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Automatic Image Analysis for Mineral Exploration

Holden, E. J. [1], Dentith, M. [1], Kovesi, P. [2]

1. Centre for Exploration Targeting, School of Earth & Geographical Science, The University of Western Australia,
2. School of Computer Science and Software Engineering, The University of Western Australia,

ABSTRACT

Quantitative analysis of geoscientific data to determine the areas most likely to contain mineral deposits is becoming increasingly common in the mining industry. The approach is based on characterising areas known to contain deposits and seeking similar areas elsewhere. This paper presents an automatic image processing technique for the prospectivity analysis of Archaean lode gold deposits, which differs from previous methods in that it is based solely on aeromagnetic data and does not require knowledge of the location of existing deposits. Instead, the aeromagnetic expressions of what are perceived to be geologically significant characteristics are sought within the aeromagnetic data. Gold mineralisation is known to occur near major crustal breaks manifesting as large-scale shear zones; which act as conduits for mineralising fluids. Mineralisation occurs in regions of structural complexity adjacent to the shear zones. Progressing towards the automatic detection of such regions, the proposed system finds firstly regions of discontinuity that correspond to both lithological boundaries and shear zones using a combination of texture analysis and bilateral symmetry feature detection techniques. Secondly, it examines the data using fractal analysis to find areas nearby with a complex magnetic expression (zones of structural complexity). The most prospective areas are those where inferred structural complexity occurs adjacent to the regions of discontinuity. A preliminary experiment was conducted using aeromagnetic data from the Yilgarn Craton in Western Australia.

INTRODUCTION

In recent years, government geological survey organizations charged with encouraging minerals exploration within their jurisdictions, have been making increasingly larger volumes of data available over the world-wide-web. As part of such initiatives, vast amounts of aeromagnetic data have been acquired and made available at zero or minimal cost. These data can be used for regional-scale geological mapping. In poorly exposed or studied geological terrains these data may be the only means of assessing the local geology. Here we present on-going research into how large aeromagnetic datasets can be automatically assessed using image processing techniques to identify regions perceived to be most favourable for minerals exploration, i.e. for regional-scale prospectivity analysis.

Existing quantitative prospective analysis techniques are often GIS based and use multiple geoscientific datasets (Brown et al., 2003; Chung, 2003; Turner, 1997). They base their model on the goal setting of known deposits, which are then used to predict prospective areas else where. The paradigm of the proposed approach differs from the above mentioned techniques in that it does not rely on specific information regarding the known deposit locations. Instead, geological characteristics considered to be significant for mineralization are sought within the aeromagnetic data. For example, there is general agreement that the first-order control on the location of Archaean lode gold deposits is the proximity to large (hundreds of kilometers in length) shear zones; although the deposits do not occur within the shear zones but nearby in regions of geological complexity. This has been particularly well studied in the greenstone terrains of Western Australia and central Canada (Robert and Poulsen, 1997; Groves et al., 2000; Berlein et al., 2006).

This paper describes a research in progress that aims to automatically identify the regions containing aeromagnetic expressions that correspond with the geological characteristics of Archaean lode gold deposits. The current system finds regions of magnetic discontinuity that are related to shear zones and lithological boundaries, and then identifies prospective regions nearby using the following three stages. The first step is to perform texture analysis using an entropy measure to represent the randomness of local texture, where similar textures may represent a homogeneous lithological unit. Regional scale discontinuities will have a consistent magnetic response which will be laterally continuous. The second step finds the regions of discontinuity by detecting bilateral symmetric features from the texture analysis output. This symmetric feature detection technique finds the skeletal regions that cut through the middle of the regions of discontinuity, which better represents the form of the overall geological entity in comparison to the detection of edges. The final stage involves analyzing nearby regions of magnetic discontinuity using a 2D fractal surface analysis

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technique to search for areas with complex magnetic responses. Our on-going research includes the selection of major shear zones amongst the regions of discontinuity and the extraction of detailed geometrical and spatial information on the geological structures captured on aeromagnetic images.

