Marcus Willson, CSA Global, Australia, provides a detailed overview of global mineral exploration expenditure and explores techniques mining companies can implement to apply their exploration funds more effectively.

Over the last 12 - 18 months, there has been a positive change in the amount of global mineral exploration expenditure. The total reported expenditure on non-ferrous mineral exploration has increased by about 20% to around US$10 billion.¹

Although this is less than half of peak expenditure in 2012, the industry continues to show a discovery trend, which historically was sympathetic to expenditure; but is now antithetic for all major commodities.²

This may, in part, relate to the increasing focus on near mine (brownfield) exploration. The challenges of increasing depths of discovery – estimated in 2014 at 65 m (for gold) and forecast to increase by 10 m per decade – likely also contributes.³

Yet, there is an ever-increasing demand for metals and minerals.

As such, exploration can be argued as the necessary evil in the mining supply chain. Companies can fool themselves into believing that they can replace resources and reserves by acquisition, but fundamentally, someone must explore in order to make new discoveries if the industry is to remain viable.
Data shows that most discoveries continue to be made by junior mining companies, with mid-tier and major mining companies sharing the next rank.¹

Junior miners, of course, typically cannot afford to purchase Tier 1 mineral assets, and more commonly seek value growth through discovery and/or apparent discovery. Junior miners also tend to be less risk-averse, allowing them to pursue and locate mineralisation in jurisdictions that more significant companies with risk committees would either not go near, or would need a very significant reason to go into (e.g., a tangible and valuable mineral asset). However, with globalisation, there is increasing competition for favourable unexplored areas in ‘low-risk’ jurisdictions.

Recent trends show, however, that major miners are once again increasing their exploration budgets. As with the global trend, these remain at something below 50% of what was available during the last boom. This is perhaps not surprising; indeed, a common adage for major miners is a requirement to discover a world-class deposit, which is very difficult. It is therefore hard to justify exploration on a resource replacement basis.

With increased emphasis on systems and oversight, the level of effective utilisation of budgets may, anecdotally, be as low as 25% of the total budget going into the ground within some companies. Assuming a US$225 million budget (similar to a number recently quoted by a global major), at this level, less than US$60 million would be spent in testing targets. This is roughly equivalent to the exploration budget range that is quoted by a number of mid-tier companies who have far smaller resource replacement requirements. To put this into context, if we assume a discovery cost of US$70/oz of gold, the US$225 million should buy you around 3.2 million oz of gold average per year on a long-term basis. However, US$60 million buys less than
0.9 million oz of this. If exploration is going to add value, mining companies must, therefore, make the most out of limited budgets. With ever-increasing depths to discovery, the need to expand the radius of influence of each data point is manifest.

As an industry, miners generally understand the geological environment within which deposit types are likely to occur, resulting in reasonable area selection. Once companies have drilled a discovery hole, well-developed resource definition through reserve evaluation methods keeps risks at a reasonable level. The pointy end of the value chain, therefore, is early stage ground testing and prospect identification. Unfortunately, it has been observed that the industry continues to turn to the same exploration methods with resultant decreased success evident.

A lot of recent research has focused on the development of cheaper, faster drilling and the ability to analyse the target commodity (and others) at a site in real time. Clearly these must be seen as positive. However, do they actually add value?

In the mid-to-late 1980s, the oil industry was faced with a similar decrease in discovery, but the cost of individual test holes was/is orders of magnitude larger than is faced in the mineral industry.

While there may have been incremental improvements in drilling, the area on which the oil industry focused was improving the location of test wells. This was done through the development of a better understanding of the target area and, ensuring that a systematic approach was used to make exploration decisions. Over time, this has improved the odds dramatically, cited anecdotally at somewhere between 25% and 50% success rates. It is, therefore, this type of approach that appears necessary for the mineral industry to adopt and for which tools/techniques are available.

**Remote sensing**

As the ability to expand the area of influence of each data set is of high importance, developments in remote sensing, using a wider definition than used typically, are key. Typically, the term ‘remote sensing’ is referred to in respect of geophysical techniques. Increased instrument sensitivity and power in, for example, electromagnetic (EM) methods, now allow for sulfide-related narrow high-grade vein zones to be mapped effectively to provide a direct drill target, under the right circumstances. The ability to invert and model EM data, with appropriate 3D modelling, in association with existing regolith drilling data, not only provides huge insight into the effectiveness of historic drilling but can also allow cover layers to be modelled sufficiently that the supergene mineralisation environment can be imaged in 3D across disparate layers.

For regional ground selection, magnetotellurics can assist with determining which crustal blocks around the world have been exposed to fundamental geological processes that predict fertility. Perhaps, however, one of the most specific and important tools is the continuing development of litho-geochemistry and alteration mapping.

Through use of high quality multi-element data, litho-geochemistry allows the objective classification of primary lithology – directly providing additional insight, not only into the geology of an area but often allows the resolution of more complex structural problems. Alteration mapping, through use of the same geochemistry data, and other techniques such as short-wave infrared (PIMA, ASD, QEMSCAN etc.), provides a direct, objective measurement of the hydrothermal system. This can be used to guide the geologist remotely from the periphery of the system to the centre, particularly when used in conjunction with other tools. As a derivative of this type of tool, satellite systems such as Worldview-3 can collect similar data over large areas. Unfortunately, the uptake of these tools is often poor or used in isolation.

