Mineral systems and data integration as part of the foundation for the future of mineral exploration

Sandra Occhipinti,
CSIRO
Perth, WA 6151
sandra.occhipinti@csiro.au

Vasek Metelka
CSIRO
Perth WA 6151
vaclav.metelka@csiro.au

Hassan Talebi
CSIRO
Perth, WA 6151
hassan.talebi@csiro.au

Dave Cole
CSIRO, Data61
Melbourne, VIC 3008
dave.cole@csiro.au

Alex Otto
CSIRO
Perth, WA 6151
alex.otto@csiro.au

SUMMARY

As exploration focuses on defining new resources under large Phanerozoic basins and thick unconsolidated cover generic exploration models, following a mineral systems approach will be vital to future exploration programs. Specific ore deposit models may not be that helpful in the early stages of exploration in these regions, as distinct geological signatures usually sought, like those in soil geochemistry, will be challenging to attain.

Sampling material at particular regolith interfaces or unconformities will be necessary to map geochemical dispersion. Understanding landscape evolution and paleoenvironments will be beneficial when determining the length scales of dispersion and their direction. Geophysical signatures mostly mapped and understood in 2D planar surfaces will have to be inverted in 3D, with an understanding of uncertainty to estimate aspects such as the extent of cover, regolith, sedimentary or volcanic interfaces, the 3D architecture of prospective basins as well as linking known geological 'piercing points' observed in a 1D drill hole (and data collected from it) into a vast 3D volume.

A mineral systems approach to exploration uses known critical elements that contribute to ore deposit formation through mapping their geological proxies. Geophysical data is abounding in Australia and can link what is understood from drill core together with mapped geology. However, its resolution or pixel size is not comparable to the detail of petrophysics measured in a drill log. This inhibits data-driven mineral systems analysis and the development of machine learning techniques for the analysis in covered regions.

Key words: mineral systems, under cover, basins, regolith, exploration

INTRODUCTION

Exploration beneath regolith cover and sedimentary basins requires focus around areas defined to contain critical elements that may have coalesced to form a mineral system. These primarily include the tectonic evolution of a region and the essential contribution of favourable geodynamics, which may have commenced millions of years before the formation of a deposit, in addition to the geology of the region, the source region of sedimentary or magmatic rocks, structural evolution, and subsequent hydrothermal events. In addition to these, the preservation levels of the crust in a particular area is important to delineate but may not be part of the mineral system. This paper illustrates a few examples where mineral systems analysis has been completed in regions where exploration is challenging due to the paucity of outcrops, depth of cover or type of regolith inhibiting the attainment of geochemical signatures of the bedrock. Three areas were studied using a mineral systems approach, from which prospectivity models were developed: (1) the east Kimberley, Halls Creek Orogen, (2) Capricorn Orogen, and the (3) Delamerian Orogen. Prospectivity modelling in these regions followed a knowledge-based approach. This approach is often used because of the perceived lack of training data, especially in areas beneath cover that could be used for machine learning methods. Another example of unsupervised spatial machine learning is shown which that aids in mapping geological units under cover, thus producing a data layer that can be used in prospectivity models.

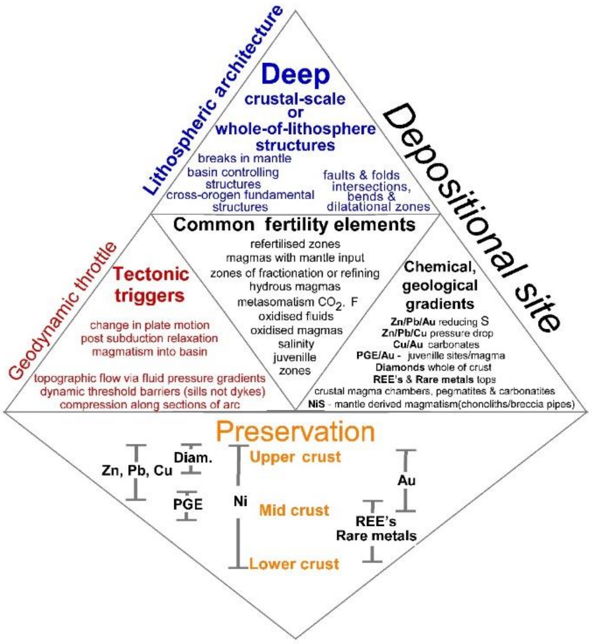

Figure 1. Summary of critical elements that contribute to the development of a mineral system and their mappable proxies (where understood, modified from Occhipinti et al., 2016).

METHOD AND RESULTS

Mineral systems analysis is simply a concept that aids in mineral exploration through a conceptual understanding of how mineral deposits form. Translation of this into simplistic extraction of 'critical element' layers that are considered either as indicators of mineral footprints or drivers of a mineral system can be completed using pre-competitive government datasets, satellite data, together with more detailed data collected by mineral exploration companies with variable properties of geochemistry, geophysics, or geology at different scales.

