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Mineral potential mapping in frontier regions: A Mongolian case study

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ABSTRACT

The quality of a mineral potential map is dependent on the quality of the input data used in the analysis. In frontier regions or those with limited or no exploration history, datasets are often of questionable quality, and are generally incomplete with data missing either due to incomplete mapping or data not being made available to the public. This study introduces a method for addressing these challenges in mineral potential mapping to derive exploration targets. Utilizing four established statistical measures, an iterative weights of evidence method is employed to assess the strength of the relationship between known deposits and a set of geological feature layers. This method acts as an indirect validation tool for assessing the quality of the data by allowing an expert user to determine whether the statistics conform to expected relationships. Taking data from Mongolia, this iterative weights of evidence method is used to produce a mineral potential map and to evaluate potential targets for orogenic gold mineralization. The success of the method is determined by the ability of the mineral potential map to predict the location of the known mineralization.

1. Introduction

Mineral potential mapping is used as a tool to delineate areas with a high potential to host mineral deposits. Utilizing a Geographic Information System (GIS) allows an expert user to rapidly evaluate spatial geoscience data for use in mineral potential mapping projects to identify exploration targeting opportunities. Quantitative methods for evaluating geoscientific data for use in mineral potential mapping include weights of evidence (Agterberg et al., 1993; Bonham-Carter, 1994; Bonham-Carter et al., 1989; Porwal et al., 2006), fuzzy logic (Bonham-Carter, 1994; Brown et al., 2003; Knox-Robinson, 2000), evidential belief (Carranza and Hale, 2002) and neural networks (Brown et al., 2000; Fung et al., 2005; Singer and Kouda, 1999).

Previous studies have typically applied such techniques to well-studied, well-explored, data-rich terranes (e.g. Carranza et al., 2005; Feltrin, 2009; Harris et al., 2008; Knox-Robinson, 2000; Mustard et al., 2004; Nykänen et al., 2008; Porwal et al., 2001; Raines, 1999). As a result of this critical dependence on data quality, brownfields-scale (near mine) approaches to exploration targeting have traditionally been the way in which mineral potential mapping has been utilized.

However, because of the extensive exploration histories that are typical of brownfields districts, it is likely that the "big one" in these districts has already been discovered. Yet greenfields terranes have a greater potential for discovery of new mineral districts or world class deposits. By definition, greenfields districts lack extensive and intensive exploration histories, and as such may benefit greatly from regional-scale mineral potential mapping exercises that may highlight regions of higher mineralization potential. Greenfields terranes may be in frontier regions of the world that have developing economies or have enduring geopolitical, economic and security issues that can hinder exploration (cf. Kreuzer et al., 2008; Penney et al., 2004; Singer and Kouda, 1999). These issues increase a nation's country risk, which can include risk factors such as its ability to cover national debt, its regulatory framework and restrictions on financial transactions (Trench and Packey, 2012). Consequently, previous exploration is often limited. As exploration facilitates an increasing knowledge-base and economic geology research, relevant academic literature in these areas is lacking which leads to poor data availability and quality.

This paper shows how mineral potential mapping can be successfully applied to frontier terranes to successfully delineate valid exploration targets despite the data quality challenges posed by working in a frontier region. Mongolia was selected as a case study area for demonstrating the usefulness of model-based mineral potential mapping in a frontier country where reliable geoscientific data are not publically available. A modified weights of evidence model and a fuzzy logic model are applied to mineral potential mapping for orogenic gold in Mongolia. The results of the mineral potential mapping are verified by their ability to predict known mineralization within the study area.

2. Data challenges in frontier regions

Successful targeting for potential mineralization in frontier regions using mineral potential mapping in a GIS poses many challenges in terms of the availability and quality of data. The adage of "garbage in,

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garbage out" holds true for any mineral potential mapping project using digital scientific data. The quality of the final mineral potential map is most strongly influenced by the quality of the data used as inputs. Dealing with data availability and quality issues is by no means limited to frontier regions, however, these challenges are often compounded by having multiple issues within the same dataset, which are described below.

2.1. Data availability

Frontier regions tend to have a lack of publically available data. Data may either (a) simply be non-existent for the complete (or parts of the) study area, or (b) exist in archives which are publically inaccessible, or (c) not be available in digital format. Dealing with non-existent data is largely a problem that cannot be overcome when dealing with a large study area. Such large scale data can usually only be acquired by national/state/provincial government surveys who have a long term view in trying to encourage investment in their part of the world and the monetary resources to acquire the data. However in some parts of the world, such government survey data are not always publicly available and may be considered secret in the interests of national security, etc. On a smaller scale, the data can often be proprietary and held by individual exploration and mining companies who will not provide the data to potential competitors.

