, geological, geophysical and geochemical data. This should highlight any untested targets or untested prospective rock volumes in the immediate area surrounding the mine (generally the mine leases).

A part of this near-mine appraisal should include a review of the orebody response to the various search techniques (geophysical, geological, and geochemical). This will help refine its signature and the size of target footprints and the best search technologies and methodology to be employed in the brownfields program.

The final goal of the near-mine program is to effectively sterilise the potential for the required target(s) on the mine lease within the defined economic search space.

The appraisal can then move onto the regional near-mine area again reviewing the economic model and how this affects the exploration search space further from mine infrastructure. All data should again be integrated and prospective stratigraphy identified. This process will identify gaps in data coverage and geological knowledge and help define the untested search space (eg below 200 metres depth).

Finally the recommendations should be outlined in a formal brownfields exploration plan. Logically these plans should follow from the brownfields asset review process outlined above, be multi-year in scope and need to incorporate clear program goals, strategic timing constraints, a clear definition of the exploration search space and required resources and budget.

Strategic timing constraints are derived from the LOM production schedule. An important point to note is that there is often a very long lead time between starting an exploration program and converting this into mineable reserves. In general, targets within the mine operating leases provide a quicker path to production than near-mine regional targets but commonly there is also a trade-off on size of opportunity. The lead time required to discover and develop a given type of target becomes critical as the mine nears the end of its life and/or faces large 'cliffs' in the LOM plan. For example, there is probably little value in exploring for a target which will take five years to get into production if the mine is due to close in one year.

A clear definition of the exploration search space would include, target size and grade, depth of investigation required, distance to processing infrastructure and other infrastructure constraints (access to roads, pipe-lines, etc).

The brownfields exploration plan should provide estimates of the realistic funding levels and human resources required to achieve the plan. These should be presented as a recommended multi-year budget and take into account the time required to scale up a program to full size.

Given that the average business cycle is of the order of five to seven years, it is very difficult to confidently schedule the start of a grassroots exploration program to deliver metal into the market at the top of the business cycle. For this reason, the amount of funding for grassroots exploration should be fairly steady from year to year (see Figure 15). In contrast, the lead times for brownfields exploration are generally much shorter. Consequently it may be possible to adjust the level of funding to meet short-term needs and opportunities – such as bringing on additional mine production during periods of high commodity prices. In particular, the level of brownfields funding may also be driven by the need to replace reserves and impending production 'cliffs' in the LOM plan. These requirements will depend on the local circumstances of the mine at the time.

Steve Enders [from Newmont] and Richard Leveille [from Phelps Dodge] have similar views on the ideal funding patterns for brownfields and grassroots exploration (Enders and Leveille, 2004).

Determining the right amount to spend on brownfield exploration

Determining what is the optimum amount to spend on exploration is not an easy task.

Ideally all of the individual exploration projects (whether they be greenfields or brownfields) should be assessed via a value-based decision making process which attempts to quantify the potential benefits they could deliver to the company. The ranking system can include economic, technical risk, geological risk and timing considerations. Ranking the results from best to worst highlights the fact that beyond a certain point, additional exploration expenditures are unlikely to deliver significant additional value to the company. With this information it is possible to build the business case for how much to spend.

In companies with multiple operating assets and commodity products prioritising the brownfields spend at each asset may be an important consideration. Such ranking schemes can be multi-dimensional depending on the corporation's needs. Figure 14 shows an example where projects are prioritised in terms of the quality of the opportunity and the urgency to replace/grow the resource.

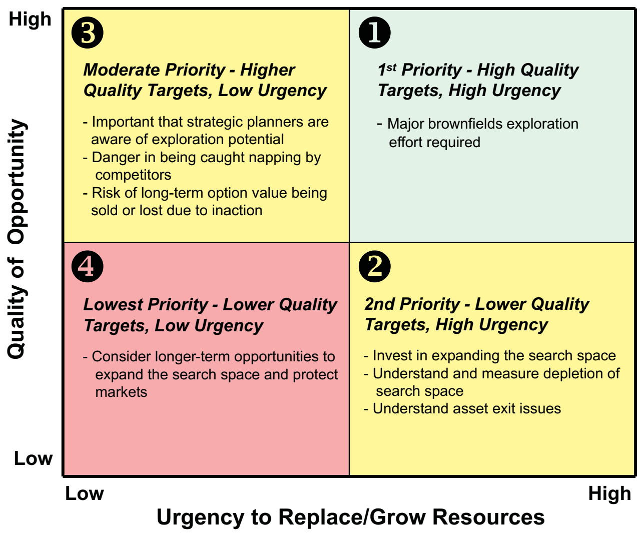


FIG 14 - Change in the optimum level of funding for brownfields and grassroots exploration over time.

