Fri. Apr. 20, 2018

• Today:
  – Review briefly Ch. 11 (Mineral Exploration)
  – Summarize Ch. 12 -- Land use classification

• Reading:
  – Skim Sabins Chapter 12 -- Land Use
    • Concept of multi-level classification important but only "upper level" numbers are standard. Don't spend time learning details of his system
    Also, will give demo of GIS system on Mon. / Wed.
  – Skim Sabins Chapter 13 -- Hazards
Mineral Exploration (Chapter 11)

- Lineaments
- General geology of mineralized areas
- Review of Goldfield, NV (covered earlier in lab)
  - Landsat TM observations
  - Hyperspectral observations
Lineaments and Mineralization

Nevada Overview

- NNE-SSW trend of Basin & Range” mountains, valleys

- Superposed on that pattern are other lineaments
  - Faults
  - Weak zones in crust

- Igneous intrusions and volcanoes tend to follow lineaments
  - Weak zones for easier ascent of magma
  - Weak zones for transport of hydrothermal fluids

- Mineralization associated with igneous intrusions, so associated with lineaments
Numerous Mining districts along Midas Trench, Walker Lane
Rich ones tend to be at intersections of lineaments
Can use remote sensing (and special filters) to detect lineaments

Note the location of Goldfield, NV (earlier lab) along Walker Lane lineament
General Character of Ore Bodies

Igneous intrusion at depth cools and residual fluids migrate into surrounding “country rock”

As fluids cool they deposit less soluble minerals

- Quartz rich veins
- Sulphide minerals such as pyrite (fools gold)
- Gold itself

If surrounding rocks are limestone, they neutralize acid fluids and enhance mineral precipitation

Outer edges of intrusion can also be mineralized – especially in “porphyry copper deposits”, as inner fluids move outward

Erosion removes part of country rock – exposing deeper mineralized sections

From Gilluly et al. 1968, after Butler & Loughlin, 1913
Different radial zones named after mineral groups formed in them (this class doesn't need to know names of zones – just general pattern)

Central SILICIC (quart rich) zone – This is the ORE – with gold in the quartz veins
  - Quart is resistant to erosion – forms ridges

Agrillic ring of highly “hydrothermally altered” rocks
  - When feldspar weathers it forms **clay**. Hydrothermal alteration is a kind of rapid “weathering”
  - Inner zone dominated by Illite, Kaolinite. Outer zone dominated by Montmorillonite

Propylitic zone of slightly altered rock

All surrounded by unaltered country rock

Iron rich minerals deposited in several zones – especially at surface
Clays all have OH in their structure – so have strong absorption bands in Near IR
- TM 7 will be much darker than TM 5 (because of the deep, broad 3 μm H₂O / OH band)
- TM 5 / TM 7 ratio will show clay areas as bright

Hydrothermal iron minerals are much fainter in blue (and sometimes green) than in the red
- Use TM 3 / TM 1 ratio to detect these. (Avoid usual TM 3 / TM 2 since Goethite is fairly bright in green)

From Sabins, 1997
Fig. 11-8 and 11-9
Circular pattern visible – with additional linear feature to the right

Use ratio image to show composition and suppress topography (i.e. shadows)

- Clay: TM5/TM7 shown as red – clear ring plus central “plug”
- Iron minerals: TM3/TM1 shown as green – similar distribution as clays
- Remember: red + green = yellow
Clay and Fe overlap, but Fe shows more “structure”

Use histograms of ratio images in deciding how to classify pixels

- Use to pick “thresholds”

Second peak in TM 5/7 suggests a distinctly class of clay rich pixels

Classifying pixels based on ratios

Clay: TM 5/7

Iron: TM 3/1

From Sabins, 1997
Fig. 11-8 and 11-9
Unsupervised classification run with 12 classes
Classes aggregated into 6 shown above
Used to produce geologic map on next page

<table>
<thead>
<tr>
<th>Color</th>
<th>Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow</td>
<td>Alluvium</td>
<td>39.2%</td>
</tr>
<tr>
<td>Blue</td>
<td>Basalt</td>
<td>14.0%</td>
</tr>
<tr>
<td>Purple</td>
<td>Tuff</td>
<td>6.6%</td>
</tr>
<tr>
<td>Red</td>
<td>Altered rocks, A</td>
<td>5.3%</td>
</tr>
<tr>
<td>Orange</td>
<td>Altered rocks, B</td>
<td>18.3%</td>
</tr>
<tr>
<td>Green</td>
<td>Unaltered rocks</td>
<td>16.6%</td>
</tr>
</tbody>
</table>

From Sabins, 1997
Fig. 11-8 and 11-9
Clear circular structure as “expected” from ore formation model

Most real world structures not this simple
- Only parts are exposed at surface
- Fluid flow complicated
  - will take advantage of pre-existing patterns such as existing fractures

Further complications
- We’re mapping clays and iron minerals because they are easily visible in Landsat TM bands
- We’d really like to map quartz rich rocks (ore body) but quartz has no visible or near-IR features
  - Can use erosion resistance to sense it
  - Can go to longer (10µm) region and measure emissivity variations

From Sabins, 1997
Fig. 11-5
More detail using Hyperspectral Data

- Landsat can detect clays but does not have spectral resolution to distinguish between different types of clay.
- AVIRIS (Airborne Visible IR Imaging Spectrometer) has 50 bands over the 2.00 to 2.50 µm range.
- Each pixel is probably a mix of different clays.
- Use “Spectral Un-mixing” and “Spectral End-member” techniques to determine amount of different clays.

\[ R(\lambda) = A_1 R_1(\lambda) + A_2 R_2(\lambda) + A_3 R_3(\lambda) + \ldots \]

where \( A_i \) is fraction of pixel area occupied by clay #i, and \( R_i(\lambda) \) is that clay’s reflectivity.

