Predictive Ore Deposit Targeting Using Neural Network Analysis

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Summary

New multispectral, hyperspectral and radar sensors provide an opportunity to improve integrated interpretation of geophysical and remote sensing data. A methodology has been developed to extract geological signatures from these data, and predict ore deposit targets using neural network simulation. It has been successfully tested on a number of deposit types.

Introduction

The objectives of the project described in this paper were twofold:

1. Develop a robust and efficient method for predictive ore deposit targeting using a variety of geophysical, remote sensing and other geoscience data types; and

2. Evaluate the applicability of current and new remote sensing sensors for mineral exploration.

This paper focuses on the first objective, but will allude to the second one as well.

For the last two decades, geophysical and remote sensing data have been imaged and layered in image processing and GIS software. However, true integrated analysis of these data has been restricted to a select few. The expertise of the geoscientist is often concentrated in one or other of the disciplines, or even just in the software operation. Our view is that prior to any semi-automated analysis of data layers, the layers themselves should provide a better reflection of geological properties than the original measured data. For example, the total magnetic field incorporates effects due to the geomagnetic field (inclination and declination), and also the effects of magnetic remanence, whereas the analytic signal amplitude computed from the total magnetic field better delineates the location of the magnetic sources. Similarly, a layer of classified alteration zones derived from a multispectral satellite image has more value for targeting than a particular spectral band.

The methodology that we developed was tested for several different geological environments and deposit types. They included:

- **Porphyry-related Base and Precious Metal**
  Target region: Calama district, northern Chile

- **Lode Gold**
  Target region: Red Lake gold district, Ontario

- **Volcanogenic Massive Sulphide**
  Target region: Rouyn-Noranda district, Quebec

- **Magmatic (Nickel-Copper)**
  Target region: Raglan Mine district, Quebec

- **Kimberlite (Diamonds)**
  Target region: Pine Creek, South Australia.

The surficial geology characteristics of each area varied. They all incorporate young cover to a greater or lesser extent, which limits the widespread effectiveness of the techniques that focus on the surface. Vegetation varied from sparse to fairly dense forests and lakes. Consequently, geophysical methods with depth-penetration capabilities (e.g. magnetic, electromagnetic, gravity) form a critical component of the targeting exercise.

Several data types were incorporated in the tests. They included:

- **Airborne Geophysics**
  magnetic, gamma-ray spectrometer, time-domain electromagnetic, frequency-domain electromagnetic

- **Hyperspectral**
  Hyperion (satellite), Probe-1 (airborne)

- **Multispectral**
  Landsat 5 TM, Landsat 7 ETM+, Aster (all satellite)

- **Radar**
  Radarsat-1 (satellite)

- **Other**
  Geology, geochemistry, digital elevation model.

Methodology

The initial stage of predictive ore targeting is to assemble the available data sets, and derive raster layers that are relevant to locating the targets of interest. The geophysical and remote sensing data are processed to obtain products that reflect particular physical or geological properties. Data that are available in point form (e.g. geochemical and geological data) or vector form (e.g. mapped structure) can be incorporated in the process by conversion to raster data.

The third dimension delineated by geophysical data is included using such products as the depth-to-magnetic-sources and depth slices extracted from conductivity-depth images. This first stage is critical and requires the necessary expertise to process the various data types properly.

Once the data layers have been prepared, they can be analyzed in various combinations using neural network software. We have developed a package that will first analyze a training data set, incorporating single or multiple targets, to determine the signatures unique to the target(s). The training area may be a subset of the larger area to be studied, extracted from a different area altogether or even synthetic data generated from forward modeling. The training matrices are then applied to the full area, and the neural network simulation generates a raster image of the target probability.

The neural network training and simulation software modules were developed in a portable package that is easily compiled to work within commercial software environments used for geophysical data processing and image analysis.

The neural network consists of a multilayer feedforward network. In this case, one hidden layer of sigmoid neurons is followed by an output layer of linear neurons. Multiple layers of neurons with nonlinear transfer functions allow the network to learn nonlinear and linear relationships between input and output vectors (Demuth and Beale, 1998). The linear output layer lets the network produce values outside the range -1 to +1. Different combinations were tried, and the most efficient one was a hidden layer of 15 log-sigmoid neurons, and an output layer with one linear neuron. More than 15 neurons in the hidden layer did not improve the accuracy of the training and slowed the process by consuming too much memory; less than 15 neurons in the hidden layer did not produce satisfactory results.

Calama Example

The Calama region of northern Chile forms part of the prolific porphyry copper belt on the west side of the Andes. The study area includes the Chuquicamata, Spence and Escondida copper deposits, amongst many others. Epithermal gold deposits form a secondary target. It is a challenging area for exploration due to fairly extensive gravel cover.

