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Building effective mineral system models; the importance of merging geophysical observation with geological inference

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SUMMARY

The minerals system approach is based on concepts that have been largely germinating for the past 20 years but are now becoming a major component of efforts to rejuvenate minerals exploration into the next decade. Geophysical mapping will take on a far more critical role in this effort as it offers very often the most cost effective means to explore the subsurface, especially when the overlying rocks are unrelated to the targets at depth.

This review will examine what might be called the 'state-of-play' in how geophysics is currently being used to start to build an understanding of what mineral systems look like in the real world. While much remains to be done, there is encouragement in what has been achieved to date, although most of it typically without the benefit that the overarching concept of developing a mineral system model.

Key words: mineral system, undercover, geophysical mapping.

INTRODUCTION

The mineral exploration industry is undergoing a 'reboot' after 10 years of rapidly increasing expenditures that peaked in 2012 at $29.5B US (Doggett, 2013; Schodde, 2013). Since then (to late 2014) all indicators show that the past levels of expenditure by junior companies are no longer being supported by the investor community or major mining companies, their two primary sources of funding over the last 10 years. The past decade also marked large increases in profits for producing companies, primarily as a result of the enormous growth of the Asian economies, particularly China. In the past several years however, an oversupply of many commodities has resulted in downward pressure on many commodity prices. In addition, development costs skyrocketed for a number of large projects, resulting in further losses, thereby accelerating the withdrawal of the majors from the junior sector for the foreseeable future. Whereas the exploration industry (comprised of both majors and juniors) enjoyed a veritable Golden Decade that began soon after the start of the new millennium, it has now come to an abrupt close with relatively few new major discoveries available to shepherd into production. A number of major gold companies have shut down their project development groups in the past year, a strong indication that they are not in the fiscal position to undertake major expenditures to either sustain or expand production. This outcome has disappointed many stakeholders and investors, given the huge expenditure on exploration during the previous 10 years (over $80B US; Doggett, 2013) and has resulted in an across the board loss of confidence in the mining business.

It is unclear when the mining industry will 'bloom' again and with it, the exploration industry 'rehydrate' and become functional again. When this does happen, however, industry observers have suggested that more attention on greenfields exploration will have to happen since this is considered the best strategy for defining new, high value deposits (Hronsky, 2009; Sillitoe, 2010). The major caveat is that much of what can currently be considered greenfields terrain lies below a surface that appears non-prospective due to either the nature of and/or thickness of the cover material. Such covered areas present a major impediment to current state-of-the-art exploration targeting methods.

To address this challenge, there are a growing number of explorationists who are proposing a fundamentally different approach. Rather than relying on traditional regional mapping to define areas for follow-up geochemistry and geophysics with the hope of developing attractive targets, the exploration community must learn to think about the mineral system as a whole. The major advantages of this approach are two-fold: first, the mineral system presents a relatively larger exploration target, and secondly, with a more complete knowledge of the entire mineral system, it should be possible to vector more effectively towards the economically significant parts of the system.

Geophysics will have a major role in mapping mineral systems. However, the state of understanding of how mineral systems respond to the available geophysical techniques is still in its infancy. Some of the past development, the current state-of-play and futures directions are reviewed here

WHAT IS A MINERAL SYSTEM?

Wyborn et al. (1994) is considered to be the first publication to formally define the concept of a minerals system. Various other authors since then have built on the concept and there has been a marked growth in interest in the past several years with the Australian Uncover Initiative (McCuaig and Hronsky, 2014).

The underlying concept of a mineral system is that while a very small percentage of the Earth hosts an actual deposit, there is a much larger volume that has been affected by the formation of the deposit. Importantly, the mineral system involves fluids which follow a 'footpath'. The fluids originate at some source (often a source of heat) and travel along the 'footpath'. At some location physical and/or chemical changes lead to metals leaving the fluids and the deposit is formed; however, the now spent fluids continue along the footpath. Although the actual deposit is the most anomalous part of the Earth in terms of physical and chemical changes (along with any possible associated geophysical expression), the overall 'footpath' has been altered as well and while the degree of alteration is far less than that associated with the deposit area, it provides a far larger volume of rock to target. When the potential deposit is located undercover, direct detection may be problematic and the footpath could be the best aspect of the system to initially try and detect. Fig. 1 shows a simplistic outline of a mineral system and the possible geophysical character that would be associated with different parts of the system.

