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Using geochemical proxies to model nuggety gold deposits: An example from Sunrise Dam, Western Australia

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ABSTRACT

Gold distribution in vein-hosted hydrothermal ore deposits is commonly nuggety (i.e. occurs as very localised concentrations of gold). In these cases samples for gold assay from diamond drill core may be too small to model the underlying heterogeneity of gold distribution and result in poorly constrained ore body models and underestimated gold resources. Hence, it is common practice to use more spatially continuous proxies for mineralisation to help define the boundaries of mineralised regions. We present a method for automating the use of geochemical proxies for nuggety gold ore bodies.

Sunrise Dam Gold Mine, in Western Australia, is a world-class gold deposit with a very high nugget effect. Multi-element geochemical data has been collected at this site in order to improve prediction of mineralised regions. Suitable proxy elements have been selected from this data set, in particular, those that are spatially related to gold mineralisation but do not display nuggety distribution, such as Sb, Rb and Cr.

We applied a probabilistic approach to the problem of quantifying the relationship between gold assay values and geochemical elements. It is shown that a kernel density estimator and Bayes conditional probability can provide an effective method for calculating the probability of a sample having elevated gold content and that this measure will be more spatially continuous than gold assay values if the appropriate geochemical proxies are selected. Using conditional probability and suitable cut-off values, we reclassified approximately 27% of samples as mineralised which returned low Au assay results. When plotted on drill holes conditional probability values provided a much more spatially continuous guide to mineralised regions than Au assay values alone.

1. Introduction

Gold deposits associated with vein-hosted hydrothermal mineralisation are commonly nuggety, meaning that the gold distribution is highly spatially discontinuous ("geological nugget effect" of Dominy et al., 2003). This makes it very difficult for geologists to establish boundaries of continuous sections of mineralised rock using drill core assays and to manually connect these boundaries from drill hole to drill hole in order to create a 3D model.

Geologists attempt to overcome this problem of separating continuous sections of mineralised and unmineralised rocks by incorporating geological information (e.g. Dominy and Johansen, 2004). The information is generally incorporated manually, on an ad hoc basis, which is not repeatable; meaning that different geologists would produce different spatial models for the ore body. The types of geological information geologists incorporate may include (1) presence and intensity of alteration styles known to be associated with mineralisation; (2) presence of a lithological unit known to be favourable for mineralisation; and/or (3) presence of structural features which may indicate a zone favourable for the transport and deposition of minerals (e.g. presence of fault, shear zone or veins). These favourable geological features are called proxies for mineralisation. The ideal proxy is one which not only is coincidental with gold mineralisation but also is more spatially continuous in nature, i.e. less nuggety. This means that the mineralised zones defined by proxy can be interpolated between drill holes with much greater confidence than the raw gold assay values.

If a single geochemical element is used as a proxy it is straightforward to model the distribution of the element. However, if it is desirable to include more than one element in the proxy (i.e. multivariate data), then we need a method which is able to combine the effect of all these elements into a single informative numerical value. For example, it may be useful to combine an element that indicates alteration with an element that indicates primary lithological variation.

In order to make the incorporation of multivariate geological information a more rigorous process we attempt to automate the use of proxies using probabilistic methods. Automation also has the advantage

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that large data sets can be processed rapidly. This method was attempted in Hill et al. (2013c) using logged geological information from diamond drill core. Whilst the method was successful in local regions, it was found that the logging of the core over a larger mineralised region was very inconsistent as it was logged by many different geologists (Hill et al., 2013a) and this was reflected as undesirable artefacts in parts of the resulting spatial models. In this paper we present a new method of automating proxies using geochemical data instead of logged data, because the geochemical data, if rigorously measured, should provide a more consistent and quantitative data set. The main difference between using geochemical data and logged data is that we are dealing with continuous numerical data rather than categorical data. The method given in Hill et al. (2013c) was specifically developed for categorical data; this paper presents alternative methods which are suitable for compositional data.

Sections 2 and 3 of this paper describe the geological setting and geochemical analysis of the samples used in this study. The test data set only sampled a small proportion of the ore body, so whilst we cannot use it to help construct a model of the whole ore body, it is of sufficient size to test that the method works. In Sections 4–6 we present, apply and discuss the method used to quantify the geochemical proxies as a probability value. In these sections we also compare some alternative popular classification methods for analysing the proxies and we demonstrate their inadequacy in this case.

2. Geological setting and mineralisation at the Sunrise Dam Gold Mine

The Sunrise Dam Gold Mine (SDGM) in Western Australia (Fig. 1) is a useful case study for proxies for Au mineralisation as its exceptionally high-nugget Au has made it very difficult to define the boundaries of the mineralised zones and estimate the resources available for mining (Nugus et al., 2009). At SDGM Au assay values are collected from samples of NQ diamond drill core (47.6 mm diameter, typically 0.3–1.0 m in length). The unreliability of Au assays as a representation of the distribution of mineralisation was demonstrated in a trial on repeatability conducted by Carswell and Clark (2013). In that study, intervals of core were cut in half lengthways and the two samples were analysed separately; the pairs of half-core samples showed low correlation. Bulk mining and recent experiments with large-diameter RC drilling of several lodes have uncovered a higher calculated grade than that estimated from the distribution of Au from diamond core assays (Carswell and Clark, 2013), supporting the hypothesis that the nugget effect typically results in underestimates of the mined grade. This is anecdotally considered to reflect that lode continuity is greater than that suggested by the diamond core assays.