A number of spectral data types were acquired for the study, since the arid environment makes such imagery ideal for mapping surface geology. We undertook a study to locate alteration in areas of exposed outcrop, as an indicator of underlying or adjacent porphyry systems. Landsat 5 TM (7 bands) was able to map hydrothermal alteration, and determine the presence or absence of ferric oxide. The thermal band from Landsat 7 ETM+ (8 bands) show ed anomalous responses over the alteration zones. The higher spatial and spectral resolution of Aster imagery (14 bands) allowed subdivision of the hydroxyl alteration mapped by Landsat into kaolinite and illite-dominated end members (Figure 1). Hyperion satellite hyperspectral and Probe-1 airborne hyperspectral imagery (220 bands) provided the greatest discrimination, delineating up to six mineral endmembers indicative of alteration (kaolinite, alunite, muscovite, goethite, chlorite and epidote).

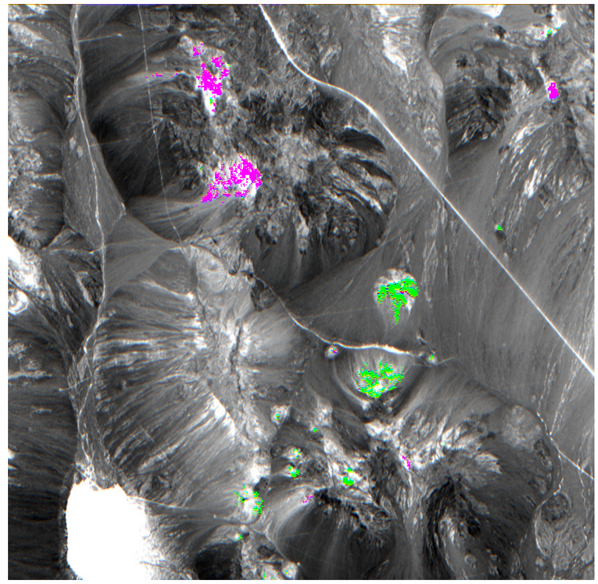

Figure 1: Example of hydrothermal alteration zone determined from processing ASTER data, magenta indicating a ‘kaolinite dominant’ field and green indicating an ‘illite dominant’ field, Calama region, Chile.

The Calama region was flown with magnetic and gamma-ray spectrometry systems over four campaigns (Ugalde at al., 2000). The survey was acquired along N-S oriented lines spaced 500 m apart (250 m for the Escondida block). The nominal terrain clearance was 120 m although it varied over high relief areas.

Figures 2 and 3 show samples of the magnetic and gamma-ray spectrometer data collected in the Escondida area towards the south end of the Calama region. The porphyry copper mineralization is associated with Eocene-Oligocene intrusive complexes controlled by major N-S oriented faults systems, hosted by older volcano-sedimentary sequences. Outcrop exposure is relatively sparse. The pole-

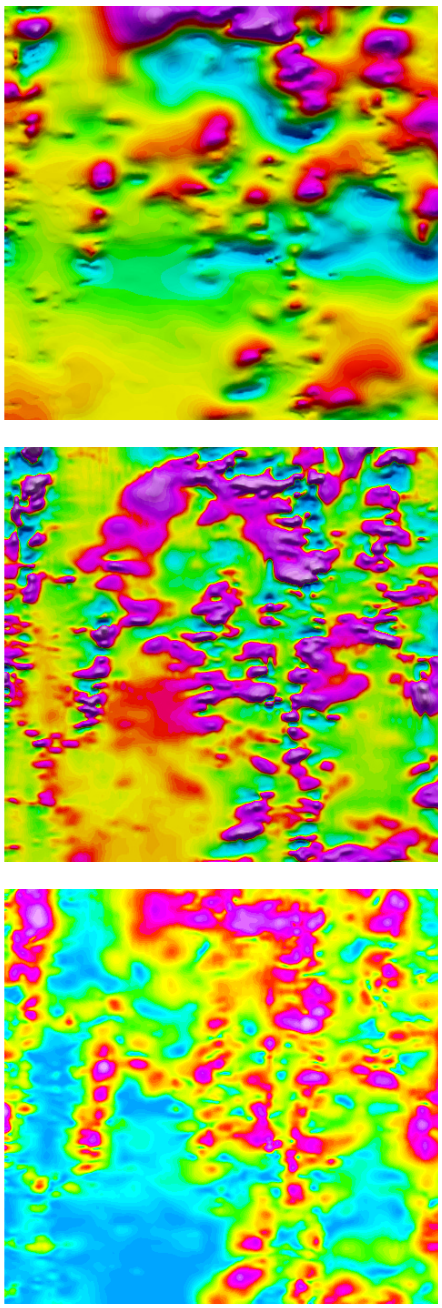

Figure 2: Window of data from the Calama data set in the Escondida area, Chile. Image area is 32 x 31 km. Top: total magnetic field, shaded from the north (400 nT dynamic range); center: pole-reduced first vertical derivative of the magnetic field, shaded from the north; bottom: analytic signal amplitude of the magnetic field.

