Applications of Remote Sensing Systems
to MINERAL DEPOSIT DISCOVERY, DEVELOPMENT and RECLAMATION

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OVERVIEW

Remote Sensing data extensively used in all aspects of resource extraction.

Almost every remote sensing system available can be applied.

Presentation focuses on representative examples of the application of Remote Sensing systems to the three main stages of the Mineral Resource Development Cycle

A more comprehensive review of each main technique including specs and costs in an associated report (see Jim to get it)
LIFE CYCLE OF A MINERAL DEPOSIT

For simplicity, 3 key stages where RSS are commonly employed:

1. EXPLORATION/DISCOVERY
2. MINE PLANNING/DEVELOPMENT
3. RECLAMATION & MONITORING

Source: http://www.mineralsed.ca/s/MinDevCycle.asp
Remote sensing applications divided into 2 general groups when utilized for mineral exploration.

1. Spectral Anomaly Targeting

2. Surface Morphological Analysis
Two physical attributes of mineral deposits allow for the two broad groupings:

1. Mineral deposits typically have a CHEMICAL surface expression or FOOTPRINT which = DIFFERENT SPECTRAL responses

2. Their location is typically controlled by STRUCTURES (e.g. faults) = DIFFERENT SURFACE MORPHOLOGY
1. SPECTRAL ANOMALY TARGETING and MAPPING

Multi- and Hyperspectral Techniques

# Landsat TM  (*least expensive*)

# ASTER

# High Res MS (Worldview3 – new ASTER?)

# Airborne Hyperspectral  (*most expensive*)
STAGE 1: EXPLORATION

2. SURFACE MORPHOLOGICAL MAPPING/ANALYSIS

LiDAR & RADAR

# Airborne Laser Scanning Surveys
# Satellite & Airborne SAR surveys
# FUSED products (e.g. LiDAR & HSI; RADAR and high res MS) currently underused in exploration and represent the largest potential growth field
EXAMPLE 1: LANDSAT

CLAY ALTERATION INTENSITY

http://murphygeological.com/imagery_4.html
EXAMPLE 1: BAND RATIOS - LANDSAT TM

Most typical (but not routine) use of Landsat data in exploration is for delineation of hydrothermal alteration zones associated with mineralization.

Technique is largely superseded by ASTER datasets, but still useful as a free dataset at the earliest stages of exploration targeting.

Technique enhances spectral differences:

HIGH REFLECTANCE BAND/ABSORPTION BAND

Source: Sabins (1999)
EXAMPLE 1: BAND RATIOS - LANDSAT TM

For altered rocks the band ratio will > 1.
The most anomalous pixel values represent locations with the highest probability of containing that specific alteration mineral.

Source: Sabins (1999)
EXAMPLE 1: BAND RATIOS - LANDSAT TM

GOLDFIELDS, NV: BAND ratio results

B. Ratio image of TM bands 5/7.

LANDSAT TM 7 BAND RATIO ANALYSIS TO DEFINE CLAY OCCURRENCE
EXAMPLE 2: ASTER
As **spectral resolution increases**, the amount of **different processing techniques** also increases

**ASTER** – (Advanced Spaceborne Thermal Emission and Reflection Radiometer)

High resolution data in 14 different bands

(3 bands – VNIR, **6 bands** – SWIR, 5 bands – TIR)

Lithological mapping and mineral alteration mapping

SWIR bands are used most for identifying Hydrothermal minerals

**Array of Processing techniques available:**

- # Band Ratios, Mineral Indices
- # Logical Operators
- # PCA
- # Minimum Noise Fraction
- # Spectral Shape Fitting Algorithms
- # Spectral Unmixing Methods
EXAMPLE 2: ASTER – LOGICAL OPERATORS (ENVI)

Logical operators perform multiple band ratios and threshold calculations on ASTER data sets in a single algorithm.

Each cell yields a T/F results and creates a new raster image delineating high probable occurrences of desired mineral.

