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

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

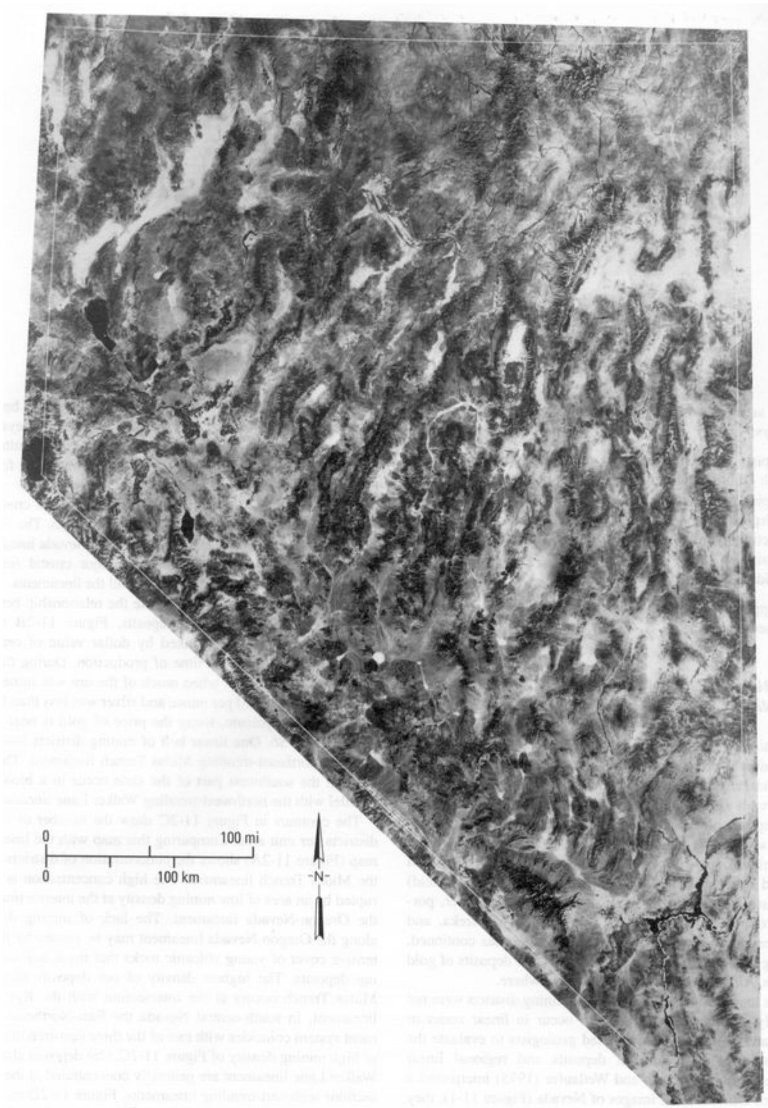


Figure 11-1 Mosaic of Nevada compiled from Landsat MSS band 5 images. From Rowan and Wetlaufer (1975, Figure 4).

Nevada Overview

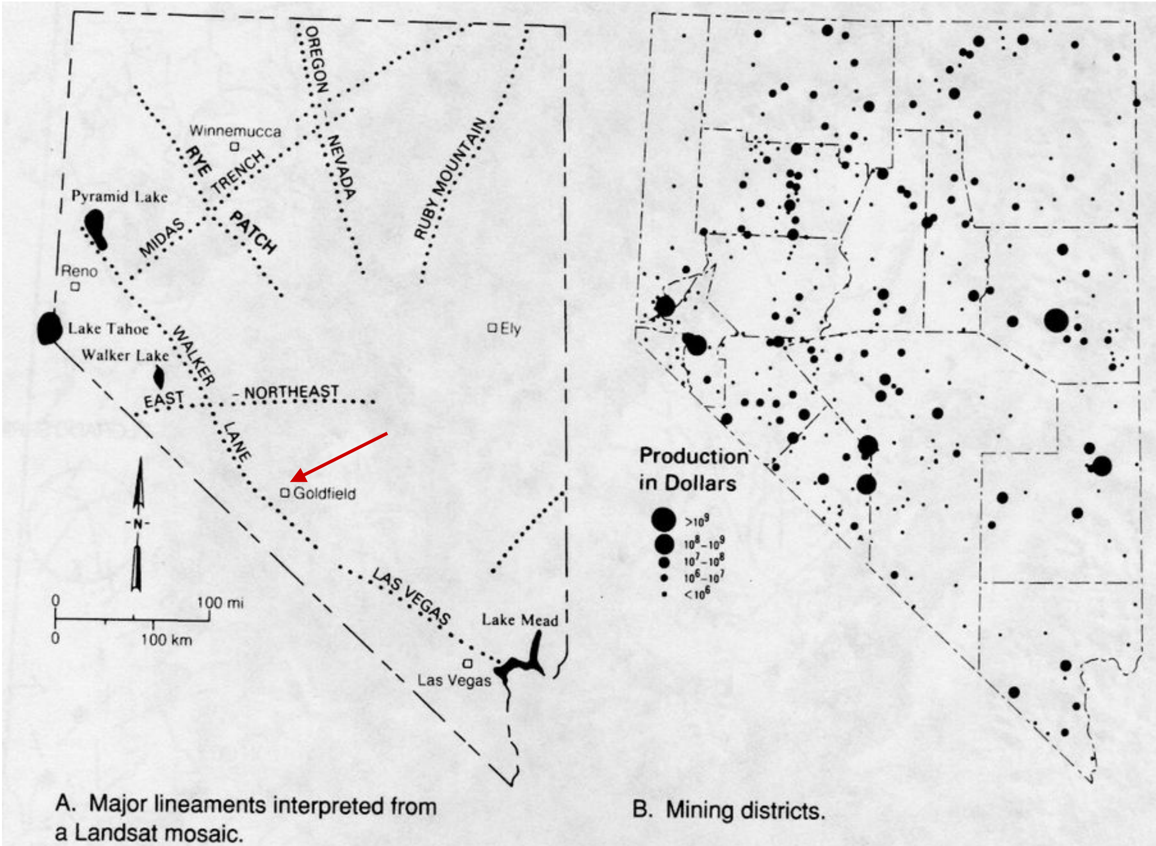
– NNE-SSW trend of
  Basin & Range” mountains, valleys

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

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

– Mineralization associated with igneous intrusions, so associated with lineaments

