IOCG Prospectivity Modelling in Namibia and Zambia Using Australian Information

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Abstract: A prospectivity model for iron oxide-copper-gold (IOCG) mineralisation has been completed for Namibia and Zambia. The model is based on the mineral systems approach and uses the geographic information systems (GIS) based fuzzy logic modelling technique. Weights of evidence models of well documented IOCG areas in Australia were used to refine the model inputs and weights. This approach reduces the subjective element, one of the shortcomings of the fuzzy logic systems.

Keywords: IOCG-type deposits, fuzzy logic spatial modelling, Namibia, Zambia, mineral systems approach.

1 Introduction

Spatial modelling using GIS techniques for indentifying areas of mineral prospectivity have become increasingly popular because of their data driven approach and transparency (Bonham-Carter et al. 1989; Agterberg et al. 1993; Harris et al. 2001). A spatial data model to assess the prospectivity of Namibia and Zambia for iron oxide-copper gold (IOCG) mineralisation was undertaken to create exploration targets for mineral companies in these countries. The commonly used weights of evidence (WoE) technique was not appropriate for this area because of a lack of publicly documented mineralisation information to identify IOCG training sites for the model. Instead an alternative technique of fuzzy logic modelling was used. This modelling requires expert knowledge of the mineral system being modelled to define the various inputs and weights (Bonham-Carter 1994; Tangestani and Moore 2003). We have used WoE modelling techniques on similar mineral systems in Australia, which have large amounts of available data and information, such as the Mt Isa region. This study aimed to incorporate the knowledge gained from these Australian models along with knowledge about IOCG deposits (Hitzman 2000; Lobo-Guerrero 2004) to constrain the fuzzy logic based Namibia and Zambia model.

2 IOCG Mineralisation

IOCG deposits include many diverse ore systems and are found on all continents generally in post-Archean rocks from the Early Proterozoic to the Pliocene (Hitzman 2000). Most IOCG deposits are located in zones of extensional tectonics, along pre-existing rifts zones. There are thought to be three end member tectonic environments that host the majority of IOCG deposits (Hitzman 2000): 1, intra-continental orogenic collapse; 2, intra-continental anorogenic magmatism; and 3, extension along a subduction-related continental margin. Common in all of these environments are significant amounts of igneous activity, high heat flow, and source rocks that are relatively oxidised (Hitzman 2000). Mineralisation can occur over a wide depth range from around 10 km below to close to the surface (Williams et al. 2005) with most deposits related to anorogenic type intrusive rocks. IOCG deposits do not appear to have a direct spatial association with specific intrusions at the structural level of mineralisation (Hitzman 2000).

IOCG deposits have strong structural and/or stratigraphic controls with mineralisation often localised on fault bends and intersections, in breccia bodies, shear zones or at geological contacts (Williams et al. 2005). Host rock replacement is the main form of mineralisation in the vast majority of deposits. Because of the variability of ore fluids and the diversity of host rock types there are a wide variety of deposit styles and mineralogies (Hitzman 2000). In general terms, the mineralised deposits contain an iron oxide nucleus that has been replaced by pyrite and chalcopyrite. Copper is the main economic mineral although LREEs and gold are sometimes present in economic quantities, uranium content might be significant, and many other metals such as silver, cobalt, and manganese may occur in economic concentrations. Copper mineralisation may be associated with the flow of meteoric fluids and redox reactions at or close to the iron oxides. Large zones of intense host rock hydrothermal alteration are a common feature of almost all mineralised IOCG deposits (Williams et al. 2005). The various alteration mineralogies depend on depth of emplacement and host rock chemistry (Hitzman 2000).

The IOCG prospects and deposits of western Zambia and northern Namibia are found in rocks of the Lufilian Arc, a Mesoproterozoic to Neoproterozoic rift basin that closed during the Pan-African orogeny (Lobo-Guerrero 2004). In this particular setting the country rocks have not been subjected to high temperatures and strong metamorphic deformation. In general, they tend to be undeformed preserving original pristine hydrothermal textures. High temperature gradients due to emplacement of nearby plutons seem to be the only cause of the major alteration assemblages present (Lobo-Guerrero 2004). In the IOCG deposits of the Lufilian Arc there is abundant evidence for a close

temporal and spatial relationship between the iron-oxide bodies and granitic rocks. To model IOCG deposits in Namibia and Zambia successfully all of this information needs to be viewed within a mineral systems framework.

