Paper 3

Geochemistry – State of the Art 2017

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ABSTRACT

The past decade has seen declining discovery rates despite periods of record exploration expenditure. Geochemistry, along with other search technologies, has not been able to arrest this trend. As exploration moves increasingly into areas of post-mineral cover, many conventional geochemical techniques have a diminishing role to play. There has been a dramatic decline in the number of large-scale regional geochemical surveys which have in the past delivered so many discoveries. The decline in collection of large scale geochemical surveys has been matched by increased availability of large volumes of legacy geochemical data, readily available at little or no cost and presenting new opportunities for organizations with the skills and motivation to compile it. More than two decades of research and industry trials have failed to unravel the complexities of geochemical dispersion through post-mineral cover and the partial digest technologies that showed so much promise are barely in use today. New geochemical techniques and technologies are urgently needed to support exploration in areas of post-mineral cover and for deeply uneroded orebodies. Ultra-low detection limits, portable / real time analytical and spectral equipment and a rapidly developing capability in mineral chemistry for fertility assessment and vectoring present outstanding opportunities both now and into the future for geochemistry to continue to support successful mineral exploration. However, the ageing demographic of practicing industry geochemists remains a critical non-technical risk which must be addressed.

INTRODUCTION

The past decade saw a dramatic ramp up in global mineral exploration expenditure in the first half followed by an equally dramatic decline in expenditure in the latter half accompanied by one of the harshest downturns in the mining sector in living memory. Over this time discovery rates have not matched the record levels of expenditure (Figure 1) and those discoveries being made are increasingly in areas of post-mineral cover and at increasing depth (Schodde, 2017).

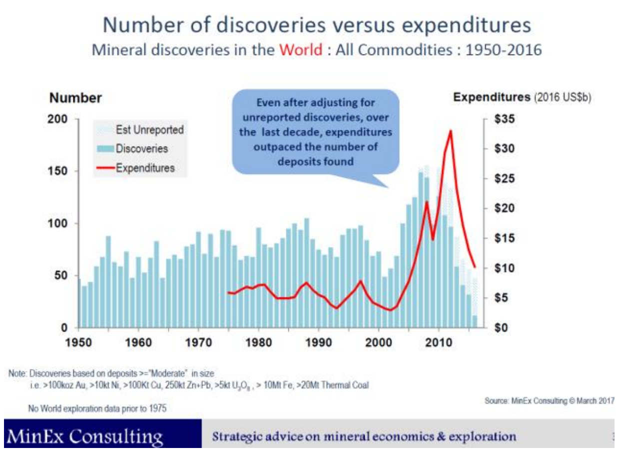

Figure 1: Discovery rate versus exploration expenditure – 1950–2015 (Schodde, 2017).

Never before has it been so important to have effective geochemical exploration tools but the challenge is significant. As exploration focus shifts towards deeper targets and moves into areas of post-mineral cover, the role of geochemistry in exploration programs is changing. New geochemical techniques and technologies are urgently needed or the role of geochemistry in making new discoveries will continue to decline. In the past decade there have been dramatic changes in the art of exploration geochemistry, some promising technologies have not delivered as expected and other developments show great potential to deliver the next generation of discoveries.

This paper critically reviews the use of geochemistry in the past decade and the technologies which support geochemical exploration. It has not been an outstanding decade on many levels and geochemists, researchers and service providers are going to need to embrace a whole new assortment of emerging technologies if geochemistry is to maintain its critical role in the discovery of new resources.

TRENDS IN GEOCHEMISTRY 2008-2017

Regional Geochemistry

Perhaps the most significant trend in the operational use of geochemistry in the past decade is the "near extinction" of large scale regional geochemical surveys. It has been relatively rare to see government organizations and exploration companies conduct large-scale regional geochemical surveys. Fueled by inexpensive multi-element analysis in the late 60s and 70s, organizations all over the world collected large numbers of stream sediment and/or panned concentrate, till and soil samples on prospect and regional scale. Whilst the trend continued into the 80s and 90s with a number of low density continental-scale geochemical mapping programs, the total volume of new geochemical data acquisition began to diminish as the key mineral belts of the world had been sampled and "open range"

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access to ground for low impact regional sampling became increasingly difficult in many jurisdictions.

Geochemical exploration is undoubtedly most effective when searching for outcropping or near-surface mineralization in residual terrains and the large regional surveys of the past have led to the discovery of many deposits. Unfortunately, we can expect discoveries made this way to become increasingly rare given the dramatic decrease in the relative volume of regional geochemical data being collected globally.