Nevada Lineaments and Mineralization



A. Major lineaments interpreted from a Landsat mosaic.

B. Mining districts.

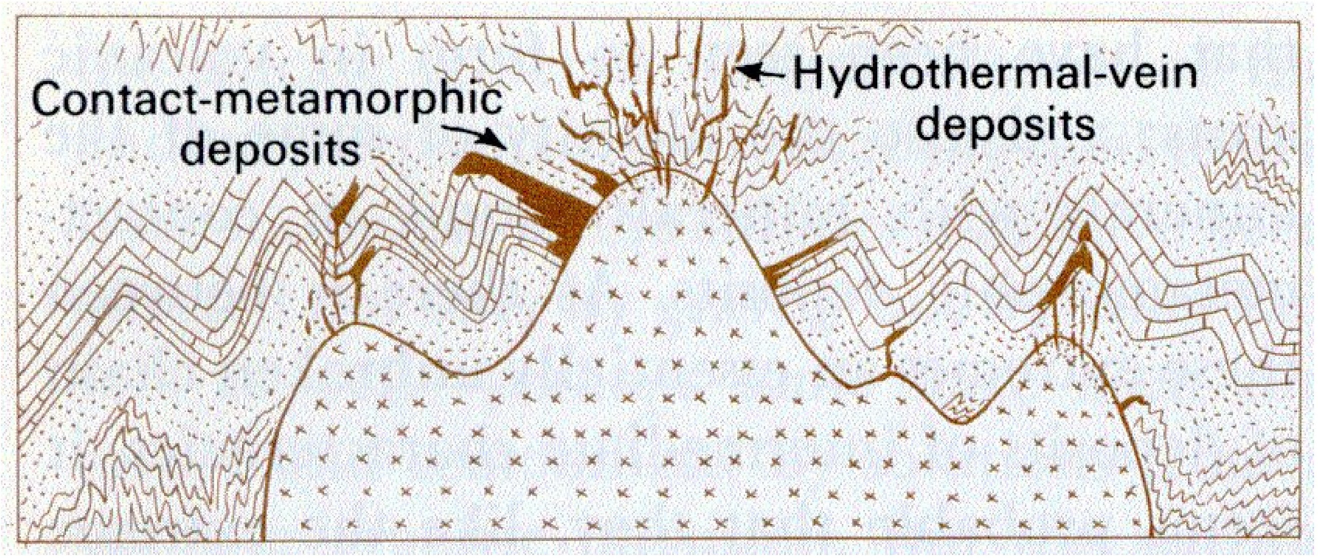
Numerous Mining districts along Midas Trench, Walker Lane

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



From Gilluly et al. 1968,
after Butler & Loughlin, 1913

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

As fluids cool they deposit less soluble minerals

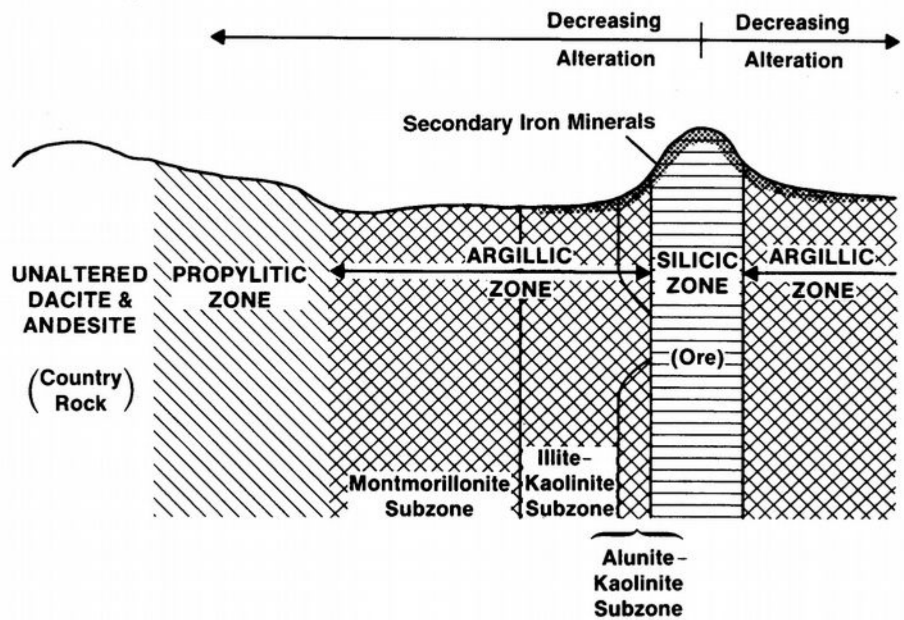
- Quartz rich veins
- Sulphide minerals such as pyrite (fools gold)
- Gold itself

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

Goldfield, NV Cross-section



From Sabins, 1997
Fig. 11-6

Caution: Only part of these zones may be exposed at the surface.

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

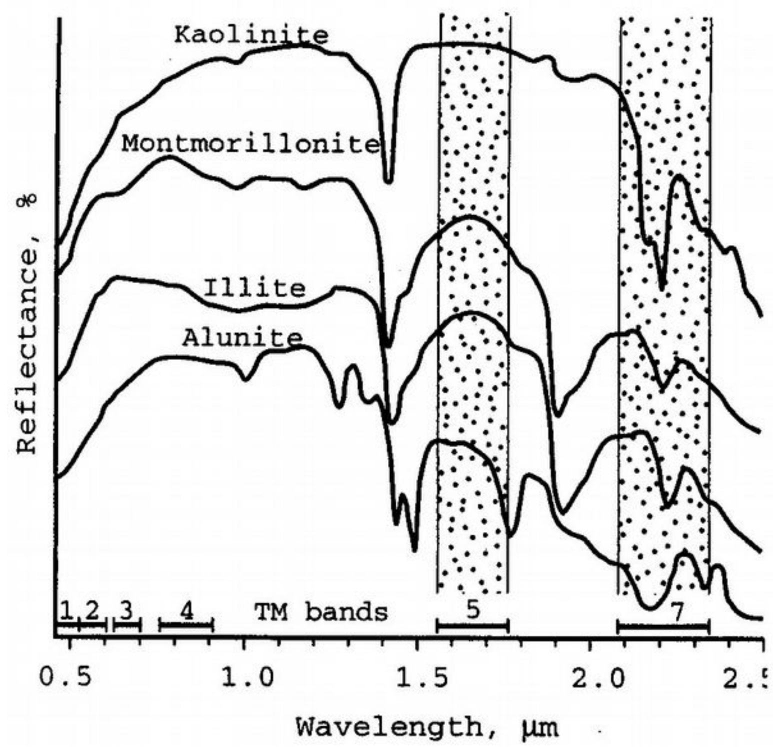
- When feldspar weathers it forms **clay**. Hydrothermal alteration is a kind of rapid "weathering"
- Inner zone dominated by Illite, Kaolinite. Outer zone dominated by Montmorillonite