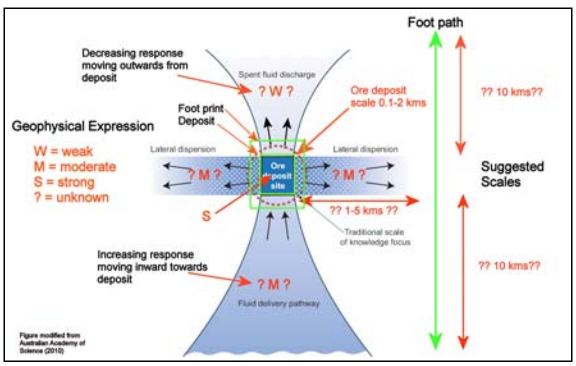

Figure 1: Outline of minerals system with geophysical "overprint"

EXAMPLES OF THE GEOPHYSICAL EXPRESSIONS OF MINERAL SYSTEMS

The main focus for the vast percentage of geophysical surveys has been and still is the direct detection of the ore system; the area inside the green box in Fig. 1.

A recent example of a significant extension to the porphyry copper deposit model is in Steinberger et al. (2013). In this study, the author's showed that the Bingham stock, while magnetic, was only a small extensive off a much larger laccolith shaped magnetic body centred about 4 km below the surface. A potential feeder dike was also part of this model but the authors indicated this was more speculative.

While the magnetic signature of porphyry copper deposits has been of interest for over 45 years (Gay and Mardirosian, 1970), few studies dealt with more than the presence or absence of a magnetic response of the primary porphyry deposit. In another situation (Fig. 3), the Pebble porphyry deposit lacks a distinctive magnetic signature but the deposit is part of a major belt with a number of porphyry systems located along a ~500 km strike length (Anderson et al., 2014). This trend has the appearance of a footpath. IP chargeability

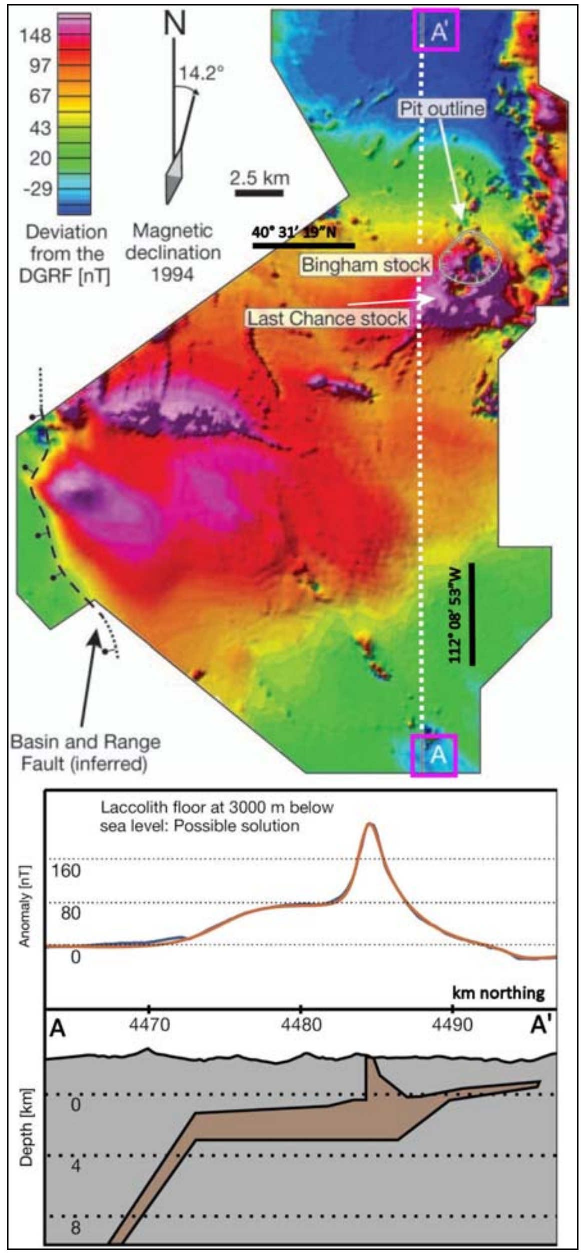

Figure 2: TMI over Bingham Canyon deposit (left) and modeled magnetic response (Steinberger et al., 2013)

coverage over Pebble (Fig. 4) shows that the Pebble deposit is part of a much larger NE-SW trending zone over 12 km in strike length (Paré and Legault, 2010). This is a far larger sulphide zone than is typically associated with a single deposit, even one as large as Pebble and could be interpreted as being part of a footprint signature.

