Abstract

The risks of developing mineral resources need to be known as accurately as possible. This process should start at the exploration stage and continue through feasibility to the development stage. Until recently, this type of analysis was carried out manually, leading to subjective judgments. Many mining companies have built up extensive exploration geological databases, which represent significant assets to the company that have taken millions of dollars to compile. In recent times, programs of digital data compilation have been undertaken to allow the use of more probabilistic data analysis techniques, moving away from the traditional expert-system methods. The GIS is the perfect management tool for compiling spatial data. Data for this project was obtained from the W. M. Keck Earth Sciences and Mining Research Information Center, the Bureau of Land Management, The Nevada State office, ESRI datasets, and digitalized maps. A geodatabase was created to optimize the storage and management of the data. ENVI was used to process the different ASTER images of the area of interest. I also used the geostatistical analyst tool to determine the Inverse Distance Weighting (IDW), which is a quick deterministic interpolator that is exact to create a spatial correlation between the samples taken and the gold content of those samples. The information stored in the geodatabase and the different referenced raster data was then put into ArcMap and later the websites were created in ArcIMS and customized using VBScripts. The result was an ArcIMS tool that can help any mineral exploration company manage in an interactive way all the necessary data required to make smart decisions about mineral exploration.

Introduction

Mineral exploration companies use diverse types of data sets to search for new mineral deposits. Data sources vary from geologic maps, hyperspectral airborne and multispectral satellite images, and geophysical images to databases in many formats. GIS is an ideal platform to bring them together and deliver meaningful outcomes.

GIS can help in many aspects of the mineral exploration activities: data collection, management, analysis, and reporting. Field geologists can now capture field data electronically using ArcPad and global positioning system (GPS) receivers. Other data sets may be downloaded from the Internet. All of these data sets can be integrated, manipulated, and analyzed using GIS.
Integration with other specialized programs for geophysical data and image processing is easily done with GIS. Raster images, such as satellite imagery or geophysical images can then be displayed in GIS and overlaid with vector data such as geology, faults, and geochemical samples.

Mineral targeting can be done based on multievidence maps analysis, either using qualitative or quantitative methods. Multiple geophysical images can be displayed simultaneously using ArcMap and overlaid by other data sets to evaluate their qualitative spatial relationships. The quantitative method is done through geoprocessing and map algebra. The standard ESRI GIS works in vector-cased operations in which geologists can conduct multiple geoprocessing tasks such as querying, creating a buffer, and intersection operations. ESRI's ArcGIS Spatial Analyst extension helps geologists calculate and predict mineral prospectivity through raster-based map algebra, either using data-driven or knowledge-driven methods.

Satellite remote sensing images have been widely and successfully used for mineral exploration since the launch of Landsat in 1972. This application relies mostly on the capability of the sensor to register spectral signatures and other geological features related to mineral deposits. Gold is one of the most important mineral commodities that have been searched with the use of satellite remote sensing images over the last 30 years.

Although gold cannot be “seen” directly by any remote sensor, the presence of minerals which form in association with this precious metal can be detected based on their spectral signatures. A group of minerals which occur in the alteration zones associated with gold deposits, generically referred as “clay minerals,” have diagnostic spectral signatures mostly in the shortwave infrared portion of the electromagnetic spectrum. These signatures can be used to locate sites most favorable to the occurrence of deposits, saving the mineral industry a great deal of time and costs in their exploration programs.

ASTER is a multispectral imaging radiometer that covers VNIR, SWIR and TIR wavelengths with 14 bands, ranging from 15 to 90m in spatial resolution. ASTER was conceived as a science instrument, aiming to improve the understanding of the processes occurring on or near the surface of the Earth and to address global change topics. ASTER data can be use to create detailed maps of land surface temperature, emissivity, reflectance, elevation, geological and environmental interpretation, and many other applications.
The basic tool for geologists in all disciplines is a map depicting the distribution and identity of rock units exposed at the earth’s surface. Using these maps, economic geologists search for metal and petroleum deposits; hydrogeologists look for ground water; structural geologists classify faults as active or inactive. With its high spatial resolution, and bands covering a wide part of the electromagnetic spectrum, ASTER provides data that will greatly improve geologists’ abilities to produce more accurate geologic maps at a fraction of the cost of conventional ground-based methods.