APPROACH

Step1: Texture Analysis

Texture analysis is performed to characterise the magnetic texture in the local neighbourhood of each image location using image entropy. Entropy is a measure of randomness of the image (Parker, 1997) using the following:

$$E = -\sum_{i=1}^{n} (p_i * \log(p_i)),$$

where p is the grey level histogram of the image in the local neighbourhood and n is the number of bins in the histogram. An image with a wide spread of intensity values has a high entropy value, where an image with little contrast has a low entropy value. Entropy thus represents the variations of magnetic intensities within the local neighbourhood for each pixel. Each of the regions of magnetic discontinuity will have a consistent high entropy measure. Aeromagnetic data of Yilgarn Craton in Western Australia and its entropy are shown in Figures 1(a) and 1(b) respectively.

Step 2: Bilateral Symmetry Detection

A scale- and contrast-invariant bilateral symmetry detection technique (Kovesi, 1997) is then employed to find a line/skeleton that runs through the middle of a region to represent its structure, i.e. in geological terms it detects geological entities such as units comprising the same lithotype and highlights their strike. This technique utilizes the periodicity represented within symmetry in objects where the symmetry point in the spatial domain corresponds to the point where the local Fourier components are at either a minimum or at a maximum in their cycles. This is effectively implemented using a frequency-based approach.

For the detection of symmetry, it is important to detect local frequency, in particular local phase information. For this, we used complex valued log-Gabor functions consisting of an even symmetric (cosine) wavelet and an odd symmetric (sine) wavelet, each modulated by a Gaussian. A bank of these filters at different scales is used. At each scale, the filters will respond to a particular band of frequencies in the image. A point of symmetry is where frequency components are at the minimum or maximum points; the most symmetric points in their cycle. This corresponds to where the absolute value of the even symmetry filter responses are large and the absolute value of the odd symmetry filter responses are small. An important attribute of this approach to local symmetry detection is that it is invariant to the local signal strength in the image and is only concerned with the local structure in the image.

This bilateral symmetric feature detection technique is applied to the entropy image in Figure 1(b), and a thresholded output is shown in Figure 1(c). The detected regions are related to both lithological boundaries and shear zones.

Step 3: Fractal Analysis

A 2D fractal surface analysis technique using the Fourier transform (Russ, 1994) is used to measure the complexity of magnetic responses in areas adjacent to the regions of discontinuity. This method performs fractal analysis on 1D profiles of the 2D surface data over various orientations, based on the Hurst analysis method. For each 1D profile data, it finds the minimum and maximum neighbourhood values with a given distance range over the profile and their difference is used to calculate the fractal dimension. It requires a plot that shows the log of the greatest elevation difference that is found anywhere along the profile against the log of the distance range, and the slope of the line that is fitted to the plot is used to measure the fractal dimension. To represent the fractal dimension of a 2D surface, the average slope over all orientations is determined. In the magnetic map, this average slope represents the complexity of the magnetism distribution of the 2D local neighbourhood, which will roughly correspond to the structural complexity of the geology in the area. Our experiment examined a 2.5 km radius of the neighbouring areas of the regions of discontinuity and their fractal measures are shown as pixel intensities in Figure 1(d). In this image, brighter regions represent more complex magnetic responses, which indicate better prospectivity for their nearby regions.

DISCUSSION

The geological model used in our approach is that the major gold deposits mostly occur within a few kilometers of the major shear zones (Bierlein, 2006). Figure 1(c) shows the regions of discontinuity that correspond with major shear zones, as well as lithological boundaries, and Figure 1(d) shows the fractal measure of areas within 2.5 km of the detected regions. From Figure 1(d), the regions with complex magnetic responses are selected by thresholding the regions with the fractal measure less than a threshold value. Then the areas within 2.5km from the selected regions are examined, and compared with the known gold deposit locations in the area. The result shows that the automatically identified regions contained 76% of all deposit locations, and 82% of the greater than 1 tonne deposit locations.