3 The Mineral Systems Approach

Ore deposit models are at the core of most target ranking schemes. The weakness of many models is that they tend to focus on the differences between deposit types rather than emphasise similarities that can be used as predictive variables when targeting. It has been recognised more recently that mineral deposits are the focal points of much larger systems of energy and mass flux that have processes mappable at the district to regional scale (Wyborn et al. 1994).

The essential geological components that define a mineral system are: A source of energy that drives the system; sources of fluids, metals and transporting ligands; pathways along which fluids can migrate; trap zones (i.e. narrow, effective pathways) along which fluid flow becomes focused, fluid composition is modified and metals are deposited; and outflow zones for discharge of residual fluids (Wyborn et al. 1994).

Ore deposit formation is precluded where a particular mineral system lacks one or more of these essential components. Applied to mineral exploration, the mineral systems approach requires identification of mappable features at various scales of the critical ore-forming processes that characterize a particular mineral system. These diagnostic features can then be used as guides in area selection and exploration targeting. This approach is particularly useful when identifying relevant input variables for mineral prospectivity modelling.

4 Prospectivity Modelling

The prospectivity model for IOCG mineralisation in Namibia and Zambia was created using data obtained from open file historical exploration reports, published geology maps at scales between 1:250,000 and 1:1,000,000, and multi-client, open file airborne geophysics. Namibia and Zambia have very few publicly documented IOCG deposits or prospects. Therefore, spatial data modelling techniques that require training data, like WoE and some neural network systems are not appropriate for developing prospectivity models for IOCG deposits in this area. However, the mineralisation models that describe the probable styles of mineralisation present are reasonably well understood and regional geological data coverage is sufficient for the use of fuzzy logic spatial data modelling techniques. Fuzzy logic is a popular and easily understood method for combining exploration datasets using subjective judgment (Bonham-Carter 1994). Each exploration dataset to be used is converted into a classified predictive map that is assigned fuzzy membership functions (values between 0 and 1). These weightings express the degree of importance of the various map layers as predictors of the deposit type under consideration. The predictive maps are then combined by a variety of fuzzy operators (e.g. fuzzy AND, fuzzy OR, or fuzzy SUM) according to a scheme that may be represented with an inference network. The output from the fuzzy logic model is a map showing mineral favourability, combining the effects of the input predictive maps.

In order to reduce the subjective element of fuzzy logic modelling two information sources were used to constrain the input predictive maps and weights for the model. These were a) the accepted mineral system model for IOCG mineralisation that has been modified for Lufilian Arc style iron oxide copper gold deposits, and b) weights of evidence (WoE) prospectivity models for IOCG mineralisation in the Eastern Fold Belt of the Mt Isa Inlier, Queensland, Australia, completed by Kenex and the Predictive Mineral Discovery Cooperative Research Centre (pmd*CRC).