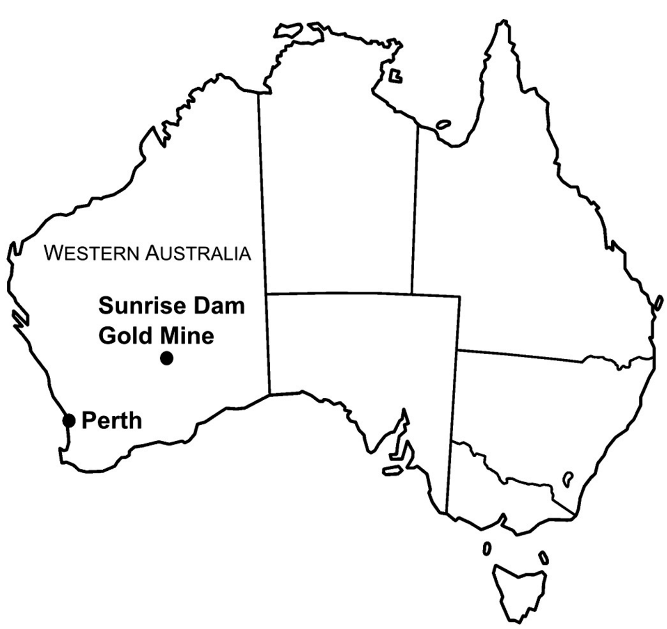

Fig. 1. Location of the Sunrise Dam Gold Mine in Western Australia.

Due to the nuggety nature of the gold, it has been widespread practice at SDGM to use proxies to help define ore body boundaries. Documented uses of proxies for gold mineralisation at SDGM include those from Haren and Williams (2000), who used the presence of shear zones and sedimentary banded iron formation, and Nugus et al. (2009) who used structural features and alteration as proxies to map zones of high grade mineralisation. Mine geologists estimating grade underground at SDGM have been able to use visual proxies to estimate gold using the intensity of alteration, intensity of deformation and the abundance of veins (Hill et al., 2013c). These manually applied proxies have provided smoother and less nuggety ore domains than the assays themselves for volumes of rock greater than $5 \times 5 \times 5$ m. However, they are prone to error due to inconsistencies between different geologist observations and personal biases.

SDGM ore bodies are hosted in a sequence of Archaean metasedimentary and metavolcanic rocks, intruded by dolerite and porphyritic microgranite and granite. The region has undergone lower- to mid-greenschist metamorphism, and multiple deformation events. An early stage of extensional deformation was followed by several phases of compressional deformation. Gold mineralisation appears to be largely associated with shear zones and breccia zones associated with the later stages of compressional deformation (Blenkinsop et al., 2007; Nugus et al., 2009). Although the relative timing of the two events is unclear, gold mineralisation is also closely spatially associated with porphyritic microgranite intrusion. Most gold is vein-hosted and there is a complex relationship between alteration and shearing and between faulting and veining which has proven difficult to unravel in detail and which varies from ore body to ore body (Hantler, 2009; Hill et al., 2013c).

The Vogue ore body, which is the subject of this study, is located several hundred metres below the SDGM open pit (Fig. 2) and shows some differences in mineralisation style to the higher level ore bodies.

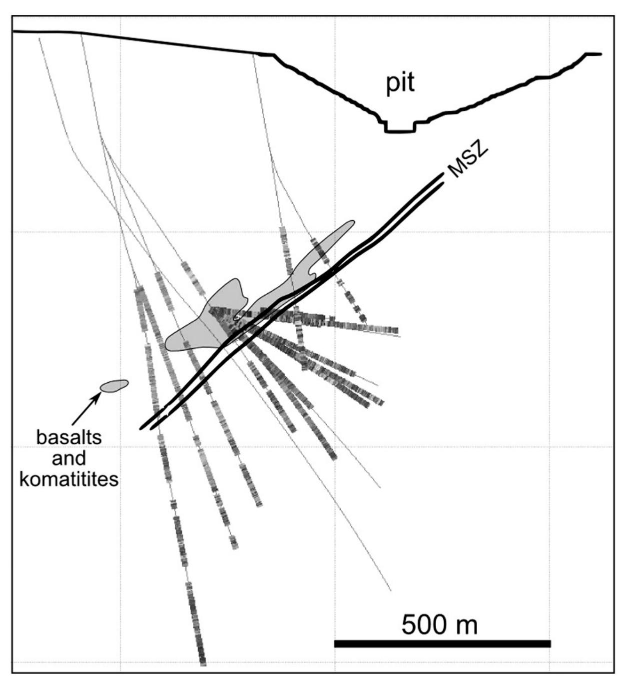

Fig. 2. W–E cross-section showing the extent of geochemical sampling for the Vogue ore body. Diamond drill holes that were sampled (thin grey lines) are projected onto the section. Location of geochemistry samples on drill holes is shown as thicker lines with grey-scale colour according to Rb composition, a proxy for sericitic alteration; darker colour = higher Rb. MSZ = midway shear zone.

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