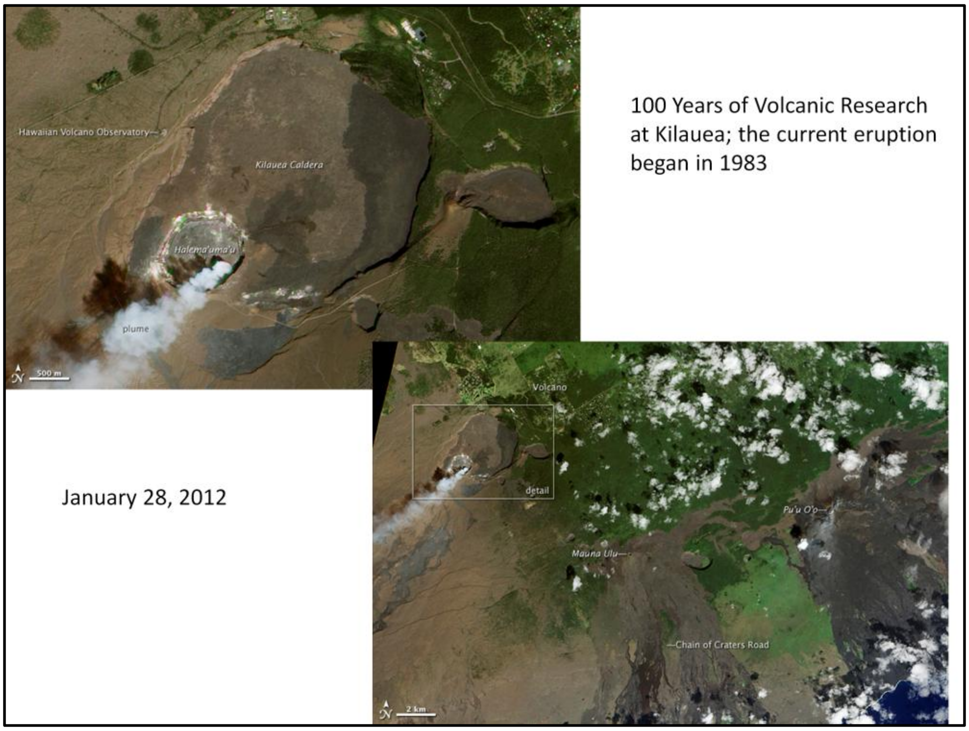


100 Years of Volcanic Research at Kilauea; the current eruption began in 1983

January 28, 2012

Kilauea has experienced a long-term eruption since 1983, though scientists have actually been keeping an eye on the volcano for much longer. January 2012 marks the 100th anniversary of the Hawaiian Volcano Observatory, which stands watch over one of our planet's most active volcanoes. Situated on the rim of Kilauea Caldera, this observatory is the oldest volcano monitoring station in the United States.

The Advanced Land Imager (ALI) on NASA's Earth Observing-1 (EO-1) satellite observed the volcano on January 28, 2012. Shown here are two natural-color views: a close-up of the Kilauea Caldera and the Hawaiian Volcano Observatory, and a wide-area view showing Mauna Ulu and Pu'u 'O'o. Within the Kilauea Caldera lies Halema'uma'u Crater. A small plume of water vapor emerges from this crater and blows toward the southwest.

The founding of the Hawaiian Volcano Observatory is generally identified as January 17, 1912, when geologist Thomas A. Jaggar, Jr., took over the continuous observations of Kilauea. In the decade before Jaggar set up shop, nearly 200,000 people died from earthquakes and volcanoes. In the wake of a devastating eruption at Mount Pelée in 1902, the National Geographic Society sponsored a volcano-observing expedition, and Jaggar was one of the participants. He soon concluded that, rather than studying the damage caused by eruptions, scientists would do more good to identify the precursors. On a trip through Hawaii, he negotiated with local businessmen and secured financial support for an observatory. In 1911, he hired volcanologist Frank Perret to monitor the volcano, then took over observations in January 1912.

Jaggar immediately brought detailed documentation to the observatory, and soon expanded the activities beyond his own observations. The installation of seismometers provided evidence of the link between earthquakes and volcanism. In the 1950s, the observatory installed tiltmeters to help measure surface deformation caused by the movement of magma below the surface. Researchers at the observatory collected gas samples in 1912—some of the earliest high-temperature volcanic gas samples ever collected—and drilled into a lava lake in the 1980s to better understand how volcanic rocks crystallize.