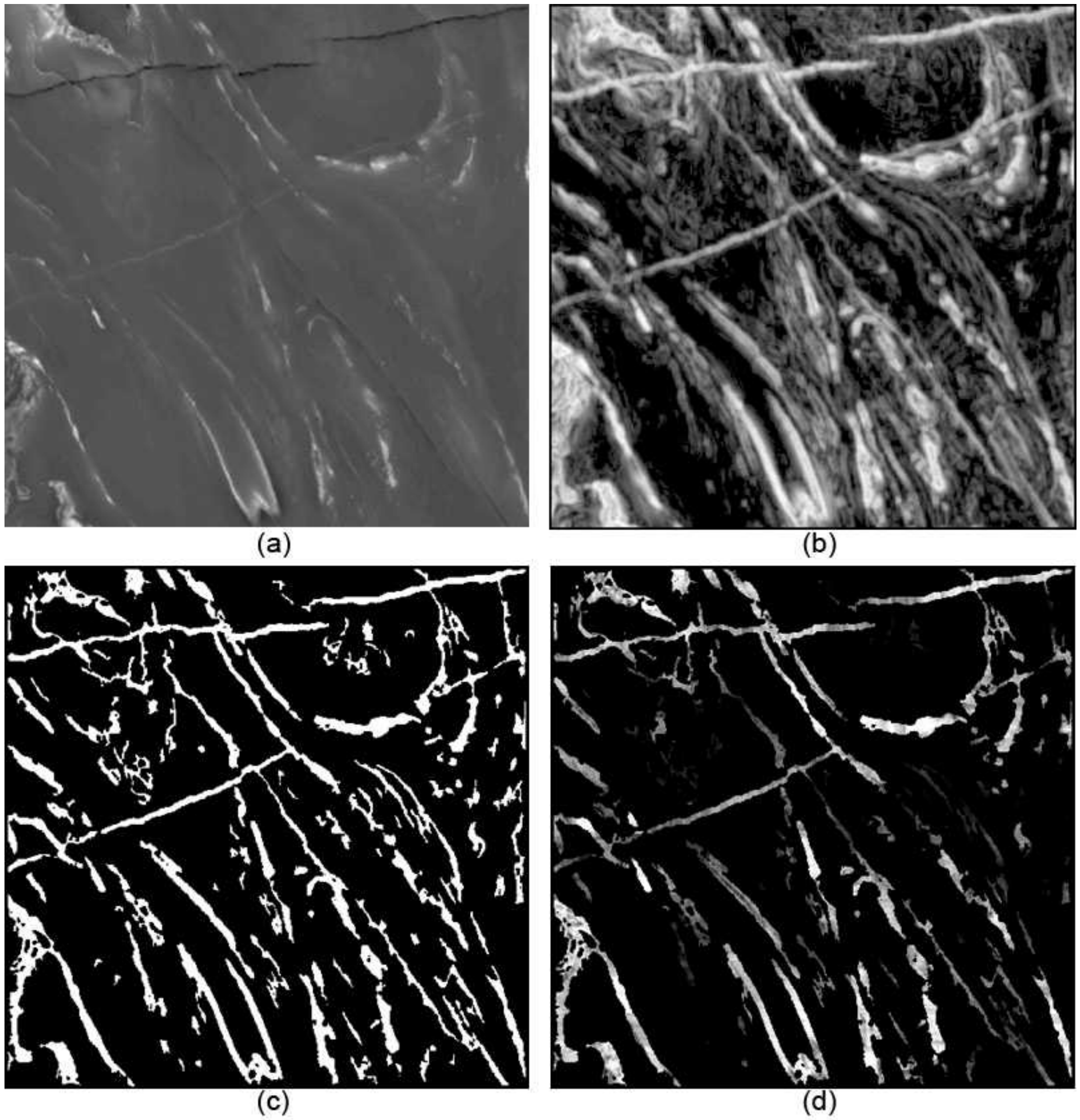

Figure 1: (a) Aeromagnetic data of the Eastern Goldfields area of Western Australia. This image is a grid with 50 metre spacing, and the image size is 1080 x 1079 pixels covering an approximately 50 x 50 km region.; (b) Entropy image of (a); (c) Thresholded bilateral symmetry image generated from (b); (d) 2D Fractal surface representation image of (c).

On-going developments include the following. Firstly, major shear zones will be identified as opposed to lithological boundaries. A dominant line detection technique such as the Radon transform method can be employed but needs to be extended to deal with a case where only a section of a shear zone appears within the image. Secondly, the system will identify characteristics of shear zones including the sudden change of orientation, as well as being broken or crossed by other structures. Thirdly, our techniques will be applied to other geoscientific datasets such as gravity, Digital Elevation Models (DEMs) and satellite spectral sensor images. The last development is to apply our technique for prospectivity analysis to other types of deposits. Fault/shear zone control of the location of mineral deposits is very common, regardless of commodity, deposit-style or geographical location. However, other factors will need to be incorporated into the method when applied to deposits other than Archaean lode-gold. For example, the tendency for nickel and platinum group elements to occur in association with ultramafic rocks suggests the identification of regions of unusually high amplitudes in aeromagnetic data.

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