Interactive Data Language (IDL)
LOGICAL OPERATORS

(A) Logical operator to map argillic alteration.
Mask vegetation
Mask dark pixels
Ratio to map 2.165 μm feature associated with argillic alteration

((float(b3)/b2) le 1.35) and (b4 gt 260) and ((float(b4)/b5) gt 1.25) and ((float(b5)/b6) le 1.05) and ((float(b7)/b6) ge 1.03)

Ratio to delineate argillic from phyllic alteration

(B) Logical operator to map phyllic alteration.
Mask vegetation
Mask dark pixels
Ratio to map the 2.200 μm feature associated with phyllic alteration

((float(b3)/b2) le 1.35) and (b4 gt 260) and ((float(b4)/b6) gt 1.25) and ((float(b5)/b6) gt 1.05) and ((float(b7)/b6) ge 1.03)

Ratio to delineate argillic from phyllic alteration

Explanation of ENVI operators:
float—convert to floating point
le—less than or equal to
gt—greater than
ge—greater than or equal to

Figure 10. (A) The logical operator algorithm that maps argillic-altered rocks using band ratios 4/5, 5/6, and 7/6, which define the 2.17 μm absorption feature. (B) The logical operator algorithm that maps phyllic-altered rocks using band ratios 4/6, 5/6, and 7/6, which define the 2.20 μm absorption feature. Pixels with green vegetation and low reflectance (dark pixels) are masked in the argillic and phyllic logical operator algorithms using a band ratio of 3/2 and band 4 threshold, respectively.

Mars and Rowan, 2006
Authors used CUPRITe test site and compared ASTER results to HSI data then applied to regional exploration in Iran.
EXAMPLE 2: ASTER
EXAMPLE 3: Hyperspectral Imagery
EXAMPLE 3: HSI

HSI is a very costly and requires significant amount of processing in addition to robust ground truth campaigns to be effective for Exploration

Numerous sensors available to provide details for all

HSI provides the next level of mineral discrimination after ASTER. With appropriate spectral libraries, detailed mineral maps can be produced.

Processing usually has a focus:

- Anomaly/Target detection
- Material Identification
- Specific Material mapping
EXAMPLE 3: SPECIFIC CLAY ID and MAPPING

Exploration company with property in NV fly 65km2 HSI survey

360 Bands
VNIR 400 – 970 nm
SWIR - 970 – 2500 nm

Ground resolution of 2 m

Ground survey was used to build custom spectral libraries and Clay MINERAL IDENTIFICATION and Mapping were carried out

Define new ground occurrences of a specific clay mineral with slightly different Compositions (and crystallinity) – Illite and Ammonium Illite which are common surface alteration products associated with mineralization
EXAMPLE 3: SPECIFIC CLAY ID and MAPPING

SOURCE:
SURFACE MORPHOLOGICAL MAPPING/ANALYSIS - LiDAR
EXAMPLE 4: LiDAR Bare Earth Models

Airborne Laser scanning surveys most commonly used in exploration.

Bare earth models (given proper QC/QA) provide valuable insight into covered terrains and subtle fault structures

Dependent on data availability but with rising popularity of LiDAR datasets, greater coverage is becoming available (e.g. USA).
EXAMPLE 4: LiDAR Bare Earth Models

LiDAR DEMS can be processed to enhance subtle linear features that represent recessive or prominent faults zones.

Figure 8. A. NAIP photograph of area immediately south of the Indian mine. B. Hillshade of LiDAR-derived DEMs of the area in A. C. Field photography of WNW-trending silicified zone (jasperoid) in limestone.

EXAMPLE 4: LiDAR Bare Earth Models

LiDAR Bare Earth models help to map surface morphology beneath canopy

Figure 10. A. NAIP photograph of area near the Blue Jay mine, North Santiam mining district, Cascade Mountains, Oregon. B. Hillshade of LiDAR DEMs of the Blue Jay mine area. Hillshade of LiDAR-derived DEMs showing location of outcrops and adits in the area.
SURFACE MORPHOLOGICAL MAPPING/ANALYSIS – RADAR FUSION

http://www.largeigneousprovinces.org/07oct
EXAMPLE 5: RADAR + TM Fusion

RADAR is **most underutilized** RS system used in Mineral Exploration – likely due to the expertise required to process and interpret the data.