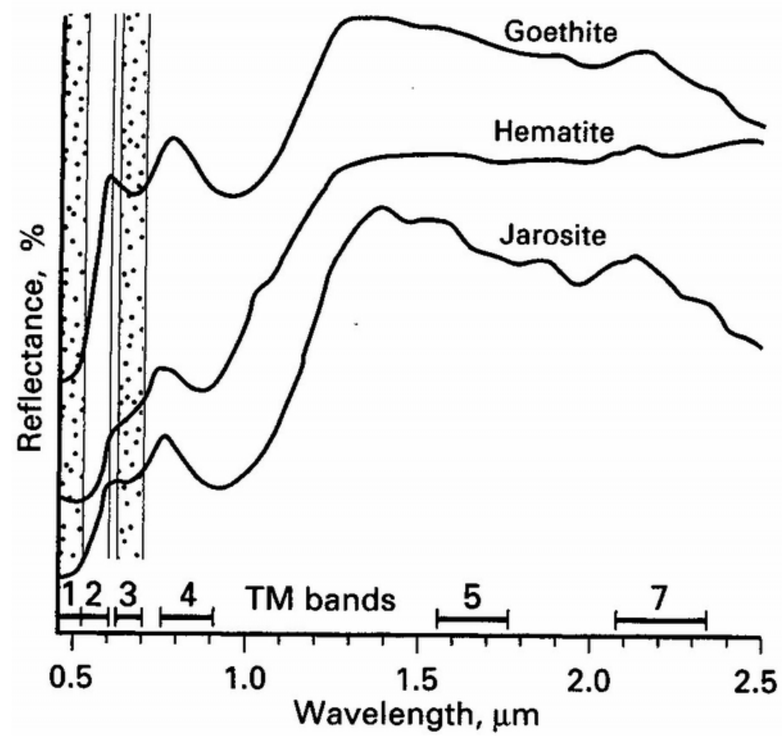
Propylitic zone of slightly altered rock

All surrounded by unaltered country rock

Iron rich minerals deposited in several zones – especially at surface

Expected Spectral Features?





From Sabins, 1997
Fig. 11-8 and 11-9

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 H_2O / 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)

Landsat TM Images of Goldfield, NV

A. TM 1-2-3 normal color image.

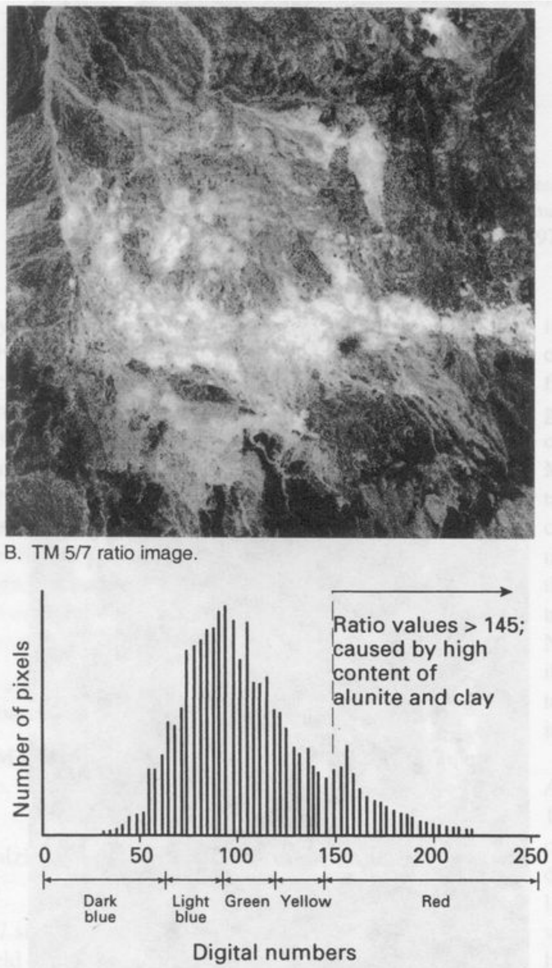
B. TM color ratio image. Ratio 5/7 = red, 3/1 = green, 3/5 = blue.

From Sabins, 1997
Plate 21

- 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

Classifying pixels based on ratios

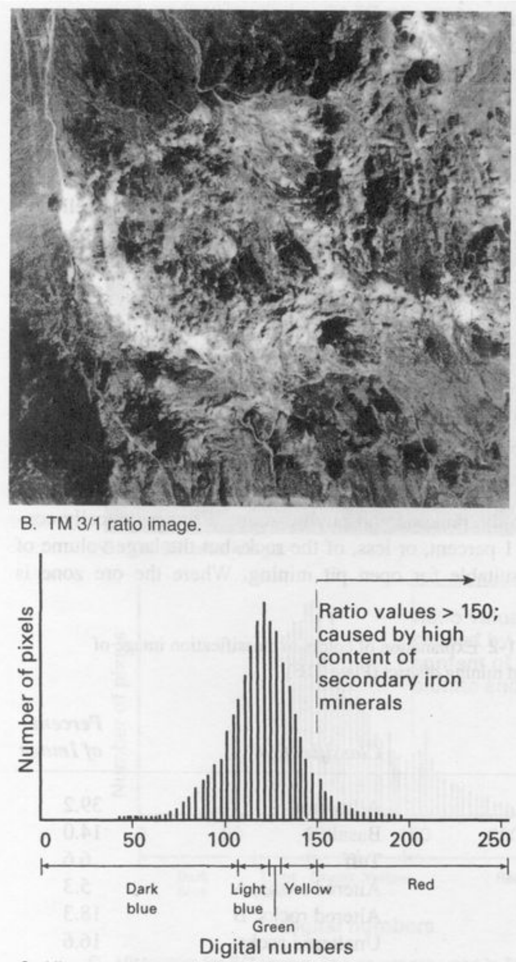
Clay: TM 5/7



C. Histogram for 5/7 image. The colors are used in Plate 21C.

Figure 11-8 Recognition of hydrothermal clays and alunite, Goldfield mining district.

Iron TM 3/1



C. Histogram for 3/1 image. The colors are used in Plate 21D.

Figure 11-9 Recognition of hydrothermal iron minerals, Goldfield mining district.