In the Athabasca Basin (Canada), explorers have been searching for unconformity style uranium deposits since the 1970s. The traditional targeting model was to focus on interface between the overlying sandstone and basement conductors. However, it has been noted that deposits can also be associated with extensive changes in the density of both the overlying sandstone and into the basement

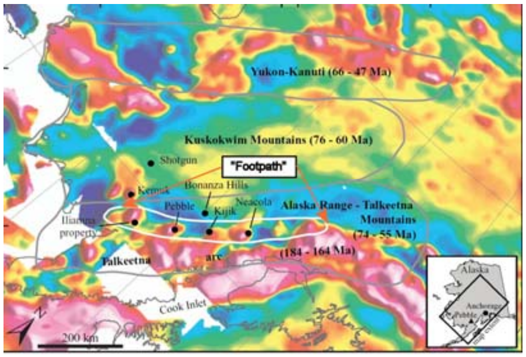

Figure 3: Aeromagnetic coverage over the Pebble deposit, Alaska (Anderson et al., 2014).

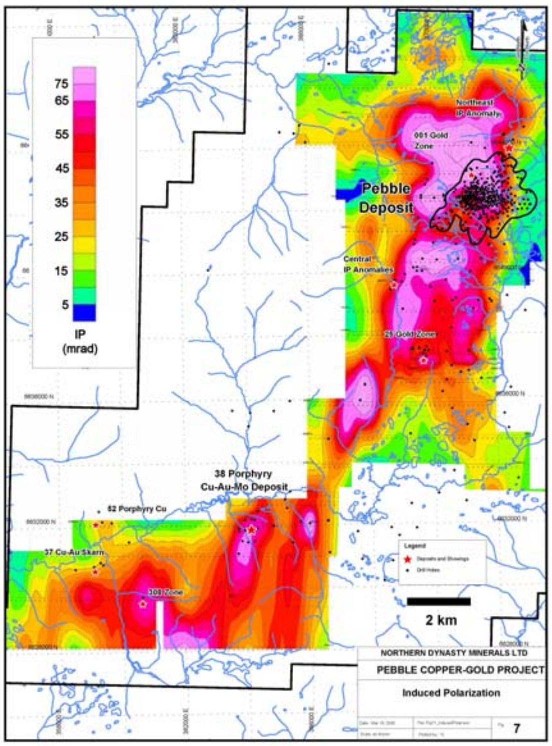

Figure 4: IP chargeability trend associated with the Pebble deposit (Paré and Legault, 2010).

In Fig. 5, a modeled line of Falcon airborne gravity gradiometer data is shown (Witherly and Diorio, 2012). In this section two zones of elevated density are modeled, which could represent an alteration footprint far larger than an actual deposit. However, without a traditional conductor also being present, it is hard for explorers to justify testing this model.

The Carlin-style gold deposit has been one of the hardest deposit styles to define a robust set of geophysical targeting criteria. Recent efforts to adapt oil industry seismics is showing promise (Townsend et al., 2010) and surveys are now recovering sufficient detail at shallow depths to be able to site drill holes (Fig. 6)

The Gawler Craton is the location of the world class IOCG deposit Olympic Dam. Since the discovery of Olympic Dam in the mid-1970s, many exploration programs have been carried out in efforts to find additional deposits.

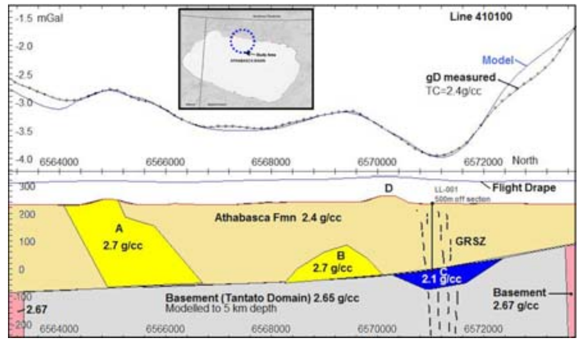

Figure 5: Mapping of alteration zones in Athabasca Basin, based on Falcon airborne gravity gradiometer data.