**Matching ‘Mine Finders’ to the task**

To be effective, however, these tools must be applied in an appropriate, coherent way. Given that discovery is the overarching theme of this article, it is useful to consider what makes a ‘Mine Finder’ geologist, the type of
geologist that some refer to as having the ability to ‘smell’ a deposit, making multiple career discoveries. Research completed some time ago by a behavioural psychologist working with Placer Dome, found a number of key characteristics associated with this type of individual.

Firstly, it was found that it was necessary that these geologists were either within organisations where management had provided an environment in which they can get on with their process with minimal interference, or work by themselves or within smaller organisations that had limited bureaucratic process.

Secondly, it was discovered that these persons were strong communicators and networkers with a high degree of curiosity. Ultimately, they use their networks to build new insight from existing knowledge. In other words, they tend to avoid reinventing the wheel in a region, but ensure that they have the data that will perhaps provide an epiphany with respect to the controls on mineralisation in the chosen district.

This epiphany is likely to come, thirdly, through their ability to interrogate and integrate the various available disparate data to provide understanding, not relying on just one or two. Mine Finders are typically very capable inductive reasoners, which is characterised by the ability to form a testable hypothesis. This is important as, at the early stage of exploration, limited available data is unlikely to provide a clear answer. Instead, the hypothesis provides the basis for specific and clear testing from which systematic knowledge gain occurs, with decision points apparent.

Lastly, and perhaps most importantly, while it often appears to the outsider that Mine Finders are ad hoc in their approach, they do, in fact, have a highly developed and very systematic internal approach to their decision-making.

However, while it seems a very good idea to encourage these types of behaviour, it also appears that skilled practitioners are hard to find. It is possible to create an environment in which the general behaviours are encouraged, and those who do have this gift or talent can be identified quickly and moved into an environment in which it will be used effectively.

At this point, it is worth making another comment about the industry. In a very large majority of cases, the early stage exploration is entrusted to the least experienced geologists in the team to whom the objective of the work programme is often not explained or they are not provided with the tools and experience with which to make high quality decisions.

So, how is the desired outcome achieved? Assuming the appropriate environment is provided with sufficient resources; encouraging the appropriate systematic approach and curiosity is then necessary. An integrated geoscience or mineral systems approach provides this.

Simplistically, this refers to the use and integration of all available data, within the context of the mineral system of interest. By now, the industry generally has, variably, a reasonable to strong understanding of the mineral systems that create deposits.

**Mineral systems approach**

However, the mineral systems approach requires that the criteria be considered in the context of the processes by which the systems are developed. In order to make a discovery, it is therefore necessary to be in the right geological environment that has had the right tectonic history (geodynamic setting and architecture). This being correct, there must be evidence of a hydrothermal system and of course, this hydrothermal system must be fertile. In other words, the fluids (or transporting mechanism) must have the right ingredients in order to have transported the metals that we are chasing. Finally, something must happen to cause the fluids to drop out metals in a way to create an economically viable concentration. The processes involved leave evidence, or signatures (the criteria that define an ore deposit model), that with modern exploration technology, can often be measured directly or by proxy (using some of the techniques mentioned previously, for example).

It is, however, important to make the point that every deposit is different. This is fundamentally where the practice of a mineral systems approach comes in. The
The vast majority of exploration is carried out on the basis of the ‘ore deposit’ models. To a large degree, these are empirical, but more importantly, they largely assume that most deposits of the type are very similar. This is a dangerous concept. For example, a recent work by Brauhart et al (2017), set out to quantify the pathfinder signature of different deposit types/models. We usually say that a deposit type has a signature of, for example: Au, As, Sb, Te and W, but only as present or absent. The relative abundance of these elements is rarely considered. In Dr. Brauhart’s work in the OSNACA project, the intent was to see if there was a systematic variation of these pathfinder elements between deposit types. That work showed that mineral systems are a continuum.

Assessment of targets
Once all of this is considered, the development of a target assessment tool is probably the most obvious way of implementing a mineral systems approach, providing a number of advantages and forcing appropriate behaviours. This is best achieved in a team environment, coached by a Mine Finder, ultimately providing ownership and therefore buy-in. These are often called ranking schemes. However, this concept can be quite dangerous if done poorly.

The assessment tool must therefore be question-based, as opposed to list-based. In other words, when considering the target, ask the question ‘what evidence is there of a hydrothermal system?’ as opposed to ‘is there alteration?’ This not only forces a considered response, but also decreases the probability (as happens in many ranking schemes) that the presence of a single criterion, measured by multiple features/data, falsely impacts the assessment. The opposite is also true, considering the fact that a single dataset in isolation is likely to incorrectly impact the assessment.

Conclusion
At present, some in the industry suggest the cost of exploration appears expensive. This may be true for ineffective exploration; however, it is actually too cheap to force high quality assessment of targets before they are drilled. This can be seen in the review of data associated with any number of exploration areas and in all commodity spaces.

Using more effective exploration techniques will not only apply those funds better, but it will also continue to enhance success and result in more appreciation for the value of investing in the science of mineral exploration.

References