From Sabins, 1997
Fig. 11-8 and 11-9

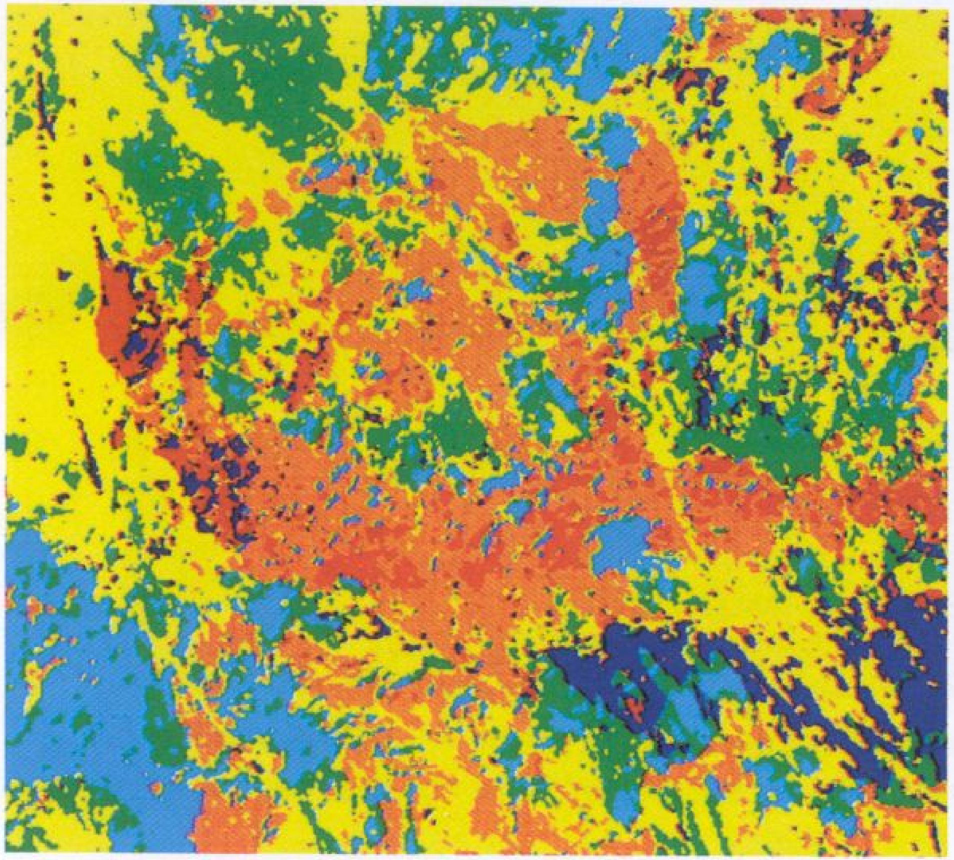
Clay and Fe overlap, but Fe shows more "structure"

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

Unsupervised classification



E. TM unsupervised classification map.

Yellow	Alluvium	39.2%
Blue	Basalt	14.0%
Purple	Tuff	6.6%
Red	Altered rocks, A	5.3%
Orange	Altered rocks, B	18.3%
Green	Unaltered rocks	16.6%

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

Geological Map

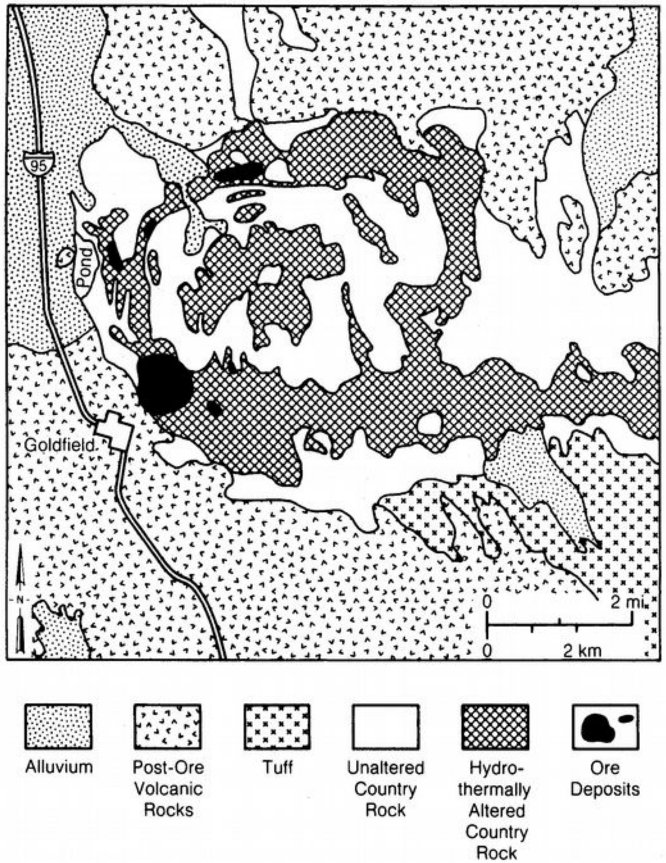


Figure 11-5 Map showing the geology and hydrothermal alteration of the Goldfield mining district, Nevada. From Ashley (1979, Figures 1 and 8).

From Sabins, 1997
Fig. 11-5

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

More detail using Hyperspectral Data

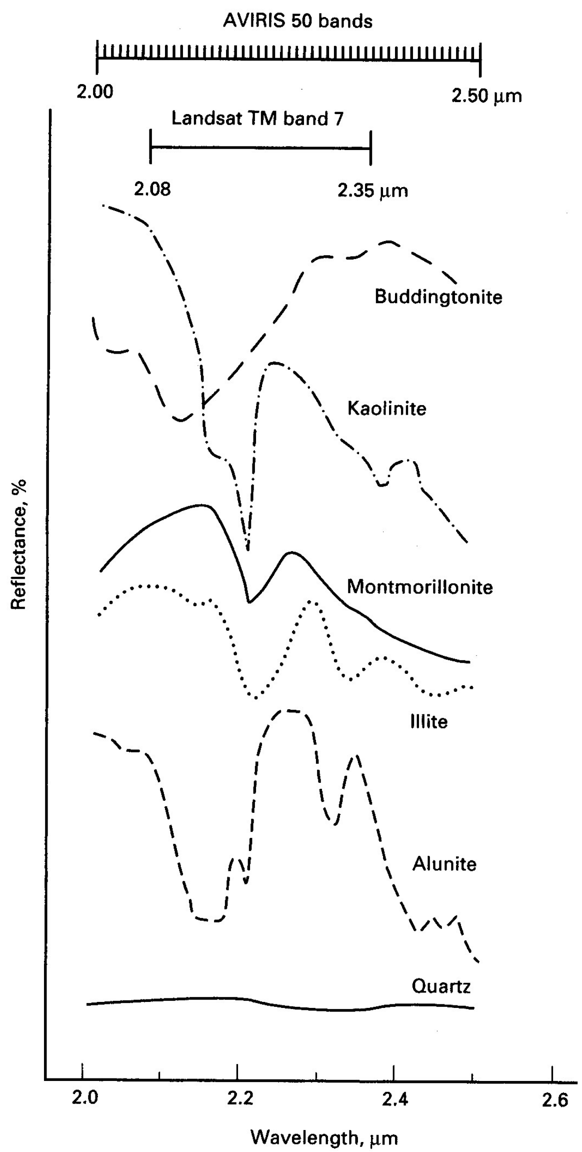


Figure 11-17 Laboratory spectra of alteration minerals in the atmospheric window from 2.0 to 2.5 µm. Spectra are offset vertically for clarity. Bandpasses of AVIRIS and TM band 7 are shown.

