The evolution of minerals exploration over 60 years and the imperative to explore undercover

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The primary mission of the minerals industry is to profitably identify and develop a steady supply of minerals at reasonable cost to support the economies of the world. All projections on consumption show across-the-board increases, driven largely by the huge demand for metals to feed the growing Chinese economy. For copper alone, forecasts are that more of this metal will have to be produced in the next 25 years than has been used since industrialization began roughly 200 years ago.

For the exploration industry, this requirement is a significant issue because over the last 60 years many of the readily identifiable mineral deposits (the low-hanging fruit) have been found and finding the next tier of deposits will require resources and ideas which many believe are currently inadequate to meet the challenge. This is of concern not only within the exploration industry but also for many governments around the world, especially those of Australia and Canada where much of the global exploration industry is based. Historically, there has been a large amount of mineral production in both these countries that has been of critical importance to sustaining their economies at significantly higher levels than would otherwise be possible, given that both nations have remote areas that would remain unpopulated were it not for mining.

Discussions within the exploration industry are ongoing regarding how to meet the challenge and, while opinion is not unanimous, a strong voice has emerged that the required new major discoveries will be made only if there is a reinvigoration of exploration in "greenfields" areas. Historically, the greenfields terrains were considered to be those unexplored areas in either remote locations or places unavailable to explore due to political or other reasons. Now as much more of the world has opened up to minerals exploration and development, greenfields exploration has come to include those areas previously too deep to explore (or accessible for the economic extraction of ores) with the technology of the day. For the exploration industry, this recasting of what is considered greenfields terrains is commonly equated with the need to understand and become proficient at exploration undercover. This change in emphasis has also been termed expanding the search space for new deposits. In this article, the technical and commercial issues facing the industry and its response are examined and some of the current and planned initiatives to address these issues are reviewed. Given the long lead times for much of what is discussed, a historical context for the events leading up to the present is provided so as to put the present era into a meaningful context.

Exploration undercover

In the past 60 years, the majority of deposits have been found within several hundred meters of the surface, with most of these in the upper 50 m from surface. The frontier that now needs to be explored will be more in the order of 0.5–1.5 km and this is the challenge of exploration undercover. The style of exploration will have to change from largely outcrop-based exploration (colloquially termed "boots and hammer" for the geological approach and "bump finding" for geophysics) to a style more aligned with how oil and gas is explored for. In that industry, there is a much greater reliance on subsurface imaging using primarily the seismic technique to model the subsurface geology. Favorable settings for deposits (if not direct detection of potential targets themselves) are defined and then drill testing of the zones of interest is undertaken. A variety of measurements are taken during the drilling process so as to optimize the definition of geology and targets at depths where measurements from the surface are inherently of limited resolution. In minerals exploration, there is no technical equivalent to the efficacy that seismic has in sedimentary environments and so a variety of potential field and electrical techniques are employed to provide a data cloud that is then modeled and cross-compared so as to better define anomalous features of interest. Drill hole measurements, either in real time during drilling or after completion, are still in their infancy in minerals, but major efforts are underway to adapt oil and gas technology to the minerals environment. Implicit in a move to exploration undercover is that the targets will need to be of a size that can be detected from distances typically greater than required in shallow exploration and have a value that permits their exploitation at a profit.

Figure 1. *Cost of discovery for gold since 1950 (McCuaig et al., 2009).*

Trends over three decades

The last 30 years have seen major changes in exploration technology, exploration practice, and the commercial framework within which exploration is conducted. These

changes, while important in terms of the present story, will be touched on here in a summary fashion only and relevant references provided so as to allow the interested reader to examine each issue in more detail. First, however, the decline in discovery rates and overall industry performance will be examined because this provides the primary economic raison d'être that drives the need to push undercover.