Has the capacity to provide **much better structural targeting data** than most commonly used datasets.

**Fusion products** with RADAR and multi/hyperspectral data represent a powerful tool that is not used in exploration.
EXAMPLE 5: RADAR + TM Fusion

Study – ERS - SAR data (polarized C band; 12.5 cm resolution) fused with Landsat 7 TM data using a Principal Component transformation

Method:

1. DESPECKLING of RADAR data
2. Image to image registration of Radar and Landsat TM data
3. PCA of Landsat TM
4. Replace landsat TM PC 1 with histogram matched (stretched) RADAR
5. Inverse PC transformation of Radar and TM data
6. Rescale to 8 bit output
EXAMPLE 5: RADAR + TM Fusion

(Fig. 1): Landst TM image (Bands 7,4,2) for the study area

(Fig. 2): ERS-2/Landst TM merged image for the study area

Mine Development and day to day operations typically involve the use of high spatial accuracy remotely sensed data.
STAGE 2: MINE DEVELOPMENT

SOURCE: http://www.terraremote.com/mining/active-operations/
EXAMPLE 1: WorldView 2 – volume calculations

PhotoSat Inc. have developed a method to use WorldView 2 stereo datasets to conduct minesite volumetric calculations.

They acquired data over the Penasquito mine (Mexico) at two time frames and extracted elevation information to create surface models to calculate volumes.

http://www.photosat.ca/pdf/penasquito_gold_mine_volumes_case_history.pdf
EXAMPLE 1: WorldView 2 – volume calculations

http://www.photosat.ca/pdf/penasquito_gold_mine_volumes_case_history.pdf
EXAMPLE 2: LiDAR underground Mobile Mapping

Indoor Mobile LiDAR mapping is growing in use for underground mine mapping.

A local coordinate system is established to which LiDAR point cloud data is referenced to.

http://www.3dlasermapping.com/products/hand-held-mapping

VIDEO LINK

https://www.youtube.com/watch?v=KbTAibR8x3I
Remote Sensing applications for Mine monitoring and reclamation fall into two general groups:

SURFACE CHANGE DETECTION (MS+HIS)

TERRAIN ANALYSIS (LiDAR)
Example 1: Change Detection using HSI

Compact Airborne Spectrographic Imager (CASI) used to monitor re-vegetation of mine tailings at Copper Cliff Mine (ON)

High spatial and spectral resolution of the data allows for discrete changes to be accurately monitored over relatively short time period (3 years)

72 spectral bands - 407 – 944 nm; pixel size 2.3 x 4.3 m
Field spectral analyses help to resolve 30 end member spectra in the data

Example 1: Change Detection using HSI

Figure 2. (a) Reflectance spectra of all the vegetation endmembers. Low photosynthetic vegetation spectra are identified as Em8 and Em24. (b) Reflectance spectra of all the tailings endmembers. Fresh tailings are associated with Em15.
Example 1: Change Detection using HSI

30 Endmembers resolved in 6 groups that were used for unsupervised classification.
SUMMARY

MINERAL RESOURCE extraction industry is a heavy user of remotely sensed data.

Data for Exploration can be divided into two groups that target (1) spectral anomalies and (2) morphological anomalies.

Mining applications require high spatial resolution imagery to carry out daily mine operations and monitoring procedures.

Very high accuracy satellite data is beginning to compete with onsite LiDAR surveys.

Mine Monitoring and Reclamation use multi- and hyperspectral data routinely to carry out land cover classifications and change detection.
Only God Should Move Mountains
Stop Mountaintop Removal Coal Mining in Tennessee

www.tnleaf.org