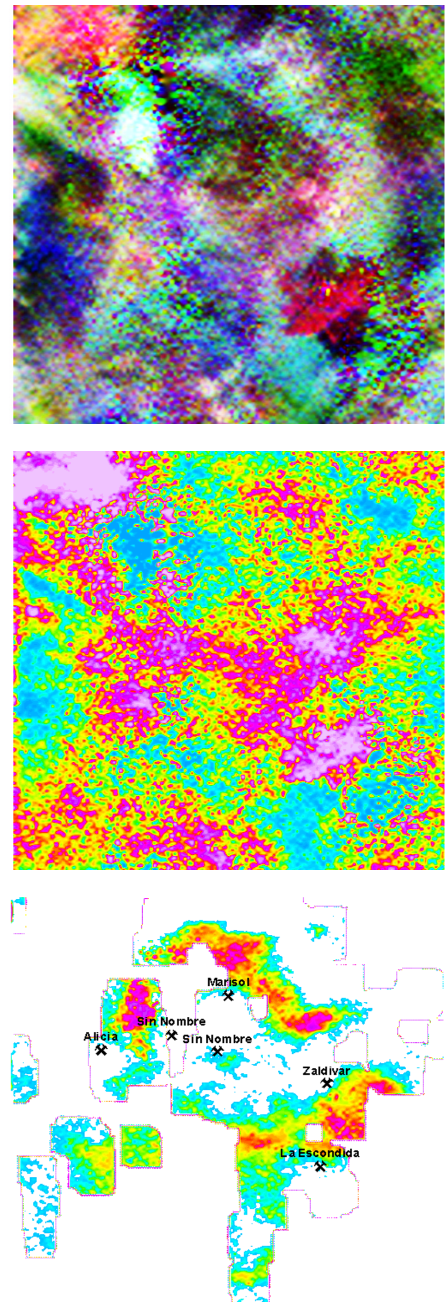

Figure 3: Same area as Figure 2. Top: ternary image of gamma-ray spectrometer data (RGB=K-Th-U, higher concentrations in light-colored areas); center: ratio of K/Th; bottom: neural net simulation image for hydrothermal alteration target, windowed to geology of interest (polygonal outlines) and clipped to the 90th percentile, with known deposits superimposed.

reduced first vertical derivative of the magnetic field provides a better indication of the intrusive activity along the N-S faults, but lacks continuity due to the low magnetic latitude. The analytic signal amplitude further emphasizes these features.

The gamma-ray spectrometer data are somewhat spotty due to high terrain clearance in places. Nevertheless, they show a wide variety of responses useful for surficial mapping, some of which reflect eroded material down slope from outcrop. The K/Th ratio image is presented because it is particularly useful for locating potassium enrichment or depletion, indicated respectively by a preferential increase or decrease in the concentration of potassium relative to thorium.

The alteration zones located using the multispectral and hyperspectral imagery were used to select training areas north of the Escondida area shown. The training results were then applied to the geophysical data for the entire Calama data set, to derive additional zones of potential alteration for targeting. The total magnetic field was excluded from the process because the anomaly geometry incorporates geomagnetic inclination and declination. The pole-reduced field, its first vertical derivative and the analytic signal amplitude were included as they provide a more direct reflection of the magnetic sources over a range of depths. The gamma-ray spectrometer data included in the process were potassium, uranium and thorium concentrations, as well as the K/Th ratio. It was found that more useful results were obtained when the data were masked to exclude areas where the Eocene-Oligocene rocks are not known to occur. The Escondida area (Figure 3) was one of the more interesting areas located in the resultant simulation image for the Calama region. It shows a large proportion of target probability above the 90^{th} percentile. The alteration signature in the geophysical data does not correlate with one particular image. It reflects elevated levels in the three radioelements on the margins of the more magnetic sources. This is a signature that would be difficult to interpret using conventional methods. The known deposits cluster on the edges of these alteration target areas, a property that was noted throughout the Calama region. This provides a well-defined vector to locate new deposits.

Conclusions

The methodology that we have developed for predictive ore deposit targeting has proven successful for a number of deposit types in several different geological environments. It will be tested as an application for classification of unexploded ordnance (UXO). It may be extended to analysis of profile-based data, such as airborne geophysical and hyperspectral survey lines, and drillhole logs.

References

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