Changes in discovery outcomes: Two critical facets of the changes that have occurred in discovery performance are summarized in Figures 1 and 2. Figure 1 shows how the fiscal return on exploration has declined markedly over time. In this example for gold exploration, compared to 50 years ago, the value obtained for each dollar spent on exploration has decreased an order of magnitude from an average of US $105 to $11. A concurrent change not captured in the figure is that the quality of the deposits found has also declined so the overall economics of finding and mining gold is becoming less attractive. This can be tied in with the increasing maturity of the traditional search space where most gold exploration has been conducted. Figure 2 shows the depth of cover for the major copper discoveries over the last century. The large majority of the finds are drawn from a shallow search space. Over time efforts have been made to push exploration deeper, and with some success, but the majority of deep deposits would be located in well-understood terrains (brownfields), as a direct result of explorers' ingrained reluctance to undertake greenfields exploration where there is significant cover. The conclusions then are that exploration and mining have been largely exploiting the shallow, well-understood areas and the discovery rates and rates of return have fallen off markedly in the last several decades; in short, the traditional search spaces for mineral deposits have become exhausted.

Exploration technology: Exploration technology has made enormous advances in the past 30 years. From geophysics, to geochemistry, remote sensing, signal processing and data management, the exploration industry now has far more precise and diagnostic tools with which to explore. Current summaries of primarily geophysical technology are tracked in the annual publication *Exploration Trends*, cosponsored by the Northern Miner and the Canadian Exploration Geophysical Society (KEGS). Postpublication copies of *Trends* can be found on the KEGS Web site (*www.kegsonline.org*). On a 10-year basis, the Canadian geophysical community hosts a major review of exploration technology. The last such review was in 2007 and the proceedings of this meeting (with links or download access to all previous meetings) can be found at *www.dmec.ca*.

Industry, government and academic groups in Canada and Australia are also trying to deal with some of the emerging issues for exploration in the next 30 years, especially those relating to exploration undercover. Examples of such efforts are the Canadian Mining Innovation Council (CMIC) (*http://www.cmic-ccim.org/en/*) and the Deep Exploration Technologies Cooperative Research Centre (DET-CRC) *(https://detcrc.centric.com.au/)* in Australia; both provide information about their programs on their Web sites.

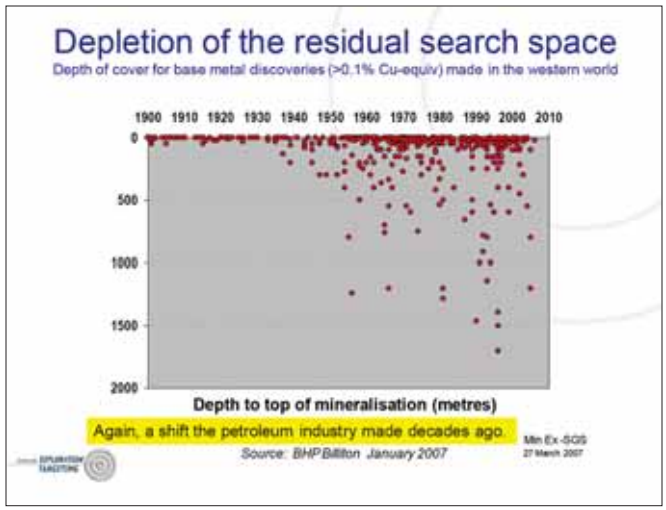

Figure 2. *Depth of copper discoveries over the past century (McCuaig et al., 2009).*

The CMIC effort is broader in its overall scope and includes mining as well as well as exploration issues whereas DET-CRC is aimed more specifically at technologies that assist exploration undercover.

Exploration best practice: Various industry and some professional organizations are taking a concerted look at exploration best practice and, while no one group speaks for all concerned, two groups stand out. The Society of Economic Geologists (SEcG) has instituted in the last several years a Views section to its quarterly newsletter that is designed to give members the opportunity to express opinions as to what is taking place in exploration and what can be done to guide current and future explorers to adapt to a changing world. The Views articles are available to nonmembers at *http://www.segweb.org/newsviews/*. On the academic side, the Centre for Exploration Targeting based in Perth, Australia (*www.cet.uwa.edu.au/*) is developing both technology and human resources to help the exploration industry improve its overall performance.

Commercial framework for exploration: In the past 30 years, there have been major changes in both how minerals exploration is funded as well as the levels of funding spent on exploration; this is captured in Figure 3 for the gold exploration business. Over this period, while the absolute amount of exploration funding has grown (albeit in an extremely cyclic fashion), the more significant change is that a larger percentage of exploration expenditure has started to come from junior explorers and the relative amount spent by actual producing companies (termed majors here) has in turn decreased (the Minerals Economics Group tracks these changes at *www.metalseconomics.com*).