In 2012, a century after its founding, the Hawaiian Volcano Observatory hosts 25 scientists and support personnel, along with students and volunteers. It tracks the activity of Kilauea, Mauna Loa, and other volcanoes in the Hawaiian Islands, as well as the associated earthquakes.

References

Hawaiian Volcano Observatory. Accessed January 30, 2012.

Kauahikaua, J., Poland, M. (2012). One hundred years of volcano monitoring in Hawaii. *EOS,* 93(3), 29–30.

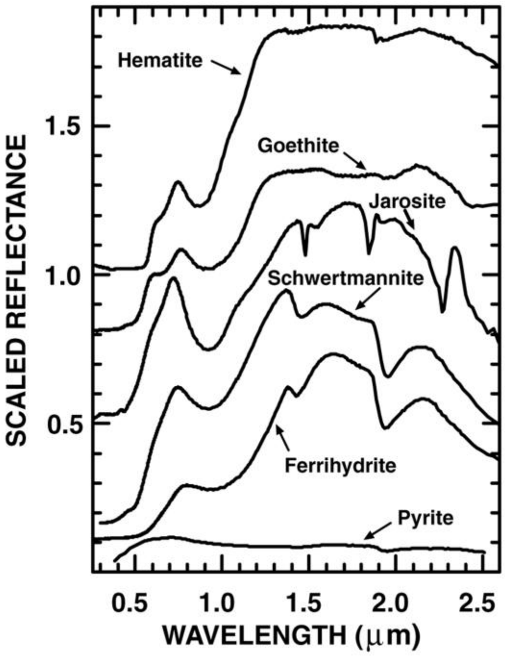
NASA Earth Observatory image created by Jesse Allen and Robert Simmon, using EO-1 ALI data provided courtesy of the NASA EO-1 team. Caption by Michon Scott.

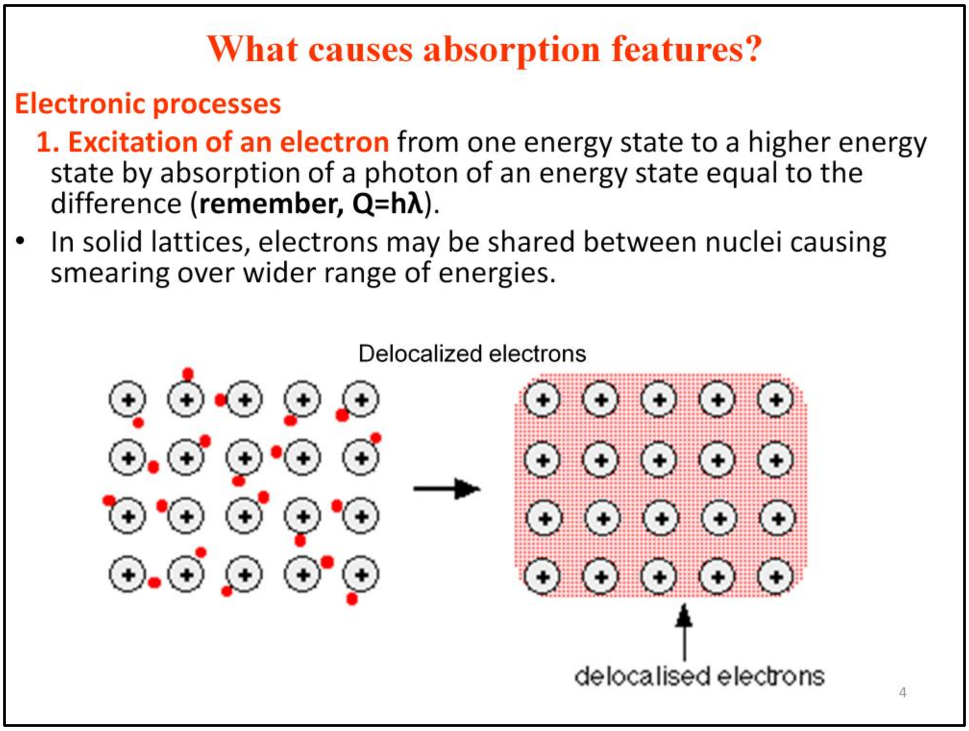
Instrument: EO-1 - ALI

What causes absorption features in geologic minerals?