From Sabins, 1997
Fig. 11-17
Abundance of three different clays

- Blue = amount of illite
- Green = amount of alunite
- Red = amount of kaolinite

From Sabins, 1997
Fig. 11-17
Land Use Classification

• Multilevel classification system (Sabins Ch. 12)
  – Classifies activities (land use) and resources (land cover)
  – Repeatable results with different people, different data sets
  – Works in multiple seasons
  – Allows subcategories as more detailed data is obtained
    • 3 levels described in Sabins
    • 4th level added in Jenkins

Level 1 standard
  • Some variations in finer levels – Sabins presents a modified system
  • Jenkin's Ch. 13 presents original USGS (Anderson 1976, USGS 1992) version.
Jonah field, near Boulder, WY

Aster data
Land Use Classification

Land Use Classification (Chapter 12)

- XYZ hierarchical scheme important, but only the "upper level numbers" (the 4 in 412) are standard

- 400 Forest
  - 410 Evergreen forest
    - 411 Pine
    - 412 Redwood
    - 413 Other
  - 420 Deciduous forest
    - 421 Oak
  - 430 Mixed forest
Level 1 Classification

- 100 Urban or built-up
- 200 Agriculture
- 300 Rangeland
- 400 Forest land
- 500 Water
- 600 Wetlands
- 700 Barren Land
- 800 Tundra
- 900 Perennial snow and ice
100: Urban: Levels 2 and 3

- **110** Residential
  - **110** Residential
  - **111** Single unit, low-density (less than 2 Dwelling Units per Hectare: DUPA)
  - **112** Single unit, medium-density (2—6 DUPA)
  - ..... 
  - **114** Mobile homes
  - **115** Multiple dwellings, low-rise (2 stories or less)
  - ..... 

- **120** Commercial and services
- **130** Industrial
- **140** Transportation
- ...

- **190** Open land and others
  - **191** Undeveloped land within urban areas
Sabins vs. Jenkins (USGS) differences

• Sabins:
  – 140 Transportation
    • 141 Airports
    • 142 Railroads
    • 143 Bus and truck terminals
  – 150 Communications and utilities
    • 151 Energy facilities (electrical and gas)
    • 152 Water supply plants

• Jenkins – uses system based more directly on Anderson 1976 and USGS 1992 papers
  – 14 Transportation, Communications, and Utilities
    • 141 Transportation
      » 1411 Roads and Highways
      » 14111 dirt
      » 14112 paved
      » 14113 limited access
      » …
    – 1412 Railroad
      » …
    – 1413 Airport
      » 14131 Runway, tarmac
      » 14132 Hangar
      » 14133 Terminal
  • 142 Communications
    – …
  • 143 Utility Facilities
    – 1431 Electricity
    – 1432 Natural Gas
    – 1433 Petroleum
    – 1434 Water
200: Agriculture: Levels 2 and 3

- 210 Cropland and pasture
  - 211 Row crops
  - 212 Field Crops
  - 203 Pasture
- 220 Orchards, groves, vineyards, nurseries, and ornamental horticultural areas
  - 221 Citrus orchards
  - ....
- 230 Confined feeding operations
  - 231 Cattle
  - ....
- 240 Other agriculture
300: Rangeland: Levels 2 and 3

- 310 Grassland
- 320 Shrub and brushland
  - 321 Sagebrush prairies
  - 322 Coastal scrub
  - ....
400: Forest land: Levels 2 and 3

• 410 Evergreen forest
  • 411 Pine
  • 412 Redwood
  • 413 Other
• 420 Deciduous forest
  • 421 Oak
• 430 Mixed forest

In general for #XYZ
  X = Level 1  Landsat TM  (30 m resolution)
  Y = Level 2  Spot or high altitude aerial  (10 m resolution)
  Z = Level 3  Quickbird or low alt. aerial  (1 m resolution)
Level 1 Classification

- Los Angeles Region -- Landsat

From Sabins, 1997
Level 2 Classification

- Western Los Angeles, Spot 10m

Figure 12-3 SPOT pan image (10-m resolution) of the western portion of the Los Angeles region, used for the level II land-use classification. Image was acquired July 20, 1986.

From Sabins, 1997
Level 3 Classification

- Central Los Angeles, Aerial, ~1m

From Sabins, 1997
Great Basin Land Use Classification

From Bradey et al.