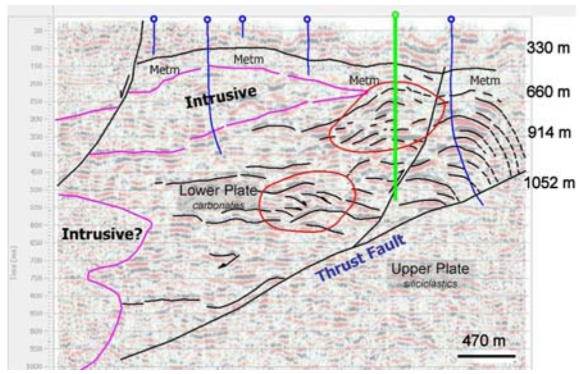

Figure 6: Seismic section from Nevada (Townsend et al., 2010).

The Prominent Hill and Carapeteena deposits are examples of other systems, largely found with geophysics, primarily magnetics and gravity plus drilling. There is however, no set signature which explorers have found and this is illustrated in Fig. 7, which shows the magnetic and gravity responses for 10 different IOCG systems. As part of efforts to better understand the effects the production of a large mineral deposit such as Olympic Dam has had on the crust below, MT and seismic surveys were carried out (Hronsky, 2011; Fig. 8).

The EM results show a large conductive 'root' extending below the Olympic Dam deposit. Much of this area also falls within a seismically opaque zone where the original rock texture has been largely obliterated by the effects of alteration. These two sets of responses extend to depths of the order of 40 km below the current surface.

CONCLUSIONS

The development of the mineral system approach is seen as a major tenet in a global effort to both revitalize the exploration industry and define a realistic but hopeful way forward for the next generation of explorers. Using geophysical techniques in the traditional fashion to try to directly detect targets at greater and greater depths, often likely under obscuring cover, is seen as problematic and more of a mapping approach whereby the signatures of altered rock which produced while the deposit was being formed is deemed a much more realistic task. However, it has been 20 years since the minerals system concept was proposed and it could well be another 20 years before meaningful results are obtained.

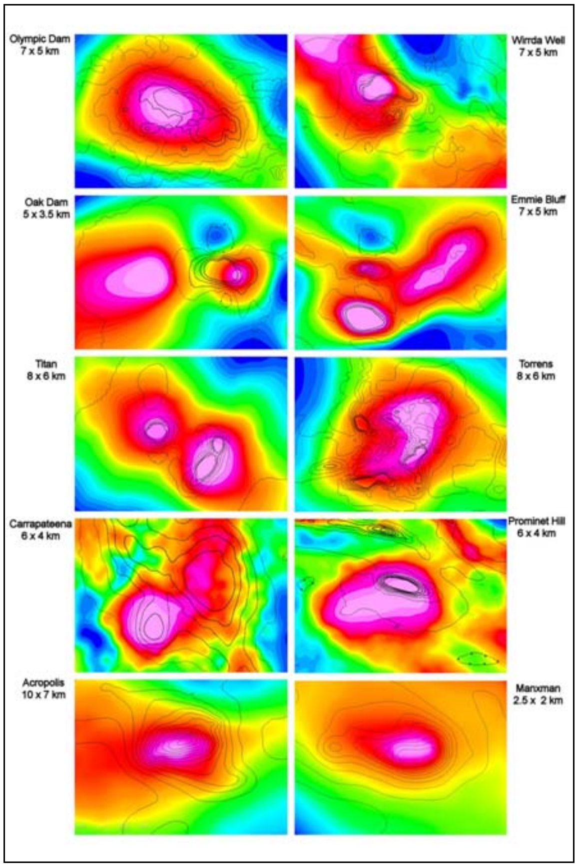

Figure 7: Magnetics (image) and gravity (contours) for 10 IOCG systems located in the Gawler Craton (Funk, 2013).

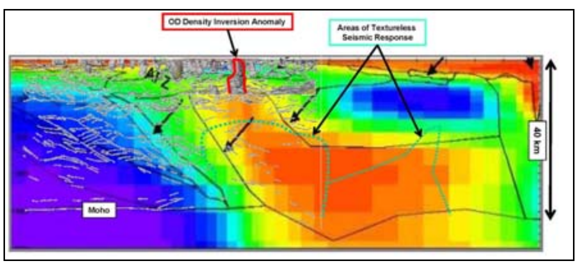

Figure 8: Magnetic modelling, MT and seismic for transect over the Olympic Dam deposit. (Hronsky 2011)

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