Moderate-resolution satellite land remotely sensed data have been used successfully over the past 30 years to provide geologists, including those exploring for non-renewable natural resources, with valuable geologic information that has been used to create regional to sub-regional geologic maps and has played a role in the discovery of new occurrences of oil, gold, copper, and other resources. As we have learned, ASTER data have characteristics that are particularly useful for geologic studies, especially where the rocks are well exposed.

GIS is increasingly important in customizing and integrating a broad range of exploration data consisting of information on drill holes with summary stratigraphic logs, rock sample and drill hole sample geochemistry, mineral occurrences, magnetic and gravity images, digital geology, current and historic exploration details, roads and railways, localities, parks and reserve forests, restricted areas and integrated bibliography.

For this project I focused in the north eastern part of the state of Nevada where a big deal of mineral exploration is being conducted at the moment with a lot of potential. First I started by surveying about 25 geologists and people that work in the exploration and mining field to get a clear idea of what information would be helpful for the to have at their fingertips when they are making a decision about mineral exploration.

**Data Used**

I created a Geodatabase with all the different information available for the area along with processed Aster images so that the samples for the mineral exploration can be taken with a better criteria taking into account the many factor affecting the area.

The personal Geodatabase contains:

- State & County Boundaries
- Existing Mines
- Topography
- Regional Geology
- DEM’s
- Mining Claim Locations & Ownership Information
- Geologic Data
  - Structures
  - Alteration
  - Silicification
• Jasperoids
  • Sample points along with available lab results.

All of the information used to create the geodatabase came from the W. M. Keck Earth Sciences and Mining Research Information Center, the Bureau of Land Management, The Nevada State office, ESRI datasets, and digitalized maps.

For this project I used ASTER Level-1B Data images of Elko County, NV, acquired on July 8th of 2001 at 6:48:19 local time. The images were requested from the Earth Observing System Data Gateway (http://edcimswww.cr.usgs.gov/pub/imswelcome/).

The ASTER Level-1B data are L1A data with the radiometric and geometric coefficients applied. All of these data are stored together with metadata in one HDF file. The L1B image is projected onto a rotated map (rotated to “path oriented” coordinate) at full instrument resolutions. The Level-1B data generation also includes registration of the SWIR and TIR data to the VNIR data. And in addition, for SWIR in particular, the parallax errors due to the spatial locations of all of its bands are corrected. Level-1B data define a scene center as the geodetic center of the scene obtained from the L1A attribute named “SceneCenter” in the HDF-EOS attribute “productmetadata.0”. The definition of scene center in L1B is the actual center on the rotated coordinates (L1B coordinates).

Method

The use of GIS in mineral exploration is now beginning to spread, allowing the integration of disparate digital datasets into a single, unified database. The recommended approach is to compile all of the available geoscientific data within the GIS in the context of an exploration model in order to produce a mineral potential map. Careful consideration must be given in developing the model so that all of the relevant, important aspects of the deposit being sought are represented. The model is also very important in deciding what weightages to apply to each of these aspects. In the final analysis, these weightages may be arbitrarily applied by a geologist, with an intimate knowledge of the model and the deposit.

The first step was to design the geodatabase according to the information that was going to be needed. After the geodatabase design was finished then I started to get all the datasets. The raw datasets were put through the different Analysis Tools in ArcToolbox to get only the data needed. Also several public databases were found that contained datasets that are updated everyday. For those datasets I created a few VB Scripts to extract the information needed from the dataset and feed my geodatabase.

After the Geodatabase was created different tools in ArcMap were used to optimized the information and then I started to bring all of my different datasets within the geodatabase along with the raster images.

The level 1B image has the geometric and radiometric corrections. For the SWIR in particular, the parallax errors due to the spatial locations of all of its bands are also corrected. This really helped with the post processing of the image.
Create a Spectral Library (from the USGS Digital Spectral Library): The purpose for this is to create a Spectral Library with known minerals in the target area and then compare the spectral library with the image and find possible sites for further investigation.

Minimum Noise Fraction (MNF): MNF rotation (using principal components calculations) is used to show the variation between bands in an image. This is a statistical method which works out differences in an image based on pixel DNs in various bands. Mathematically, this uses eigenvectors and eigenvalues to work out the principal vectors and directions of the data cloud (collection of data values for the image). The idea is to show the differences rather than the similarities between bands. So in principal component images you are looking at the maximum differences between what the sensor is picking up in different bands rather than where different bands are recording the same thing i.e. reducing redundancy. The calculations also identify noise in the image. After doing this analysis we can then go and do some band ratios, compare to the MNF or principal components image, and perhaps assign each MNF band to some feature characteristic. Remember that these are statistics and do not indicate any specific mineral, merely differences between areas of the image. This method works best with SWIR images.