Junior explorers are typically publically traded companies that are nonproducers and rely on speculative investors to fund their programs. While making a mineral discovery is the normally stated objective of a junior, investors can still extract considerable value from the junior's shares simply through opportune trading. Majors on the other hand, have ongoing production and can be expected to use a portion

of their income to re-invest in exploration so as to replenish their inventory of mined-out ores.

At one time the perception was that juniors would take on higher-risk exploration in the unexplored but prospective greenfields areas. However, the reality is that most investors in juniors are not interested in backing long-term exploration in unproven, high-risk areas. As a result, most juniors are "forced" to explore in brownfields areas where shorter-term (and more modest) outcomes are likely to be found.

Over the same period, many majors began to modify their roles from fully integrated mining houses that were expected to find the deposits they would mine to companies that specialized in the development and mining of the ores themselves. The expectation was that juniors could accomplish the task of discovery using their shareholders funds and then the majors could acquire the new untapped ores deposits at fair market value. For the majors, this was seen as the more efficient use of capital, relieving them from being directly involved in what many saw as a long-term, high-risk activity. Brownfield or mine-site assessment was seen as being of acceptable risk for the majors as the resulting discoveries, while often incremental in nature, allowed for continued and efficient use of the company's existing investment.

Over time, these changes meant that a growing amount of exploration funding was speculative discretionary spending by investors and not tied to needs of resource renewal. Consequently, the levels of exploration funding became increasingly tied to the external vagaries of the global economy and a higher degree of fluctuation in spending has become the norm (as is well illustrated in Figure 3).

The present

An unplanned consequence of these two changes, first who explores and second the extremes in funding, together have resulted in a chronic instability of geoscientist employment levels and, with this, a marked decline in the industry's ability to attract and retain young professionals. The human resources issue can be considered to be comprised of two components; in the short term, the industry is not seen in a positive light and has for some time been finding it difficult to get the younger generation to consider mining as a career choice. A complicating longer-term factor is that the mining business currently is largely sustained by the baby-boomer generation who entered into the field when virtually all aspects of mining were considered to be a high-prestige/high-reward career. Now with the inevitable exiting of the boomers from the profession, serious human resource sustainability issues are developing in all aspects of the business.

Rather than expecting this situation to change in any significant way, there is a growing realization that work practice in exploration will likely have to change and there will be more of a need for broader skilled explorers, with less reliance on rigid professional disciplines such as geology or geophysics. With the large majority of geophysicists now working for service companies, there are simply not enough geophysicists left to interpret the surveys being undertaken

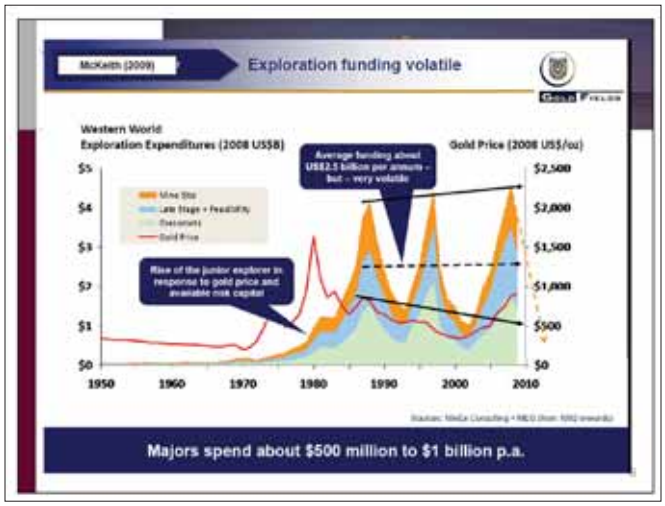

Figure 3. *Patterns in exploration funding over the last 60 years (Hronsky 2009).*

by various organizations. As the focus in exploration shifts more to exploration undercover, this situation will be greatly exacerbated. The answer in part appears that geologists will have to become more adept in working with geophysical data as a proxy for the traditional geological information they have been accustomed to.