- 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

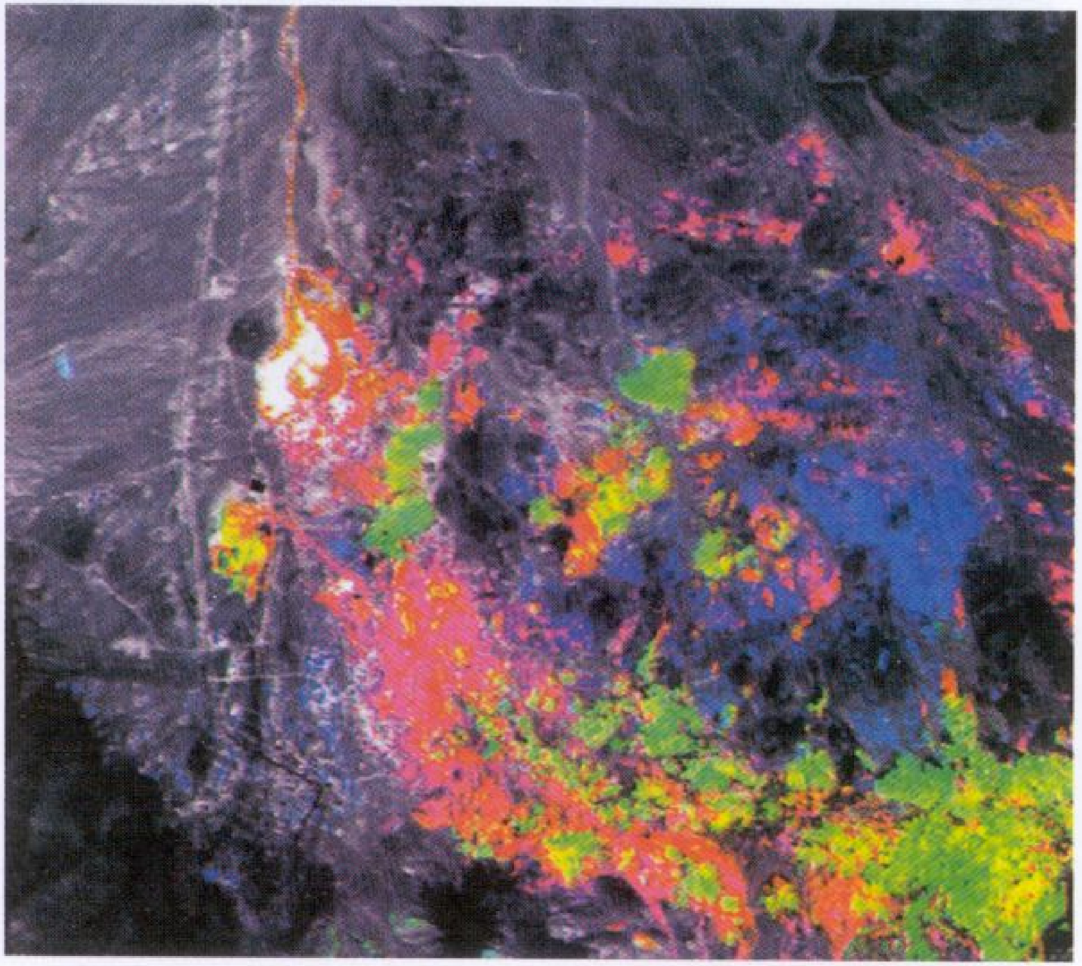
- Each pixel is probably a mix of different clays
- Use "Spectral Un-mixing" and
  "Spectral End-member" techniques
  to determine amount of different clays.