However, the giant Kamoa sediment hosted Cu deposit in the Democratic Republic of the Congo (DRC) was discovered by Ivanhoe Minerals using systematic application of conventional regional stream-sediment and soil geochemical surveys supported by airborne magnetic-radiometric surveys and ultimately drilling (Broughton et al., 2010). This outstanding discovery demonstrates the effectiveness of regional geochemical surveys in residual terrains. Underexplored terrains in high sovereign risk jurisdictions are increasingly the setting for modern day large-scale regional geochemical surveys. The rewards are there but the non-geological risks are significant and are an effective deterrent to many explorers.

Legacy Public Domain Geochemistry

The decline in collection of large scale regional geochemical surveys has fortunately been matched by ever increasing availability of low cost or no cost digital data from legacy government-facilitated regional surveys and increasingly from compilation of open-file geochemical data from statutory company reports in jurisdictions where such reporting is mandatory and geological survey organizations have the resources and will to capture the vast quantities of geochemical data in their archives. In 2014, the Western Australia Department of Mines and Petroleum released a database with in excess of 5.4 million surface geochemical data points and 25 million drill sample analyses, captured from decades of statutory company reporting.

Never before has such a huge volume of global legacy geochemical data been so readily accessible via the internet. Rio Tinto Exploration has been compiling publically available geochemical data globally since the start of the decade and to date has collected in excess of 16 million geochemical records globally at very low cost (Figure 2). Of course, issues around preservation of analytical and sampling metadata and the huge variety of formats and data structures remain a challenge for compilation into a single, uniform data structure. But for those organizations with the persistence, skills and resources to clean and categorize such data, the rewards are only just beginning to be realized.

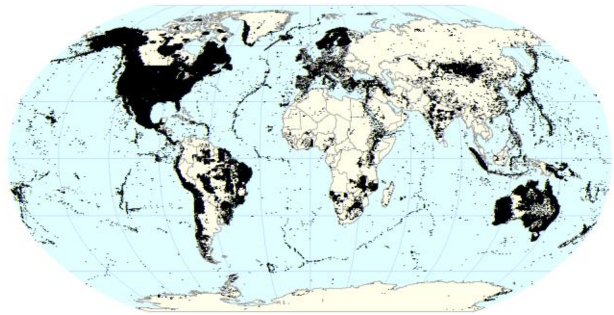

Figure 2: Global public domain geochemical data compiled by Rio Tinto Exploration Pty. Ltd.

Visibility of pre-existing geochemical coverage provides explorers with two important strategic advantages; firstly, the capacity to review the accumulated geochemical data on any scale for the detection of regional trends and anomalous responses that may not have been apparent or relevant in the past. Opportunities for advanced interpretation methodologies (Grunsky and de Caritat, 2017, this volume) are numerous. There is also rapidly growing interest in data analytics and machine learning for geoscientific applications and very large regional geochemical data sets are one of many layers of information that, when combined, may deliver insights and opportunities not accessible via conventional data interpretation approaches. Unfortunately, variance associated with different analytical techniques, sample media and size fractions can overwhelm the patterns that might deliver real geological insight. Extracting value from large volumes of legacy geochemical data can be complex, but not always. The 2012 Sirius Resources NL, Nova Ni-sulphide discovery in the Albany-Fraser Orogen of Western Australia, was initiated by follow up of a single anomalous regional geochemical sample collected by the Geological Survey of Western Australia (Bennett et al 2014).

Secondly, visibility of pre-existing geochemical coverage provides explorers an opportunity to understand where “gaps” exist in both physical geochemical sampling coverage and equally importantly, gaps in data quality which could have led to an anomalous response being undetectable in the past. The capacity to complete this type of analysis of exploration opportunities and gaps without requiring ground access is increasingly important with the time, cost and complexity of gaining physical access to ground increasing year on year in most jurisdictions.

Analytical Detection Limits

Many of the most important developments in geochemical exploration capability in the past have been driven by constantly improving analytical technology. The past decade is no exception, with the detection limits of multi-element packages offered by commercial providers reaching new ultra-low levels well below crustal abundances for important distal pathfinder elements such as Mo, W, Se, Te, Bi, Sb, As, Li, and Tl. Without such low detection limits, these low crustal abundance elements have been of very limited use in the past. Sader et al., 2017 and Buskard et al., 2017 (both in this volume) discuss the impact of new generation inductively coupled plasma mass spectrometry (ICP-MS) technology.