Current initiatives

There are a number of initiatives attempting to get the exploration community engaged in the looming complexities of having to conduct more exploration undercover. One of the ever-present challenges is getting most explorers to pause in their increasingly frenetic work schedules to think lucidly about the issues they and their profession are facing. As with any imposition on people's time, the intruding story needs to be seen as relevant, convenient to the individual, and hopefully engaging. A number of some recent efforts are discussed below.

Keystone Exploration Undercover workshop: The SExG Mining Committee sponsored a workshop conducted as part of the SEcG Keystone 2010 meeting held in October 2010. The workshop, titled Exploration in 2020; the Tools and Techniques to Explore Undercover, was designed to give attendees hands-on experience using modern GIS and 3D visualization technology to explore for hidden porphyry copper-gold deposits in central British Colombia, Canada. The two-day workshop brought together geology students from the Colorado School of Mines who provided operational support of the computing resources, lecturers from Canada and Australia, and over 35 SEcG Keystone Conference delegates (Figure 4). Seven teams of delegates conducted a simulated exploration exercise using modern geophysical, geochemical, and geological data acquired by Geoscience BC over the last several years to stimulate exploration in this remote part of the province of British Colombia. A second workshop based around the same theme was carried out in Vancouver, Canada in October 2011.

PDAC 2011: At the Prospectors and Developers Annu-

Figure 4. *Team at SEcG Keystone 2010 workshop assessing Quest geoscience data.*

al Conference in Toronto in March 2011, a special session (Looking Under Cover) focused on issues related to exploration undercover. The proceedings from this session can be found at: *http://www.pdac.ca/pdac/conv/2011/presentations-tech-sessions.aspx#March_9*. At the same convention, the DMEC group organized a half-day workshop that focused on successful integration of the geosciences and challenges faced when exploration goes undercover. The proceedings from this workshop can be accessed at the Web site provided earlier in this article. Both these sessions were well attended, showing that there is an encouraging degree of interest on the part of the exploration community.

Going forward

The challenges faced by the global minerals industry to be successful at exploration undercover are significant. The current business model was developed over the last 60 years and while it has undergone major changes in the past 20 years, many of these changes have been only to create short-term opportunity for speculative investors and have, in many respects, actually weakened the industry's longer-term capability to meet future resources needs.

The inventory of resources available to address the issue is lopsided. On the technology front, the array of acquisition, processing, and visualization tools is impressive and the industry as a whole has shown a long-term ability to deliver cost-effective solutions to problems either through innovation or invention. Work practice in the oil and gas industry, arguably the experts at exploration undercover, needs to be examined closely and where appropriate, applied directly or adapted to mineral exploration problems.

On the funding side, the speculative juniors have an important role to play but their aversion to long term risk has to be understood and if possible, used in a creative fashion. Juniors are good at self-promotion and this in turn creates a buzz both for the industry itself and importantly for the communities in which they operate. Fundamental change will not occur however, until there is a more rigorous linkage between discovery and reward.

Majors need to return to long-term greenfields exploration but will do so only in a serious fashion if they can be convinced the risks can be predictably managed. Whether the majors choose to conduct primary exploration themselves or task this to strategic partners is an interesting issue and likely creates significant opportunities for groups who can respond and deliver accordingly.

To ensure an adequate supply of technically skilled and highly motivated individuals to actually carry out exploration, the same innovation that has been so well applied to developing technological solutions for the industry, needs to be turned to the human resources front. Based on various assessments of the actual capacity to generate new geoscience students, it would appear that the industry's needs will exceed the universities' capacity to deliver. However, these estimates are also based around the assumption that we need to populate the industry with people skilled in the traditional exploration work practice models. If there is a greater emphasis on exploration undercover, then the curriculum and to some extent aptitude of the students undertaking the programs will be different.

Drawing from how the industry has transformed in the past generation, it is expected that into the foreseeable future the majority of the geophysicists will continue to stay engaged in the primary acquisition and processing of exploration data, typically working for large airborne or ground contracting firms. This means there will be a serious short fall in interpretive geophysicists to perform the actual assessments of geophysical surveys. The expectation is that this short-fall will have to be filled by a new generation of geologists who not only are conversant with classical skills of economic geology such as mineral identification, outcrop mapping, and deposit definition but can also integrate these skills using geophysical images as a proxy to the successful boot-and-hammer approach of the past generation of geologists. TLE

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