- **Electronic transitions** – absorption in wavelengths up to about 1.0 µm

- **Vibrations** –‘shake, rattle and roll’ – at the molecular level – absorption at wavelengths beginning about 0.7 µm and extending beyond the TIR.


Hematite
Goethite
Jarosite
Schwertmannite
Ferrihydrite
Pyrite
SCALED REFLECTANCE
1.5
1.0
0.5
0.5
1.0
1.5
2.0
2.5
WAVELENGTH (μm)



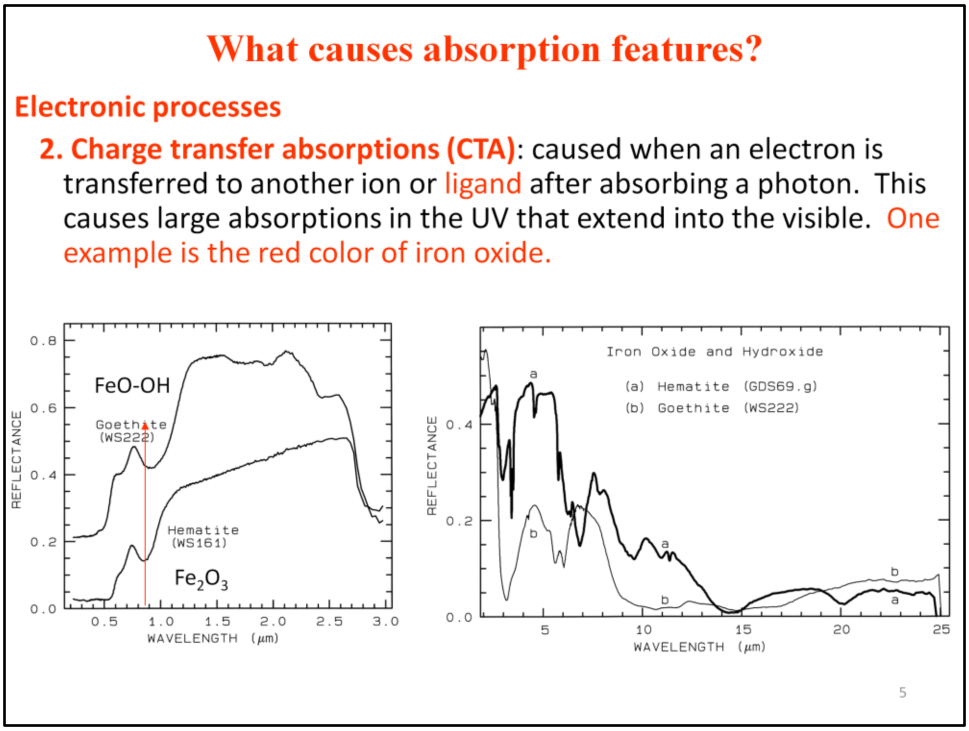
What causes absorption features?

Electronic processes

1. **Excitation of an electron** from one energy state to a higher energy state by absorption of a photon of an energy state equal to the difference (**remember, Q=hλ**).

- In solid lattices, electrons may be shared between nuclei causing smearing over wider range of energies.

In a solid (like a crystal) electrons may be shared causing the energy levels to be smeared over a range. Energy level depends on valance state of atom (e.g., Fe+2, Fe+3), coordination number, and symmetry of the site.
The electrons can move freely within the orbitals of the molecular lattice and so electrons become detached from its atom. The electrons are said to be ***delocalised.*** The metal is held together by the strong forces of attraction between the positive nuclei and the delocalised electrons.



What causes absorption features?

Electronic processes

2. Charge transfer absorptions (CTA): caused when an electron is transferred to another ion or ligand after absorbing a photon. This causes large absorptions in the UV that extend into the visible. One example is the red color of iron oxide.