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

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



F. Color composite of AVIRIS endmember abundance images (Figure 11-18). Illite = blue, alunite = green, kaolinite = red.

- 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

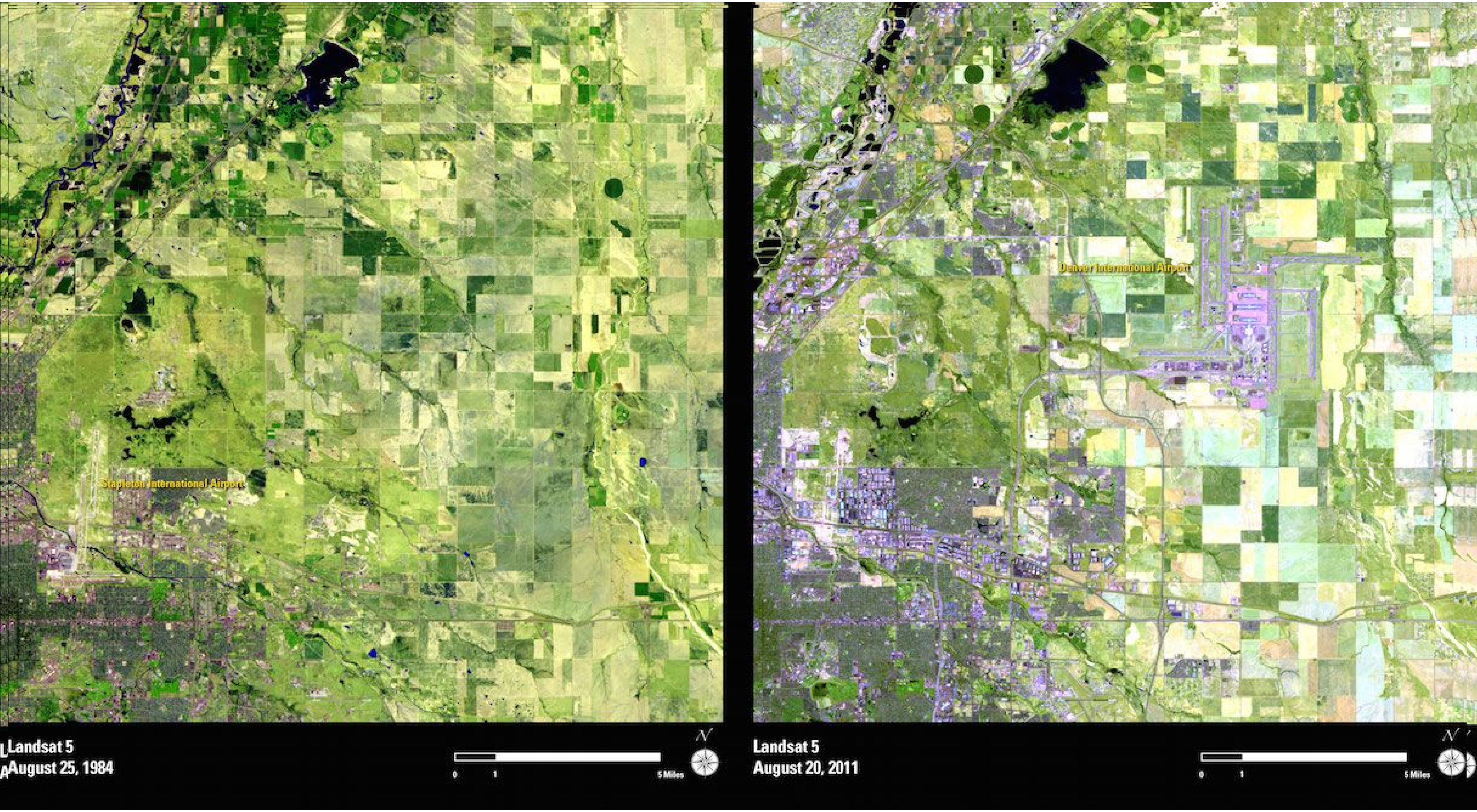
Level 1 standard

- 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

Denver Growth From Landsat



Land Use Classification

Land Use Classification (Chapter 12)

- XYZ heirarchical 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

Figure 12-1 Landsat TM band 3 (red) image of the Los Angeles region, used for level I land-use classification. Image was acquired July 3, 1985.

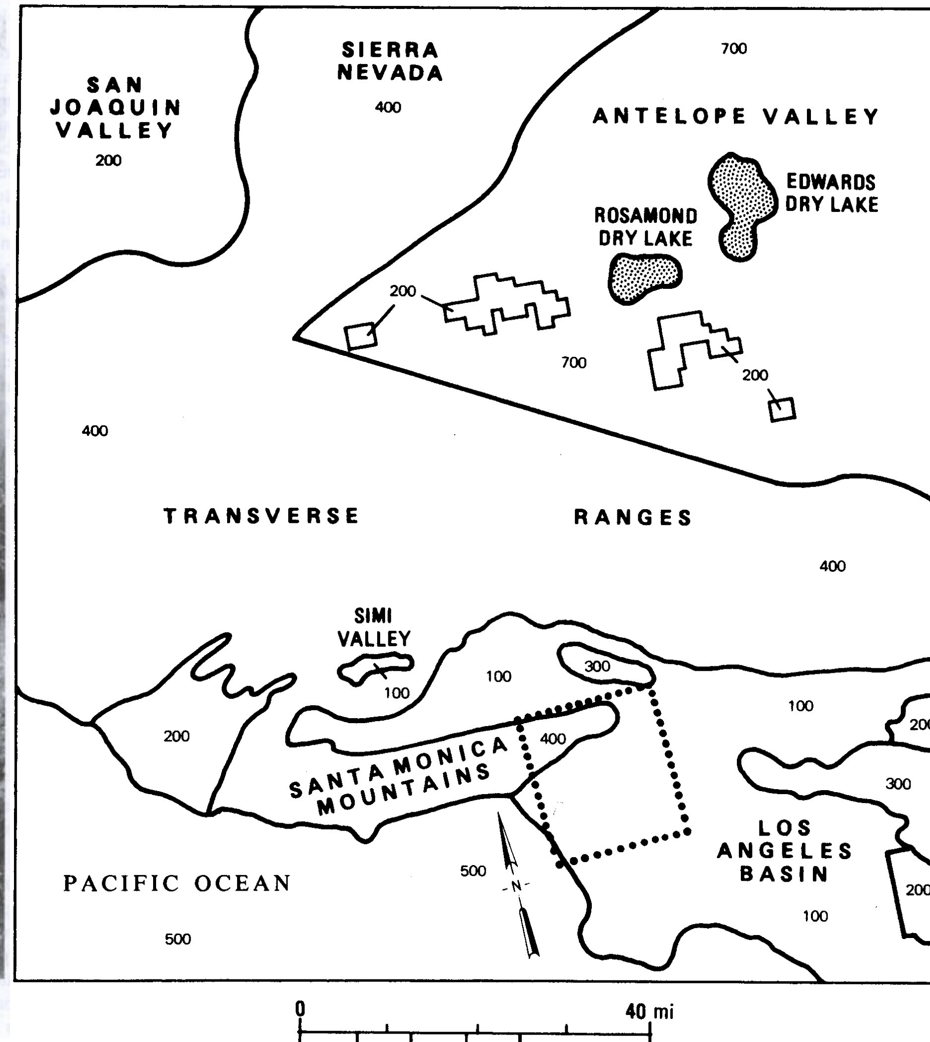


Figure 12-2 Level I land-use classification map interpreted from the Landsat image of the Los Angeles region (Figure 12-1). Categories are explained in Table 12-2.