In studies over the last ten years, a number of different methods have been used to integrate these data using knowledge or data-driven approaches or a combination of these. Unfortunately, no method has been developed that offers a smoking gun or solution to mineral exploration. Like many computational methods, all of these techniques involve data of variable resolutions that measure the different properties (e.g. geochemistry, physical properties) and essentially combine them through various numerical algorithms.

This contribution presents a few examples of mineral systems analysis driving the prospectivity modelling and mapping at the regional scale. Results for the analysis of different systems, e.g. Au-Cu, Ni, were found to vary depending on what data and interpretive products were included. For example, in the studies for the east Kimberley (Halls Creek Orogen), Kohanpour et al. (2020) introduced a fertility layer (relative input of mantle material in magmatic rocks in the region) based on conceptual interpolation of Nd values across magmatic units in the region. This resulted in prospectivity maps for Ni and Au differing from those produced by Occhipinti et al. (2016), illustrating results are highly subjective (Fig 2).

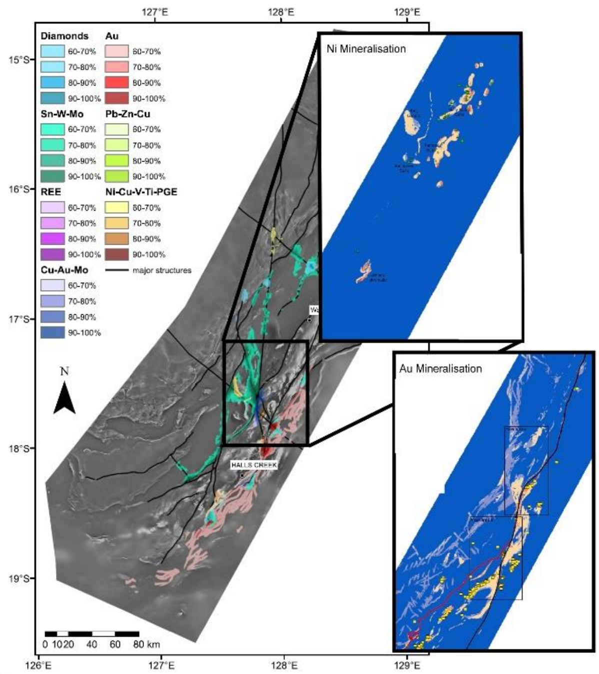

Figure 2. Prospectivity maps for the East Kimberley region from Occhipinti et al., 2017 and Kohanpour et al., 2020 (inset). A proxy for 'fertility' was added in Kohanpour's models resulting in different prospectivity map results for Au and Ni. For insets (Kohanpour et al., 2020) red to blue = relative high to low prospectivity, respectively for Ni and Au.

In the Capricorn Orogen, the basis for the mineral systems analysis for the Au and base metal components was similar to that used for the Halls Creek Orogen. However, for this region, older Archean structures and domains from the underlying Yilgarn Craton (in the south) could be used for the analysis. In addition, the geodynamic throttle component of the analysis, in the form of possible, advancing 'orogenic' fronts, were mapped for the Capricorn Orogeny in the north and south, and the Glenburgh Terrane (south, and from west to east), respectively.

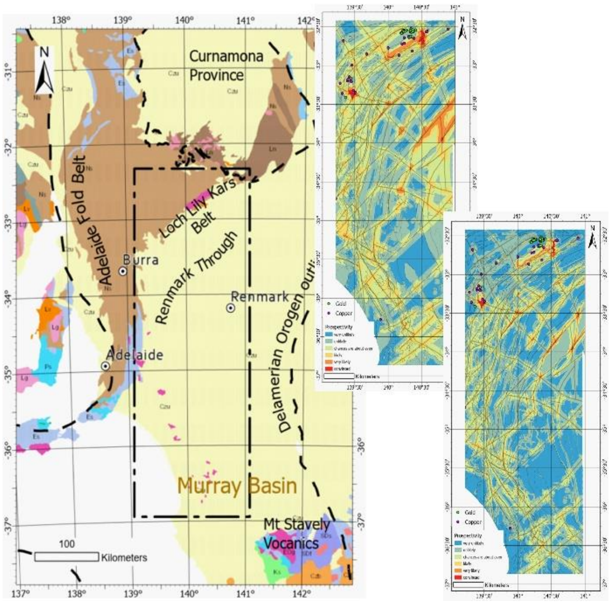

Figure 3. Delamerian Orogen in South Australia. Area outlined on the map is a focus area for the national drilling initiative (NDI) within the MinEx CRC. Mineral systems analysis for Cu-Au (porphyry) style deposits was completed for this region beneath the consolidated Murray Basin cover. Grey lines are 'deep crustal-scale structures' derived from Bouguer Anomaly map and lithological boundaries inferred from magnetic data. Top inset, a model where depositional site structural and geochemical gradients were combined with a fuzzy OR operator, bottom where they were combined with a fuzzy AND operator.