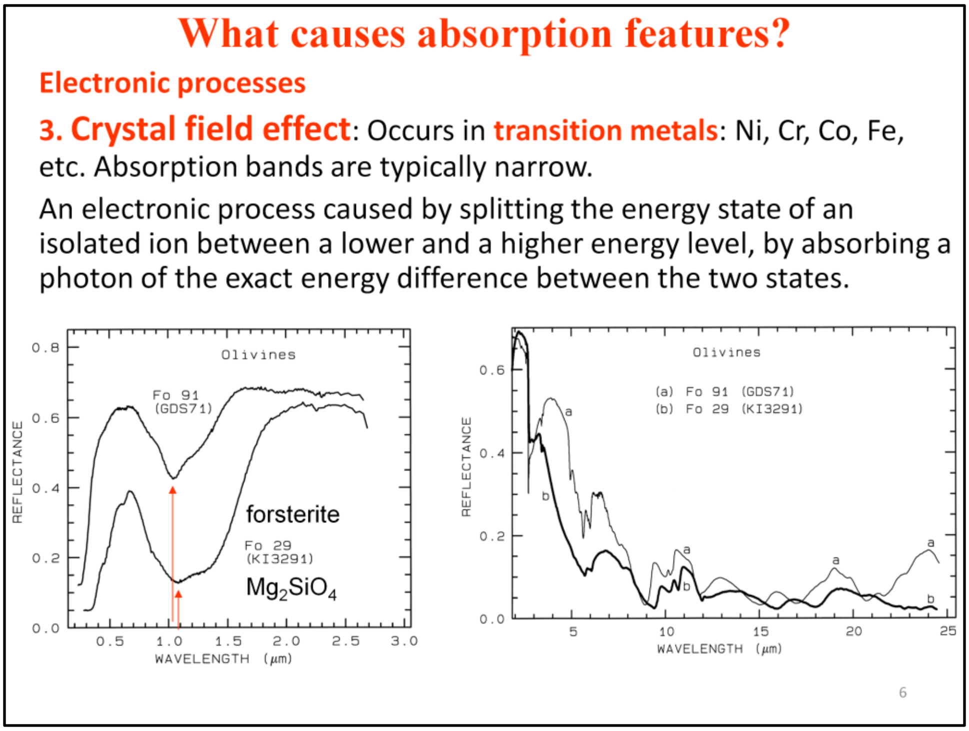
Transfer of an electron between ions or between ions and ligands. Can occur with different valence states in a metal (e.g., Fe^{+2} and Fe^{+3}).
A ligand is an atom, ion or functional group that donates its electrons through a coordinated covalent bond to one or more central atoms or ions, usually metals. An array of such ligands around a center is termed a **complex**.

CTA are generally diagnostic of specific minerals. They typically occur in the UV and have wings that extend into the visible. The shape may change with grain size. Absorption bands rapidly decrease in intensity in small sized grains because of the increased surface/volume ratio.

MnO_4^- : The permanganate ion having tetrahedral geometry is intensely purple due to strong absorption involving charge transfer from molecular orbitals derived primarily from oxygen to manganese(VII).
CdS: The color of artist's pigment cadmium yellow is due to transition from Cd^{2+} (5s) ← S^{2-}(π).
HgS: it is red due to Hg^{2+} (6s) ← S^{2-}(π) transition.
Fe Oxides: they are red and yellow due to transition from Fe (3d) ← O^{2-}(π).

(Left on slide) Reflectance spectra of the iron oxide hematite (Fe_2O_3) [ion Fe^{+3}] and iron hydroxide goethite (FeO-OH), [Fe^{+2}] from Clark *et al*., 1993b). The

intense charge-transfer band in the UV (< 0.4 µm) is "saturated" in reflectance, so only first surface (specular) reflection is seen in these spectra. The 0.9-µm and 0.86-µm absorption features are due to Laporte-forbidden transitions (e.g. Morris *et al,* 1985; Sherman, 1990 and references therein). The absorption at 2.7-3.0 µm is due to trace water in the samples., and in the case of goethite, the OH. The goethite spectrum is offset upward 0.2 units.
(Right) For mid-infrared wavelengths, without offsets



What causes absorption features?