The model combined predictive maps that represent all stages of the mineral system model as defined in section 3. Felsic and mafic intrusive rocks provide information on the fluid and metal source; E-W to NE-SW trending regional scale and pre-Silurian faults are a proxy for migration; host rock reactivity and competency are a proxy for trap zones; and geophysical and geochemical data are a proxy for metal deposition and outflow (Fig. 1). The predictive maps for the model were created using values obtained from Mt Isa WoE modelling and literature on IOCG systems in the Lufilian Arc as a guide. The predictive maps were weighted according to the importance of each variable in the mineralisation model and relative weightings for predictive maps were kept consistent with the Mt Isa modelling. The model was developed using Arc-SDM software through Spatial Analyst in ArcMap. The final predictive model (Figure 2) consists of a grid response theme containing the intersection of all of the input predictive maps in a single prospectivity map. The final map has been reclassified to display those areas most prospective for IOCG mineralisation and is a continuous probability scale from most prospective to least prospective.
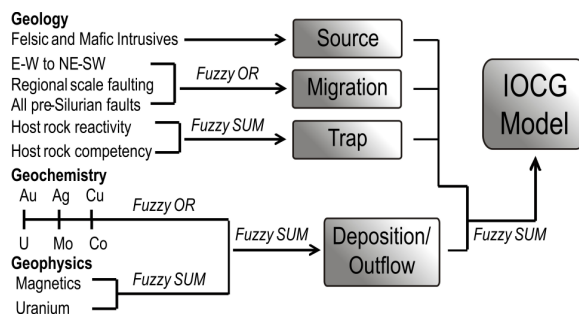
Figure 1. Fuzzy logic decision tree illustrates how the predictive maps were combined using fuzzy logic operators to create the intermediary mineral systems maps and the final IOCG model for Namibia and Zambia.
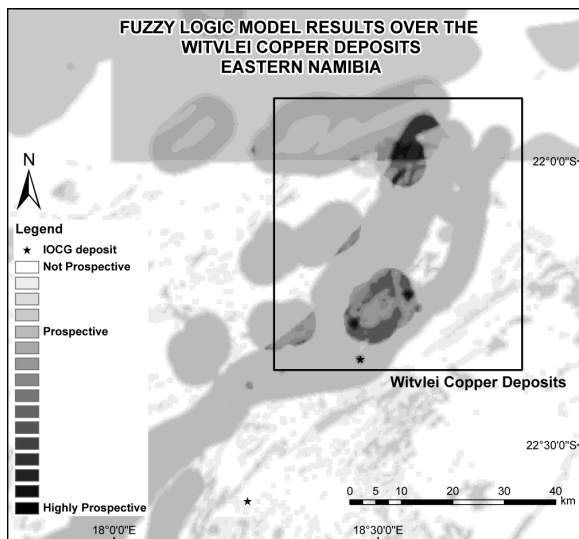
5 Results

Fuzzy logic modelling has reduced the search area for of IOCG mineralisation in Namibia and Zambia by at least 90 percent. Due to the large scale of the geological and geophysical data used in the model and

lack of available geochemistry the model should be treated as a prospecting tool and guide for finding areas for more detailed regional models. The highly prospective areas have the same geological features as IOCG deposits in the Mt Isa region and therefore have increased potential to host IOCG mineralisation. The model has identified the Witvlei Copper deposit in Eastern Namibia (Figure 2), and the Dunrobin Gold Mine in Zambia. Scale differences in geology files between Namibia and Zambia have resulted in broader zone definition in Zambia than Namibia.

The prospectivity modelling highlights the importance of geological and geochemical data sets as predictors of mineralisation, with reactive and brittle host rocks, geology, and NE-SW and E-W faults being particularly important. With every modelling project there is the potential for data errors and human bias (Bonham-Carter 1994). For this model we have used the best data available over Namibia and Zambia, although the model could be greatly improved with the addition of more detailed data if it becomes available. The inherent biases of a knowledge driven fuzzy logic approach have been reduced by basing the model on the less biased and data driven WoE modelling in Mt Isa.

The results of this model should be viewed with the above limitations in mind, although when combined with current tenement information and viewed in relation to specific strategic and exploration priorities will greatly enhance acquisition planning and exploration risk management in Namibia and Zambia.

Figure 2. Modelling results over the Witvlei Copper Deposit of Eastern Namibia.

6 Summary and Conclusions

Information from models of IOCG mineralisation in the Eastern Fold Belt of the Mt Isa Inlier in Queensland, Australia has been used to constrain the fuzzy logic inputs for this IOCG model in Namibia and Zambia. Without this additional information the model would have relied heavily on current generalised knowledge about IOCG mineral systems in Africa and would have produced a more subjective result. This method can potentially be used to assess the prospectivity of other areas where training data are limited and the mineralisation style of interest has been successfully modelled elsewhere using WoE techniques.

Acknowledgements

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