Areas beneath thick consolidated basins, such as the east Delamerian Orogen (Fig. 3), pose a significant challenge to mineral systems analysis. Critical components to mineral systems are underpinned by geological units, their properties and structural features. In areas beneath cover, the age of structural features is often difficult to ascertain. At the same time, the nature of geological units and their links to the tectonic setting may be unknown, rendering extracting factors of fertility, geodynamic throttle and trap difficult to interpret. Despite this, geological interpretations, even with significant uncertainty, can be used with key geophysical datasets for delineating structure or fertility (Metelka et al., 2021) and used for prospectivity analysis. For the Delamerian Orogen (under cover), the lack of outcrop may have influenced the geological interpretation whereby geological units in regions furthest from outcrop were considered less fertile or less favourable as depositional sites when compared to the known, exposed areas. This inherent uncertainty may have affected the resulting prospectivity maps (Metelka et al., 2021).

In order to aid geological interpretation in areas of thick cover, spatially aware machine learning (ML) can be used as a decision support tool for geologists, applied to potential fields data sets. However, many ML techniques require vast training datasets, which are generally not available in these areas. Novel spatial random forests (SRF) clustering can learn complex spatial patterns and delineate clusters of data that may coincide with geological units (Talebi et al., 2021a,b). The predicted geological boundaries beneath the cover (Figure 4b) via SRF are likely related to hidden geological contacts. These layers can be used for mineral systems analysis and subsequently in prospectivity models as a proxy for geology (Fig. 3). Additionally, transfer learning and application of computational neural networks or other techniques can be applied in these regions in order to delineate features similar to geology for later interpretation by a geologist.

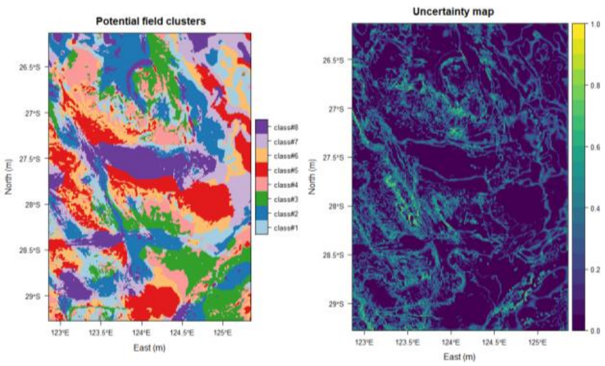

Figure 4. a) Spatial domains of potential field data defined via unsupervised SRF and b) quantified uncertainty map via SRF (from Talebi et al., 2021a) from the east Yilgarn Craton.

CONCLUSIONS

Mineral systems analysis alone may not provide immediate solutions to 2D or 3D mineral exploration targeting. However, the concepts and findings offer guidance to our understanding of what principle data components to integrate and mechanisms for integration to translate the knowledge of mineral systems into a prospectivity model and subsequent production of prospectivity maps.

The generated prospectivity models explore different ways of integrating data extracted from various datasets, such as known or interpreted geology, geochemistry, or geophysical data. These models should not be taken as fact but as displaying features that can be tested using sound geological knowledge, perhaps underpinned by the collection of subsequent data and refinement of the analysis. With the increasing need to explore beneath consolidated and unconsolidated cover decision support systems through data fusion, integration and machine learning applications can be used as tools to predict geological units and features. These, once tested, can be integrated into a mineral systems model (noting uncertainty) and subsequent prospectivity modelling and mapping providing additional tools to help focus exploration efforts.

ACKNOWLEDGMENTS

The authors acknowledge Project 9 members of the MinEx CRC, particularly geological survey staff, for their discussions and refinement of mineral systems analysis and prospectivity modelling in the National Drilling Initiative regions. Fariba Kohanpour and the CET-UWA Kimberley and Capricorn teams are acknowledged for their contribution to the understanding of mineral systems formed in the Kimberley region and Capricorn Orogen.

REFERENCES

Talebi, H., Cole, D., and Otto, A., 2021a, Unsupervised modelling of potential field data: Project 9: Interim report, MinEx CRC, 8p.

Talebi, H., Peeters, L.J.M., Otto, A., and Tolosana-Delgado, R., 2021b, A truly spatial Random Forests algorithm for Geoscience data analysis and modelling, Mathematical Geosciences, https://doi.org/10.1007/s11004-021-09946-w

Kohanpour, F., Occhipinti, S., Lindsay, M., Gorczyk, W., Jourdan, F., Poujol, M, 2020, Mineral systems prospectivity modelling for gold and nickel in the Halls Creek Orogen, Western Australia: Ore Deposit Reviews, 103809, doi.org/10.1016/j.oregeorev.2020.103809

Metelka, V., Occhipinti, S.A., Otto, A., Wise, T., Fabris, A., Hong, W., 2021, Project 9: Delamerian orogen mineral potential mapping Cu-Mo-Au mineral system, Interim Technical Report, MinEx CRC, 20p.

Occhipinti, S.A., Metelka, V., Lindsay, M., Hollis, J.A., Aitken, A.R.A., Tyler, I.M., Miller, J.M., McCuaig, C., 2016, Multicommodity mineral systems analysis highlighting mineral prospectivity in the Halls Creek Orogen, Ore Geology Reviews, 72, 86-113.