- Los Angeles Region -- Landsat

From Sabins, 1997

Level 2 Classification

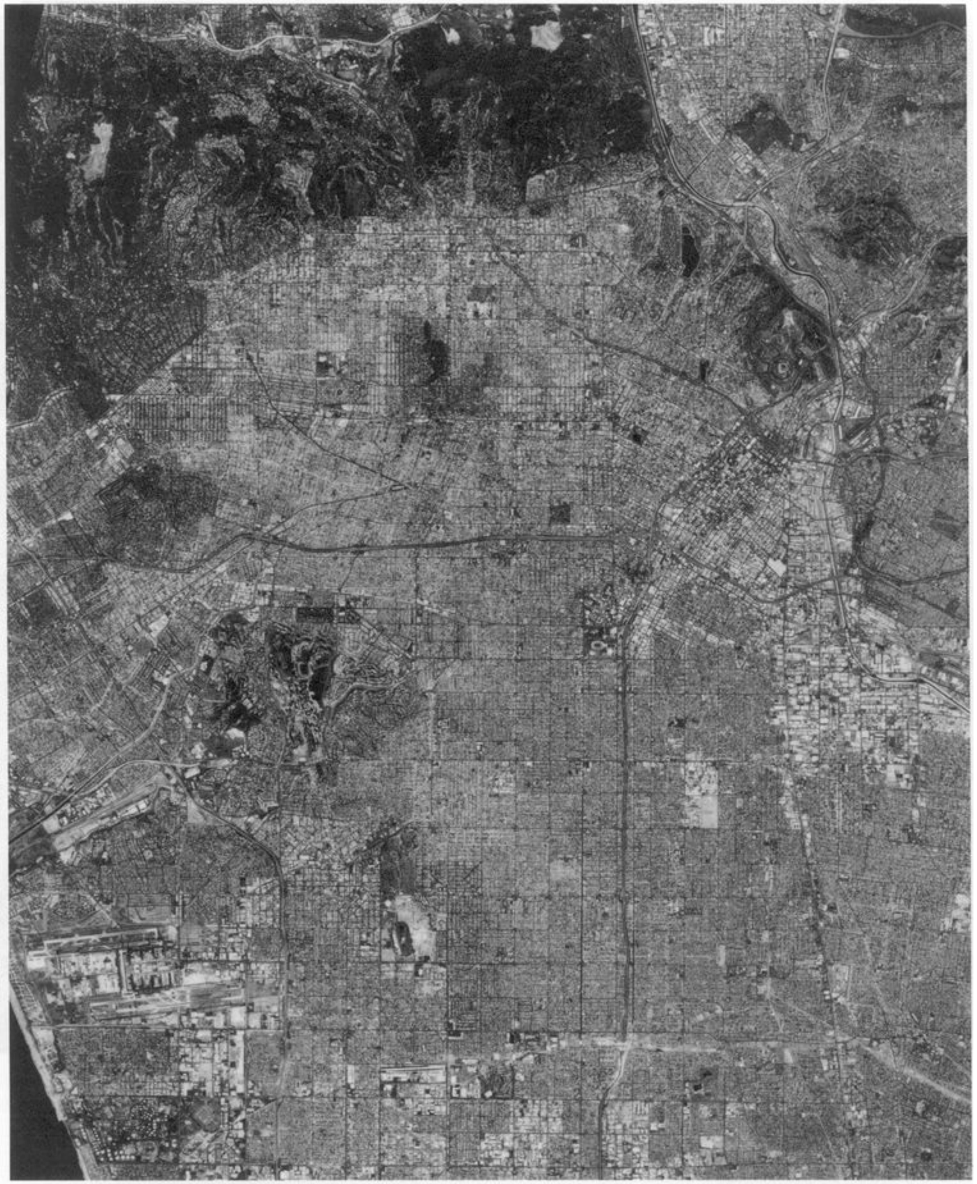
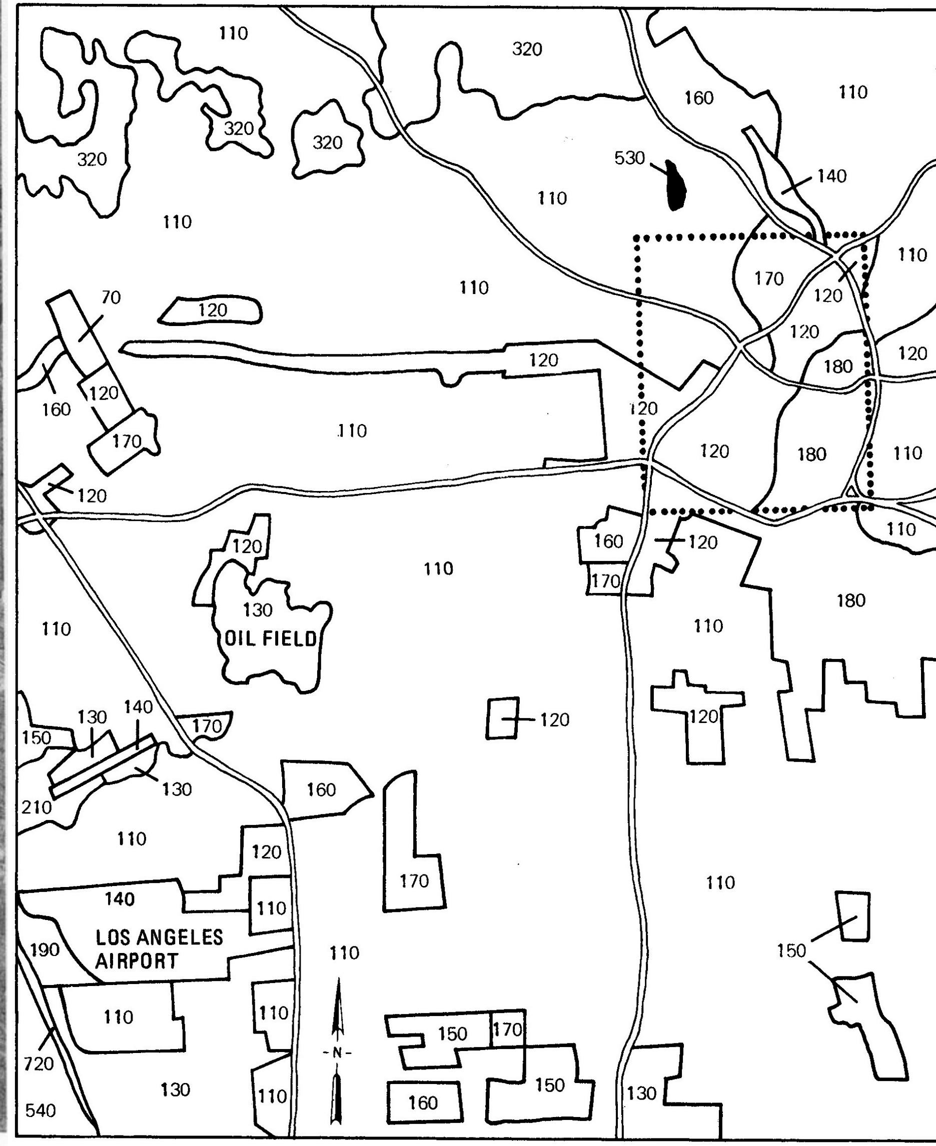


Figure 12-3 SPOT pan image (10-m resolution) of the western portion of the Los Angeles region, used for the level II land-use classification. Image was acquired July 20, 1986.