The geochemical detection of mineral systems that remain deep and uneroded at the current surface as well as distal primary dispersion halos on the edge of post-mineral cover are critical exploration capabilities today and into the future as the number of outcropping discoveries inexorably declines. These distal pre-mineral host rocks on the edge of cover and hanging walls which conceal the next generation of discoveries frequently contain subtle geochemical signals just above crustal abundance levels, (Halley et al., 2015). But without analytical detection limits well below crustal abundance levels, it has not been possible in the past to define background populations and detect these subtle geochemical responses. Detection of very subtle, primary and secondary distal geochemical responses is an important new capability. However, vectoring towards a distal and likely covered source remains a challenge for the next decade which must be solved if we are to extract discoveries from the remarkable analytical capability geochemists have access to.

The Portable Geochemistry Decade

Recent technological advances in on-site and portable instrumentation to support real-time or near-real-time data acquisition and decision making in exploration are reviewed in this volume (Lemière et al., 2017, this volume). The start of this decade saw the seventh generation of pioneering NITON™ portable X-ray fluorescence spectrometer (XRF) analyzers enter the market as well as new models from competitor manufacturers. Whilst the early applications of portable XRF analysis were largely directed towards alloy analysis, by 2008, applications for mining and mineral exploration were a significant part of the growing market. Data management, GPS integration and machine interfaces in some models were clearly aimed at capturing the mineral exploration market.

Field portable analytical capability has been a long held aspiration of geochemists stemming back to the early 60s when CRA Exploration Pty. Ltd. had a small mobile laboratory on the CRASTAR boat which served as a base for helicopter supported reconnaissance stream sediment sampling in the Papua New Guinea (PNG) islands. The stream sediment samples collected during the day were analyzed overnight using basic AAS equipment, providing the geologists the opportunity to follow-up any anomalous samples the next day. Today we have the ability to analyze rocks, soils and sediments in real time with growing element suites and greatly improved detection limits. The applications in mineral exploration were obvious but the limitations of this remarkable portable equipment took some time to become clear. In 2011, the first results of two Canadian Mining Industry Research Organization (CAMIRO) industry collaborative studies into the use and reliability of portable XRF technology clearly demonstrated the limitations and risks of over-reliance on portable XRF analyses, (Hall et al., 2011). Sample representivity was and remains a fundamental limitation, particularly when dealing with coarse grained / inhomogeneous rocks. This is further compounded by the roughness of the surface presented to the equipment and the moisture content. The need for careful and regular calibration of instruments and compelling evidence for different results from different manufacturers and indeed, different instruments from the same manufacture, was a sobering reality check for all those geochemists who believed real-time geochemical analysis had finally arrived.

Field-portable XRF does have a role to play in assisting geologists and geochemists make real-time decisions in the field. And for those who make the effort to dry and somehow homogenize samples prior to analysis, data quality can be adequate if the device is regularly calibrated and well maintained. But for those “point-and-shoot” practitioners, perhaps the best application is simply confirming the likely species of enigmatic minerals in hand specimen or making real-time lithochemical comparisons and anomaly assessment, recognizing that accuracy will require representative sampling and commercial sample preparation and analysis.

Spectral Mineralogy and Core Scanning

Without question, one of the most significant advances in geochemistry in the past decade has been the integration of spectral mineralogy with geochemistry and the use of both data sets to model and predict alteration mineralogy. Semi-portable spectral devices such as the TerraSpec™, have recently become genuinely field portable with the TerraSpec Halo™ offering real-time mineral identification from a hand-held portable device. Some commercial analytical laboratories are now offering to collect spectral mineralogy on the crush reject of every geochemical sample, offering geochemists seamless integration of mineralogy with geochemistry. aiSIRIS™ processing of the spectra offers a dramatic improvement in the quality and quantity of information routinely extracted from spectral readings. Mineral identification is more robust than conventional spectral processing methods, the spectrally active component is semi-quantified and a wide array of scalar calculations that offer important compositional and crystallinity information from a range of alteration minerals are provided.

The latter part of the decade has also seen the rapid emergence of drill core scanning systems. Hyperspectral systems such as Corescan™ and TerraCore™ offer a step-change in resolution and spatial detail compared to the pioneering Hylogger™ technology. These systems not only identify spectrally active minerals (and thermally active minerals in the case of TerraCore), they also map their distribution in the core offering remarkable insights into alteration styles, controls and cross-cutting relationships. The Minalyse™ core scanning system offers XRF geochemical analysis on cm scale and Lab-At-Rig™, developed by the Deep Exploration Technology CRC incorporates XRF geochemistry, spectral mineralogy and XRD mineralogy into a self-contained mobile system located at the drill rig. These technologies deliver vast quantities of data in time-frames that are dramatically shorter than in the past. They herald a new era of real-time geochemistry and mineralogy which will demand new data analytics approaches to interpretation and rapid 3D model update if we are to capture full value. Automated boundary detection and complex multi-dimensional characterization of domains in drill holes is set to transform the consistency and accuracy of core logging and geological modelling and ultimately to deliver robust material type characterization to support geometallurgical modeling and mine optimization.