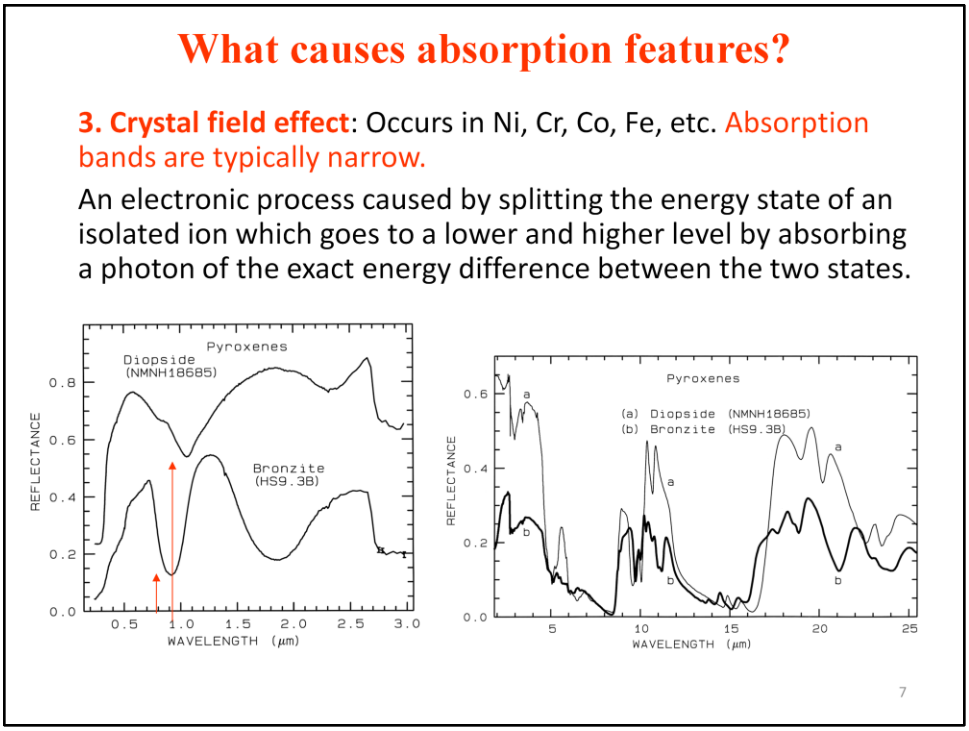
Electronic processes

3. Crystal field effect: Occurs in **transition metals**: Ni, Cr, Co, Fe, etc. Absorption bands are typically narrow.

An electronic process caused by splitting the energy state of an isolated ion between a lower and a higher energy level, by absorbing a photon of the exact energy difference between the two states.

(left) Reflectance spectra of two olivines showing the change in band position and shape with chemical composition. The 1-µm absorption band is due to a **crystal field absorption of Fe^{2+}**. “Fo" stands for forsterite (Mg2SiO4) in the forsterite-fayalite (Fe2+SiO4) olivine solid solution series. The Fo 29 sample (KI3291 from King and Ridley, 1987) has an FeO content of 53.65%, while the Fo 91 sample (GDS 71; labeled Twin Sisters Peak in King and Ridley, 1987) has an FeO content of 7.93%. The mean grain size is 30 and 25 µm respectively. The 1-µm band position varies from about 1.08 µm at Fo 10 to 1.05 µm at Fo 90 (King and Ridley, 1987).

(Right) Same as left, but for mid-infrared wavelengths. Note the shifts in the spectral features due to the change in composition. See text for discussion of vibrational absorption bands.
From Roger Clark, Spectroscopy of Rocks and Minerals, and Principles of Spectroscopy.