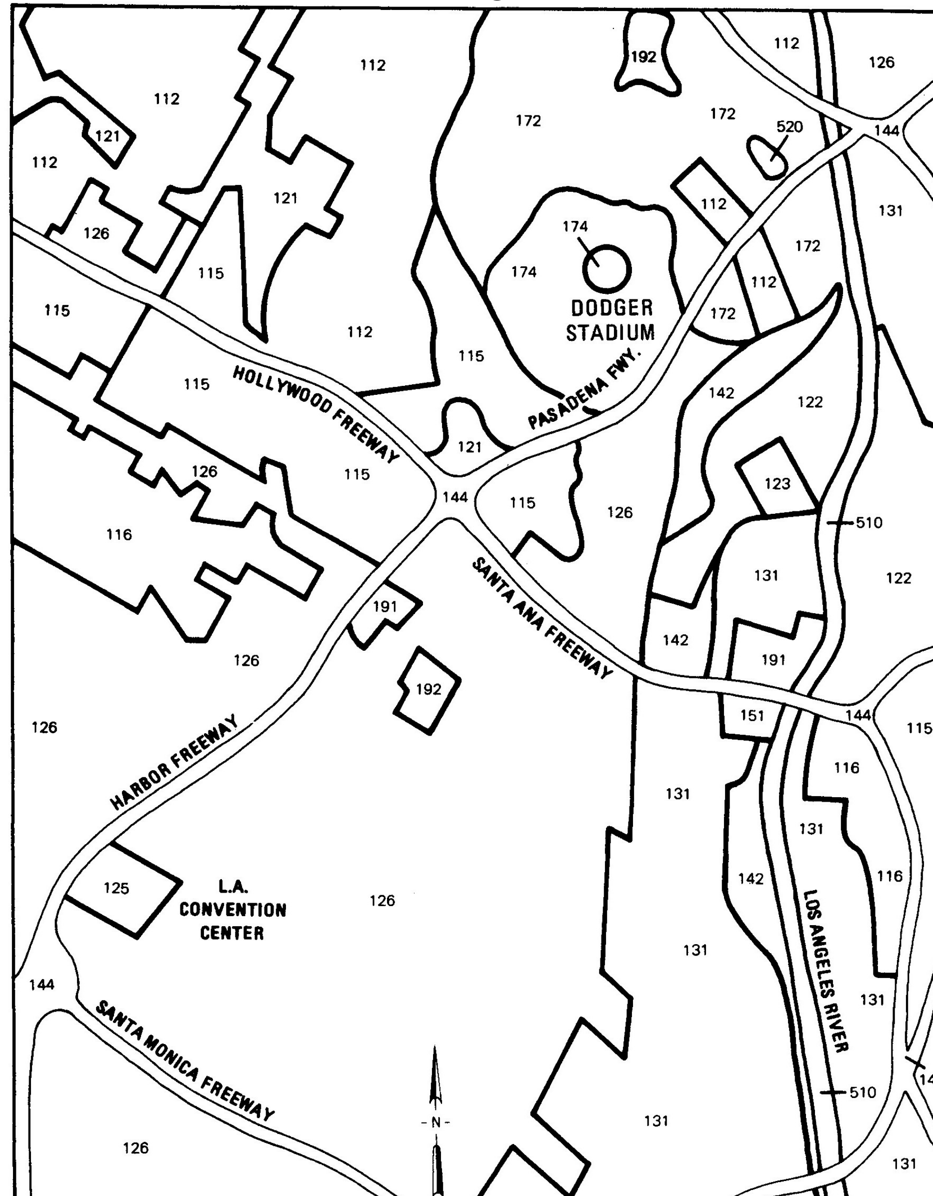
- Western Los Angeles, Spot 10m



From Sabins, 1997

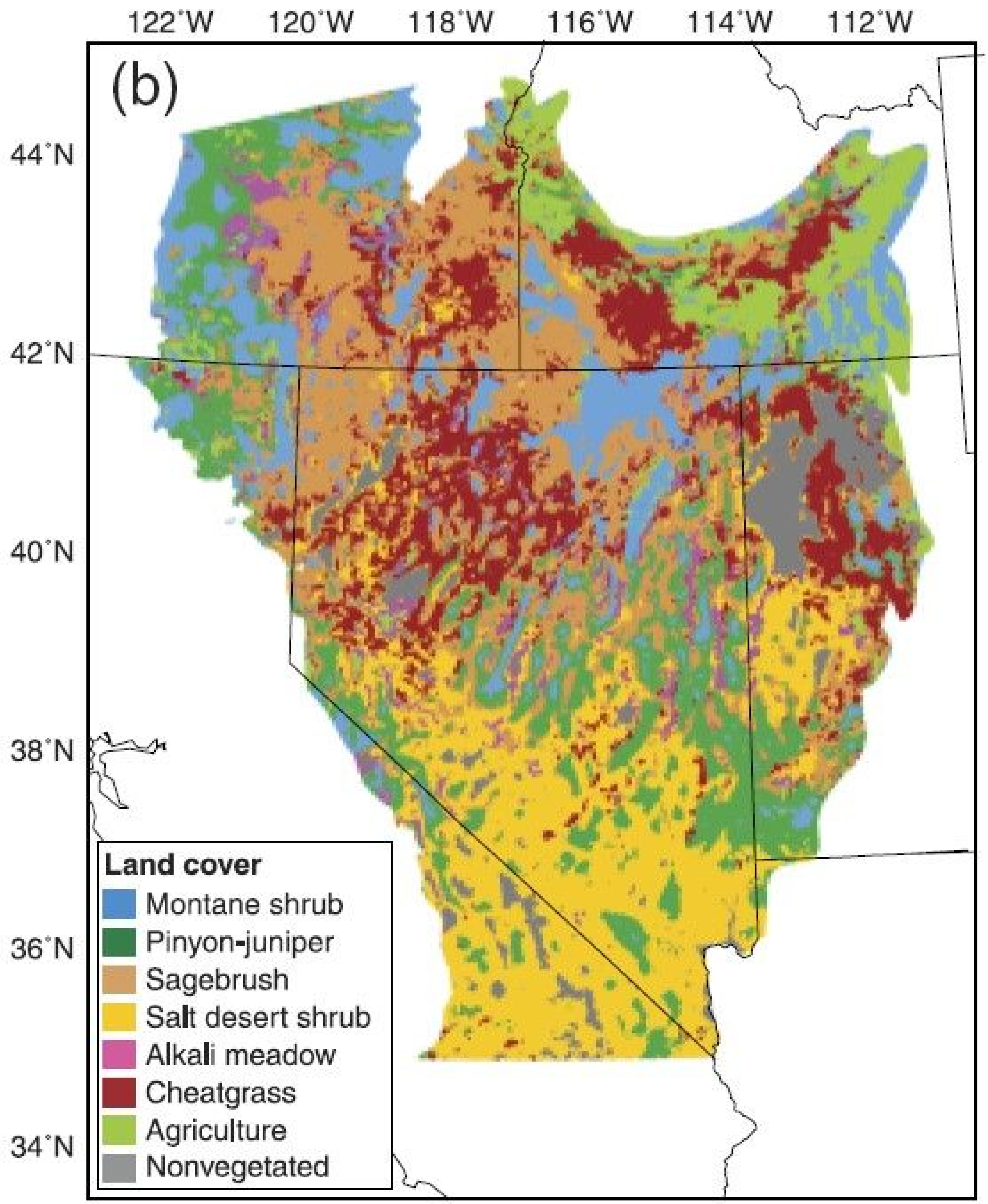
Level 3 Classification

- Central Los Angeles, Aerial, ~1m



From Sabins, 1997

Great Basin Land Use Classification



From Bradey et al.