Many of the key advances in spectral mineralogy and core scanning have occurred in the latter half of the decade and their impact on discovery is yet to be seen. However, there is little doubt that mineralogy is the fundamental control on bulk geochemistry, and the better we understand the mineralogy of samples sent for geochemical analysis, the more robust and insightful our interpretation of geochemistry will be. Consultant Scott Halley has pioneered new approaches to geochemical and mineralogical data interpretation and demonstrated important applications in both exploration and orebody characterization / geometallurgy (Halley, 2016). As exploration moves into areas of post-mineral cover, we are going to need to learn to characterize alteration patterns from relatively sparse drill holes penetrating the cover and vector towards mineralization centres. This is a significant challenge, but the integration of mineralogy with ultra-low detection geochemistry is an important capability to support discovery in areas of post-mineral cover.

Geochemical Dispersion Through Post-Mineral Cover

The 90s saw the emergence of a range of partial digest and soil gas techniques such as MMI, Enzyme Leach, SGH, etc. which reportedly detected geochemical dispersion through post-mineral cover. A flood of positive orientation surveys and pioneering research from Eion Cameron (Cameron, 2001) generated a rush of geochemical sampling in areas of post-mineral cover in the late 90s that lasted more than a decade. There was widespread belief and indeed scientific evidence that geochemical dispersion through post-mineral cover did occur and should be detectable with the appropriate surface sample, digestion and analysis. Industry uptake was significant, and a spike in discoveries should have followed as the deposits concealed by shallow cover in obvious "along trend" settings were lit up with effective "deep penetrating geochemistry". Sadly, it never happened. Almost two decades later, Winterburn et al. (2017, this volume) are still calling for process models for anomaly generation in post-mineral cover and the industry enthusiasm for deep penetrating geochemistry has all but evaporated. With hindsight and more detailed scientific investigation in Australia (Anand et al., 2009), it appears geochemical dispersion through post-mineral cover is highly complex, very variable, difficult to preserve and even more difficult to reliably detect and recognize. Whilst this still remains something of a holy grail for geochemists, perhaps it's time to focus on other approaches.

Professional Geochemists

The first-ever comprehensive review of geoscience capability in Australian research and government institutions, recently completed as part of an AMIRA road mapping project, has identified potential for a future deficit in Australian geoscience research capacity because a significant number of the older cohort of experienced geoscientists will be retiring in the 10–20 year timeframe (Rowe, pers. comm., 2017). Whilst the review included all geoscience disciplines, geochemists were very much a part of this trend. The review did not include industry geochemists but anecdotal evidence suggests the situation is no different if not worse. The aging demographic of industry geochemists is clear to many industry practitioners. Simply put, there are more experienced geochemists retiring than there are young geochemists graduating and joining industry.

The reasons for this concerning trend are many-facetted and beyond the scope of this paper, but a lack of training opportunities, both at undergraduate level and in industry must be key contributing factors. In order to attract young geoscientists into the discipline of exploration geochemistry, they need to be aware of the critical, specialized role of geochemistry in all stages of the exploration and evaluation process and suitable training opportunities need to be provided. For those practicing industry geochemists, mentoring is a low cost, high impact activity which can motivate existing young geoscientists to seek the necessary experience and training to become part of the next generation of industry geochemists. The contribution geochemistry makes to discovery in the next decade and beyond will to a large extend depend on the skills-base available to industry. We cannot afford to ignore this issue.

THE NEXT DECADE

Declining discovery rates have been an unfortunate but inescapable trend in the latter half of the decade past. It follows that despite some of the technological advances that have become operationally available in the past 10 years, geochemistry, along with other search technologies, has not been able to address globally declining discovery rates. The challenge is clear. We need new geochemical technologies that are effective for detection of deep uneroded mineral systems and mineralization concealed beneath post-mineral cover. The opportunities to use more traditional geochemical methods for the detection of outcropping mineralization are still there, particularly for those explorers with tolerance for the greater sovereign risk that generally coincides with the remaining under-explored terrains on earth. However the majority of exploration remains focused in mature terrains and geochemists are going to need to deploy new technologies and new strategies to support geophysical search technologies, or risk being completely superseded by them.