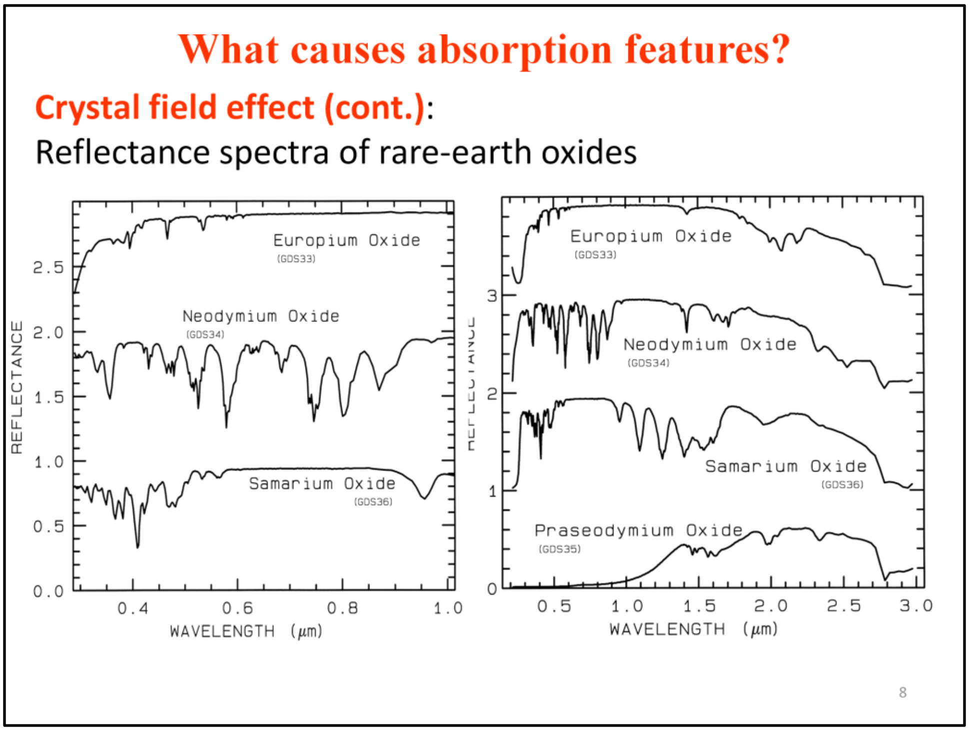
What causes absorption features?

3. Crystal field effect: Occurs in Ni, Cr, Co, Fe, etc. Absorption bands are typically narrow.

An electronic process caused by splitting the energy state of an isolated ion which goes to a lower and higher level by absorbing a photon of the exact energy difference between the two states.

7

Spectra of two pyroxenes. Note shift in band position and shape between samples of different mineral compositions



What causes absorption features?

Crystal field effect (cont.):

Reflectance spectra of rare-earth oxides

(Left) Reflectance spectra of rare-earth oxides, showing absorptions in the visible region. Spectra are offset 1.0 units for clarity. Spectral resolution is about 1 nm.

(Right) Reflectance spectra of rare-earth oxides. These absorptions are due to crystal-field transitions involving deep-lying electrons of the rare-earth elements and do not shift when the rare-earth ion is in another mineral. Each spectrum is offset by 1.0 units for clarity.

Spectra from Clark *et al.* (1993b).

Spectralon: Approved NIST Standard

99% White Reflecting Panels

Gray panels of known reflectance

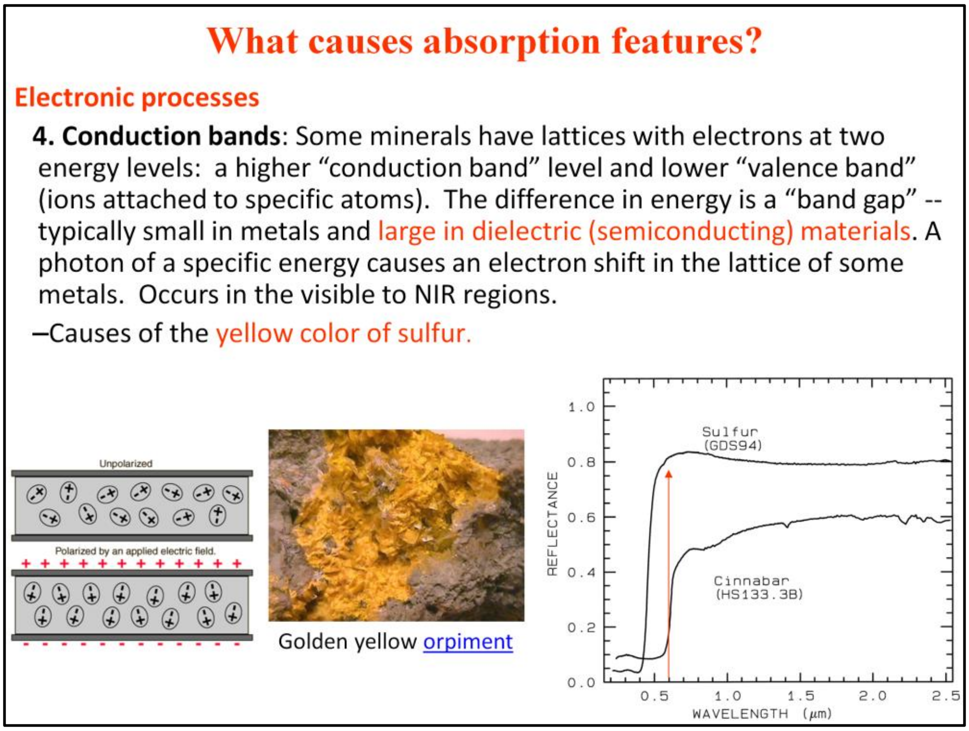
Rare Earths calibrate wavelength positions