The use of the MNF Rotation transforms is to determine the inherent dimensionality of image data, to segregate noise in the data, and to reduce the computational requirements for subsequent processing. The data space can be divided into two parts: one part associated with large eigenvalues and coherent eigenimages, and a complementary part with near-unity eigenvalues and noise-dominated images. By using only the coherent portions, the noise is separated from the data, thus improving spectral processing results.

Defining Regions of Interest: Regions of interest (ROIs) are portions of images, either selected graphically or selected by other means, such as thresholding. The ROIs are going to be created using a shape file from ArcGis with specific points where Gold has been identified so that we can perform a Supervised Classification.

Supervised Classification: Supervised classification is much more accurate for mapping classes, but depends heavily on the quality of the training sites or regions of interest (ROIs). The strategy is simple: we must recognize conventional classes (real and familiar) or meaningful (but somewhat artificial) classes in a scene from prior knowledge, such as, personal experience with the region, by experience with thematic maps, or by on-site visits. This familiarity allows us to choose and set up discrete classes (thus supervising the selection) and then, assign them category names. Training sites are areas representing each known land cover category that appear fairly homogeneous on the image (as determined by similarity in tone or color within shapes delineating the category). For each class thus outlined, mean values and variances of the DN for each band used to classify them are calculated from all the pixels enclosed in the site.
Spectral Library

Minimum Noise Fraction (MNF)

MNF SWIR band R 1, G 2, B 3.
Region of Interest

[Image of a region of interest with colored bands and labels for geological materials such as Unclassified, Calcite, Jarosite, Kaolinite, Muscovite, Opalized, and Alunite.]
Image using different bands for the project
I also used the geostatistical analyst tool to determine the Inverse Distance Weighting (IDW), which is a quick deterministic interpolator that is exact. There are very few decisions to make regarding model parameters. It can be a good way to take a first look at an interpolated surface. The reason I used IDW on this project was to create a spatial correlation between the samples taken and the gold content of those samples.

**Results**

Here we can see the layers for the state boundaries, counties and the geology of the three counties that I’m most interested. These are the basic layers for where I started building the map file in ArcMap.
Here we can see the current mines operating in the state of Nevada. Since I wanted to create something that was accurate and up to date, I decided to link to the database offered by the Bureau of Land Management to have the most recent mine information in the area.
The lithology of the area is very important because it gives us a description of the gross physical characteristics that define a particular rock, including colour, texture, mineral composition, and grain size. The magnetic field layer is very important also because it gives us the region of physical space surrounding a permanent magnet, electromagnetic wave or current-carrying conductor, within which magnetic forces may be detected.
There are a few things to note when using ASTER imagery for regional mineralogical mapping. Firstly, cloud cover, vegetation and atmospheric effects can severely mask or alter surface signals. Secondly, bands and band ratios do not indicate the occurrence of a mineral with absolute certainty or with any idea of quantity, so ground truthing and setting appropriate thresholds is essential. Thirdly, every terrain is different, so ratios which work in some areas for a particular mineral or assemblage may not show the same thing elsewhere. As a result of these factors, it is important not to look at ASTER images in isolation from other data. If possible, datasets such as geology and structural maps, geochemistry, PIMA analyses (ground truthing), radiometrics, and any other available data should be used in conjunction with ASTER for best results.
IDW – Exact deterministic interpolator

In this case IDW gives us a better understanding of the spatial correlation between sampled points and its gold concentration.
For each sample point I created a link to the location on Google Earth so the person looking at the data can have a better understanding of the data.
This picture shows how the actual website looks like. I built different queries that the user can do to get the different point data to be able to analyze the information at hand and make a decision about where the best place for exploration and mining is in a determinate area.

**Summary**

This semester was for me a really good experience. Taking the remote sensing class last semester and the advanced GIS and internet served GIS this semester helped me understand the importance of GIS to represent the different things that happen in real life so that we can put it into the software to be able to analyze the information and make better decisions in our field of interest. Creating this tool for me was very important because I was able to apply what I learned at school to what I do at work.

Getting the right information was a challenge since most of the raw data was found in very different formats and sources, but while dealing with all that I was able to learn even more things. Now it is important to finish polishing the tool so it can be use to advance the mineral exploration process while saving time and money and increasing profitability and efficacy.
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