Mineral Chemistry

The past decade has seen one of the most remarkable advances in mineral exploration for many decades. Researchers at CODES, University of Tasmania, led by Dr. David Cooke and Dr. Bruce Gemmel have for more than 10 years been developing mineral chemistry techniques for assessing the fertility of porphyry Cu systems and vectoring towards the system centre from distal propylitic ("Greenrocks") and lithocap environments. This research makes use of laser ablation ICP-MS microprobe (LAM) technology to collect large volumes of trace element mineral chemistry from minerals such as epidote and chlorite in the large propylitic alteration zone around porphyry Cu deposits and minerals such as alunite, quartz and pyrite in lithocaps which are host to high sulphidation Au-Cu mineralization and are frequently associated with deeper porphyry Cu systems. The science is complex and application in operational exploration programs is equally complex but the potential utility has been well demonstrated at a large number of study sites, only made possible through sustained industry collaborative support for a series of AMIRA Projects, (Cooke et al. 2014, Wilkinson et al. 2015; Cooke et al. 2017, this volume).

Bulk chemical analysis of rocks and sediments has been the fundamental tool of geochemists for decades. But the research at CODES is demonstrating that mineral chemistry signals detectable in specific minerals in a rock offer robust insights into the potential fertility and likely distance to the system that are simply not detectable when the entire rock is analyzed. The chemical composition of individual alteration minerals in a rock represents a somewhat less complex geochemical system than the combined chemistry of all the minerals in the rock. This is intuitively a reasonable hypothesis, but only in this decade have we had the analytical equipment to cost-effectively collect sufficient mineral trace element chemistry to begin to understand the power of this approach.

When drilling through post-mineral cover it is a simple but unfortunate fact that we are more likely to intersect the periphery of a mineral system than make a direct hit. The larger the target is, the better the chances of hitting part of it. This is why detection and mapping of alteration is so important; it enlarges the size of the target. Ultra-low detection limits and spectral mineralogy are important to detect subtle distal responses, they enlarge the target. But "Greenrocks" technology has demonstrated potential to give early indications of fertility as well as robust vectors towards mineralization from remarkably sparse data; 10's of samples rather than the 100's or 1,000's commonly collected for conventional geochemical surveys.

Operational use of mineral chemistry for fertility and vectoring in porphyry and lithocap environments is still relatively limited across the industry because the analytical technology and expertise is not widely available in commercial laboratories. However, Rio Tinto Exploration Pty. Ltd. (RTX) has developed in-house micro-analytical capability to support the operational use of Greenrocks and the ongoing development of interpretation and data visualization capability. The technology is widely used across RTX's global porphyry Cu projects and is delivering exciting results.

The role of mineral chemistry in mineral exploration is still emerging but applications are likely to extend beyond porphyry and lithocap environments. Supported by high volume, low cost analytical capability from the new generation of electron microscopes such as the Mineral Liberation Analyzer™ and QEMSCAN™, research is demonstrating that looking at geochemical samples grain-by-grain, mineral by mineral is a potentially powerful exploration tool for a variety of styles of mineralization (Layton-Matthews et. al., 2014). This is the ultimate "unravelling" of the bulk geochemical response, and the applications are only just beginning to be understood. Instead of searching for subtle geochemical signals which can be modified or undetectable against background, we now have the capacity to search for specific mineral grains which we know are intimately related to the target mineralization. With LAM and rapid low cost EDS major element quantification, we also have the capability to use specific mineral compositions as pathfinders in transported materials.

CONCLUSION

The past decade has seen several new technologies emerge which show great promise and may play an important role in turning around global discovery rates. There needs to be a fundamental shift in the geochemical techniques and strategies deployed in the next decade. Industry needs to maximize value from the vast quantities of existing geochemistry that has been collected in the past 50 years. Routine use of ultra-low detection limits and spectral mineralogy on geochemical samples will be essential to detect subtle distal alteration and dispersion. High resolution spectral mineralogy and XRF geochemistry on drill core will transform our understanding of alteration mineralogy and geochemistry and enhance our capacity to robustly vector to mineralization from increasingly distal settings. And micro-analytical technology will facilitate the development of fertility indicators and vectoring tools that can be applied on sparse sample arrays, on the edge of cover and beneath post-mineral cover. The future of geochemical exploration is bright, but only for those willing to embrace change.

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