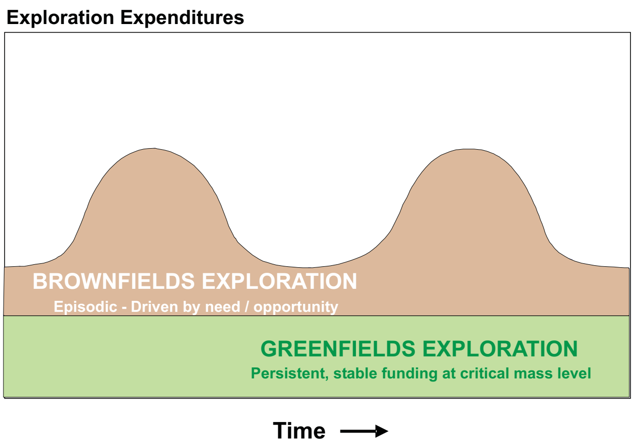


FIG 15 - Change in the optimum level of funding for brownfields and grassroots exploration over time.

In practice, due to inherent uncertainties associated with exploration, measures of the target quality tend to be subjective rather than objective in nature. As a cross-check it is best to benchmark the exploration team's current performance against industry averages and/or against past performance. An example of this would be the cost per unit of metal discovered (eg $ per ounce or cents per pound of resource found). As discussed before, tracking this over time also gives management a sense of whether the exploration potential for the camp is maturing. It also gives them a basis for assessing whether it is cheaper to secure additional reserves through acquisition rather than exploration.

Implementing and monitoring the exploration plan

The brownfields exploration plan should be regularly reviewed by monitoring achievement of key performance indicators (KPIs) and key decision points, and setting new KPIs and decision points. Besides benchmarking cost per unit discovery costs other short-term metrics such as the number of targets tested, metres drilled, drilling costs or the number of economic intersections may be tracked (the best short-term metrics are commodity dependent). The quality of resource additions discovered is best assessed via the estimated NPV addition to the overall asset value.

The respective roles of participants in brownfields reviews will be company and commodity dependent but could be split as follows, particularly in companies with multiple operating assets and commodities. Generally the senior exploration management team have an accountability to help ensure best-practice quality of all brownfields programs so that the best possible assessment is made of brownfields exploration opportunities at every asset and make recommendations to senior mine management concerning the brownfields exploration plan. They would also ensure that the exploration spend is optimised across between greenfields and brownfields programs, based on the potential to maximise the value-added to the business. The relevant asset is responsible for identifying future resource requirements to support the LOM production schedule which are key exploration targets for the brownfields program. In general the asset would be responsible for the funding of the agreed brownfields exploration program.

From a human resources perspective, the transfer of exploration staff between greenfield and brownfield activities should be encouraged, as this increases the skill, capability and judgement of both teams.

CONCLUDING REMARKS

In order to maximise the full potential of the operation, it is critical that the mine manager ensures that the mine has sufficient reserves to both operate at a steady level and have the flexibility to respond to any changing needs (eg expand to take advantage of improved commodity prices). A key part to this end is to have a good understanding of the potential resource in the area.

To ensure best practice in attaining this aim, the roles and responsibilities of corporate grassroots exploration teams and the mine operation should be clearly understood. It is important for the explorers and the operators to have shared views about what needs to be done. Typically, mine operators would be accountable for identifying future resource requirements to support the life-of-mine production schedule whilst explorers would be accountable to ensure best-practice assessment of brownfields exploration opportunities. This would include an assessment of the global undiscovered endowment in the regional near-mine area. The balance between exploration and resources to reserve conversion will need to be decided to ensure efficient operations are maintained. Both need to agree the optimum level of brownfields funding.

The senior management of the company has a very important role to play in helping set the consistency of purpose and effort in exploration in general. A commitment to a program which aims to maximise the full value of the operation through the business cycle is very important and can often mean embracing counter-cyclic thinking.

The ultimate cost of ignoring the full brownfields potential of an operating asset can be significant, ranging from inefficient and poorly planned operations, lost opportunity-cost and resultant value through under-utilised resources and in the worst case early exit from the asset at the bottom of the commodity cycle – leaving behind huge amounts of shareholder value.

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