Many frontier parts of the world have undertaken some form of geological mapping in the past (e.g. West Africa and Central Asia). However, this type of data is not always available in digital format and can often come in the form of hand drawn maps or in image formats that lack spatial context such as projections or datums. This lack of digital data can sometimes be overcome by digitizing the hard copy data in a GIS. Problems can then arise due to the quality of digitizing and attributing geological maps.

2.2. Data quality

The quality of the data can often be poor or questionable. This can be due to inaccurate data or having sporadic (heavily biased) data. Inaccurate data can be a result of digitizing of hard copy maps due to the poor quality of the original hard copy maps, lack of knowledge about the coordinate system used, distortion of images in image processing software as well as the general errors inherent in the digitizing process by humans. Georegistration of image files, while a simple task in a GIS, can lead to major discrepancies between the registered image and the actual location of the data if the original coordinate system is unknown or incorrect, or if the image itself has been distorted in some way through processing.

Inaccurate data can be verified by comparing different geoscientific datasets against each other for logical inconsistencies. At some scales, this may require revision of geological maps through additional field mapping. However, at country-scales, this is infeasible due to the cost and time taken to undertake the geological mapping exercise. Data which are heavily biased towards certain regions can still be used in mineral potential mapping, however one must be careful how such data are used. Inaccuracy can also result as a consequence of incorrect coordinate systems being used to spatially represent the data. Trial and error can be used to test various alternative coordinate systems until the misrepresented data can be shown to fit an accurate dataset. However, this is not always successful if the data come in a user-derived or local coordinate system that is not available or known under the standard systems within a GIS package.

Incomplete data coverage can be accommodated by utilizing specific methods for mineral potential mapping. These methods are discussed below. However, this raises the question of whether the data coverage is truly incomplete or whether the geological features in question are simply not present in a given region. This can lead to subjective inputs going into the mineral potential mapping process, which in turn raises an issue of data quality.

3. Methods for mineral potential mapping in frontier regions

Mineral potential mapping is dominated by three main methods: data driven approaches such as weights of evidence and neural networks, and knowledge driven approaches such as fuzzy logic. Each of these methods have been shown to have strengths and weaknesses for mineral potential mapping (e.g. Agterberg and Bonham-Carter, 2005; Brown et al., 2003; Harris et al., 2003; Singer and Kouda, 1999).

Given the potential challenges with data in frontier regions discussed previously, we chose to focus on using the weights of evidence and fuzzy logic methods. Neural networks offer a well established method for analyzing geoscience data (Bougrain et al., 2003; Feltrin, 2009; Singer and Kouda, 1999). However, this method was not considered in this study as it is a more "black box" method that does not allow for interpretation of the relative strengths of each evidential layer in terms of its data quality and relationship to known mineralization.

The process for generating mineral potential maps using data from frontier regions is discussed below for the weights of evidence and fuzzy logic methods.

3.1. Weights of evidence

Weights of evidence is a data driven method for mineral potential mapping. Subjective input is required from a geologist to develop a deposit or mineral systems model, and the data are then analyzed using statistical methods. This data driven method requires a mineral deposit dataset and a series of geological features in order to generate a mineral potential map.

In a frontier region, the quality of both the mineral deposit data and evidential layers may be questionable. Selection of the mineral deposit data to be analyzed should attempt to filter the data for a specific style of mineralization, which will be analyzed using various statistical measures. However, with the lack of available research on existing deposits in frontier regions, the training data for a deposit style must be limited to those deposits or prospects for which data can be sourced. This may include peer reviewed scientific publications, government reports or company data such as NI43-101 reports from Canada.

One of the benefits of using weights of evidence is that incomplete data can be used, as it is possible to specify a separate class for areas of missing data. Such data can be common in frontier regions, as structural mapping can be incomplete in remote mountainous regions where no geophysical data are available to complete the mapping.

The strength of the spatial association between known mineral deposits and a geological feature can be measured by a contrast value in weights of evidence (Bonham-Carter, 1994). The contrast C can be calculated from

$$C = \ln O(B|A) - \ln O\left(B\middle|\overline{A}\right)$$

where $O(B|A)$ represents the odds of B (e.g. a mineral deposit) occurring given the presence of A (e.g., a specified geological feature) and $O(B|\bar{A})$ represents the odds of B occurring given the absence of A.

Further, statistics are calculated in order to determine which evidential layers are most appropriate for use in the final mineral potential map:

- *Confidence* (C/σ) — studentized contrast values from the weights of evidence statistics where C is the previously defined contrast value and σ is its standard deviation (Bonham-Carter, 1994).
- *Deposit–Area statistic* $(d(d/a))$ — measures the capture efficiency, where d is the percentage of the total number of deposits within a specified distance from a feature and a is the percentage of the total study area covered by that distance (Brown et al., 2003).