FACTS, FIGURES AND FUMES: GEOCHEMISTRY AND THE SEARCH FOR CONCEALED MINERAL DEPOSITS.

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Introduction

Exploration Geochemistry is currently facing its greatest challenge; a challenge that sits high on the shoulders of success. For more than 80 years, exploration geochemistry has been applied with clearly documented success to the discovery, delineation and evaluation of numerous exploration targets taking them from prospects through feasibility studies to operating mines. However, as was noted in the mid 1970s, discovery of new outcropping ore-bodies or ore bodies with sufficient surface evidence such as alteration or peripheral mineralisation, are becoming increasingly rare (Govett 1977). Whilst changing economics, land access and new metallogenic belts will continue to result in new surface discoveries; there are large areas of the world such as the Atacama Desert of northern Chile, significant parts of Australia, southern and central Africa and China and large swaths of the formally glaciated northern hemisphere, where younger formations overlie potential economic mineralisation in known mineral belts. These formations vary from contemporary volcanic ash and lava through Cenozoic glacial sediments and colluvium to consolidated Palaeozoic formations.

The search for robust cost effective methodologies to aid in the discovery of buried mineralisation has on the whole been remarkably unsuccessful. Despite the research dollars spent, the steady stream of orientation exercise “successes” and the plethora of commercialised “silver-bullet” techniques (both open-method and black-box), geochemistry as a tool to identify buried mineralisation has overall failed to excite the exploration community and is more often than not regarded with a great deal of cynicism and scepticism. Unfortunately, it is often not a difficult task to identify critical failures within the many reported datasets (Noble *et al.,* 2013), often as a result of financial constraint on the research activities. Rarely are statistical techniques such as those detailed in Stanley and Noble (2008) applied to test the robustness of anomalies. Indeed perhaps one of the greatest failures is the lack of critical assessment of proclaimed results and success stories prior to subsequent support and application.

The exploration geochemistry community carries forward a heavy burden. If the application of exploration geochemistry to buried targets is to be successful a paradigm shift is required.

Concealed Deposits

A concealed deposit is defined as economic mineralisation with no significant expression or indication on the earth's surface that would allow the conventional application of surface geochemical or geological tools to lead to discovery. Geophysics is purposefully omitted here, as in some instances it may be a key tool that leads to discovery.

Orientation and Research Surveys – Coincidental Geochemistry

A significant amount of industry and academic research using surface sampling over concealed mineralisation comprises detecting geochemical responses above a known mineralised body. From the data collected, sometimes using multiple analytical methods and media, a range of components with responses coincidental with the mineralisation are identified which are deemed to have identified mineralisation. Whilst in some instances there is a clear link; in others the link is more tenuous. In few cases, with perhaps the notable example of vegetation sampling (Anand et al. 2007; Dunn 2007), and the CAMIRO work in northern Chile (Cameron 2013), is an attempt made to evaluate the signal at the surface in relation to the surface environment, potential migration pathways, and chemistry at the overburden – bedrock mineralisation interface. In few cases are attempts made to identify the environmental conditions and setting under which such a signal may be expected to be present and conversely where the signal should not be expected. Success stories are commonly reported, unlike failed projects (and the lessons learned).

Selective Extractions, Partial Digestions and the Organic World

Exploration geochemists employ a wide range of analytical techniques ranging from the well documented through to the black-box. As noted by Smee (2003), the level of understanding of methodologies even within the commercial laboratory environment is often poor. Methods are often applied without qualification of whether the critical components on which the digest/extraction is based are present in the sample media, and without quantification of those same components. Background variability of these key components may well be sufficient to mask the presence of any genuine anomaly. Detailed microscale work reviewing the interaction between the extractive agents and the sample is likewise relatively limited (but see Chipley et al. (2003)).

The role of organics in the exploration for non-petroleum based mineral deposits is an area ripe for research. There is now sufficient evidence to support the likely presence of a hydrocarbon signal associated with mineralisation. Whether this signal is generated in the ore during oxidation (Luca *et al*. 2008), at the ore-cover interface, in the cover, or at or near the surface is unclear. Given the current appreciation of the abundance of microbes in the environment and their sensitivity to environmental change, their involvement is probably inevitable. This remains a field completely open to fundamental research through the use of gas chromatography ICP-MS and genomics.

Regolith Mapping

Landscape Geochemistry was a concept initially developed by the Russians in the early 1960s (Fortescue 1980) which during the 1990s was well entrenched in exploration geochemistry, culminating in the application of detailed regolith maps in Australia for both the design and interpretation of exploration geochemical data. Outside of Australia, West Africa and central southern America, detailed regolith studies have seen little application. In general, few attempts have been made to map and understand areas of depositional regolith. In Chile, for example, the depositional environment in the Atacama Desert can range from Miocene age land surfaces encrusted with a variety of salts, to stripped or re-deposited surfaces resulting from the most recent surface water flow. Thus the geochemistry and mineralogy of potential sample media can change considerably over a short distance and time interval. These factors must be taken into account when designing surveys, selecting a media, collecting samples, and in the analysis and interpretation of the data in order to separate out responses above the background. In the northern hemisphere, the same approach must be applied to glacial terrains. Whilst depositional by nature, these terrains are being actively eroded and re-deposited, hence the same principles apply.

Scale

Exploration scale has generally been an underappreciated factor in the research and development of geochemical techniques for the detection of concealed mineralisation. There appears to be an almost tacit assumption that an alternative technique will lead us to a concealed target and geochemistry will subsequently be used to assess that target. Given that regional geochemical surveys have been a primary targeting tool at a regional scale for much of the history in the application of exploration geochemistry, it is perhaps a poor assumption to make. Unfortunately the sampling scales often recommended for orientation surveys are quite unrealistic in a commercial environment and impossible at a regional scale. Whilst target assessment is still a key role, the potential to apply geochemical tools for discovery of mineralisation at a broader scale must not be overlooked. The tools must be robust enough that, as with regional scale un-concealed exploration, a single point would elicit follow-up. Many styles of mineralisation have alteration haloes extending for several kilometres away from mineralisation. Little if any research has been undertaken to determine if alteration at depth would produce a response at the surface (Winterburn 2014).

Time

The time interval over which anomalies form requires further investigation. In some instances, for example the gravels of the Atacama Desert, surface anomalies may have been accumulating over more than 30Ma, whereas seismic pumping could produce anomalies within a scale of minutes (Cameron 2013). In other parts of the world, the time frame for anomaly formation is more restrictive, for example, the constraint of the age of the last glacial retreat at 9000 years in Canada. The timing of anomaly formation is influenced by several factors, including the physical process responsible for anomaly formation, whether the overburden is sufficiently old enough to have accumulated a response, and whether a response will be preserved.

Conclusions

The successful application of exploration geochemistry as a tool to aid in the discovery of mineral deposits concealed under younger cover is still in its infancy, despite the investment made in research through academia, industry and collaborative partnerships. There is a need for a paradigm shift in the research community from seeking coincidental relationships and hoping the same coincidences are applicable elsewhere, to understanding the relationships between, and processes acting on, the sources and generation pathways of surface anomalies. Only once the processes of anomaly formation and their preservation in different surface environments is understood, will we be in a position to design appropriate sampling and analytical programs to minimise background variability and maximise the signal to noise ratio. This is highly unlikely to result in a "one-size-fits-all" approach, but will involve increased complexity and cost of the exploration process. However, if this results in an increased discovery rate, any costs will be worthwhile.

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