National Institute of Standards and Technology (NIST)

See Rare Earth spectra in previous lecture. The narrow band spectral features are used to determine wavelength calibration. Holmium Oxide for UV-VIS-NIR applications

Dysprosium Oxide for NIR applications

Erbium Oxide for VIS-NIR applications



What causes absorption features?

Electronic processes

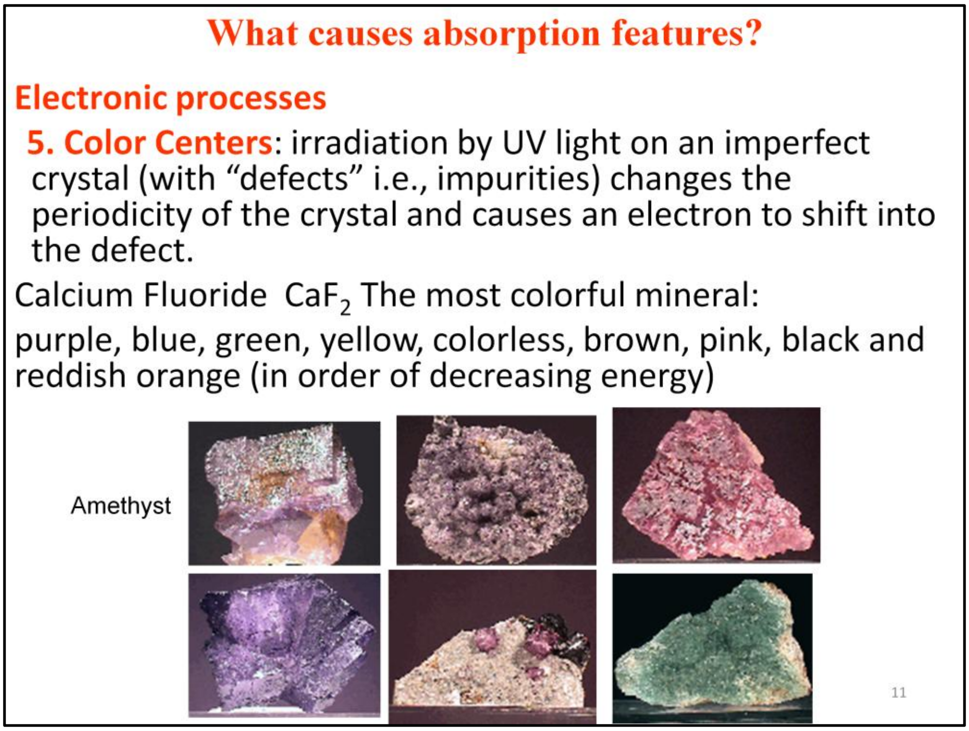
4. Conduction bands: Some minerals have lattices with electrons at two energy levels: a higher “conduction band” level and lower “valence band” (ions attached to specific atoms). The difference in energy is a “band gap” -- typically small in metals and large in dielectric (semiconducting) materials. A photon of a specific energy causes an electron shift in the lattice of some metals. Occurs in the visible to NIR regions.

–Causes of the yellow color of sulfur.

Golden yellow orpiment

A dielectric material contains polar (partially charged) molecules. An applied electric field will polarize the material by orienting the dipole moments of polar molecules.
Cinnabar is HgS

In compounds of sulfur (where known), the most common oxidation numbers of sulfur are: **6, 4, 2, and -2**.



What causes absorption features?

Electronic processes

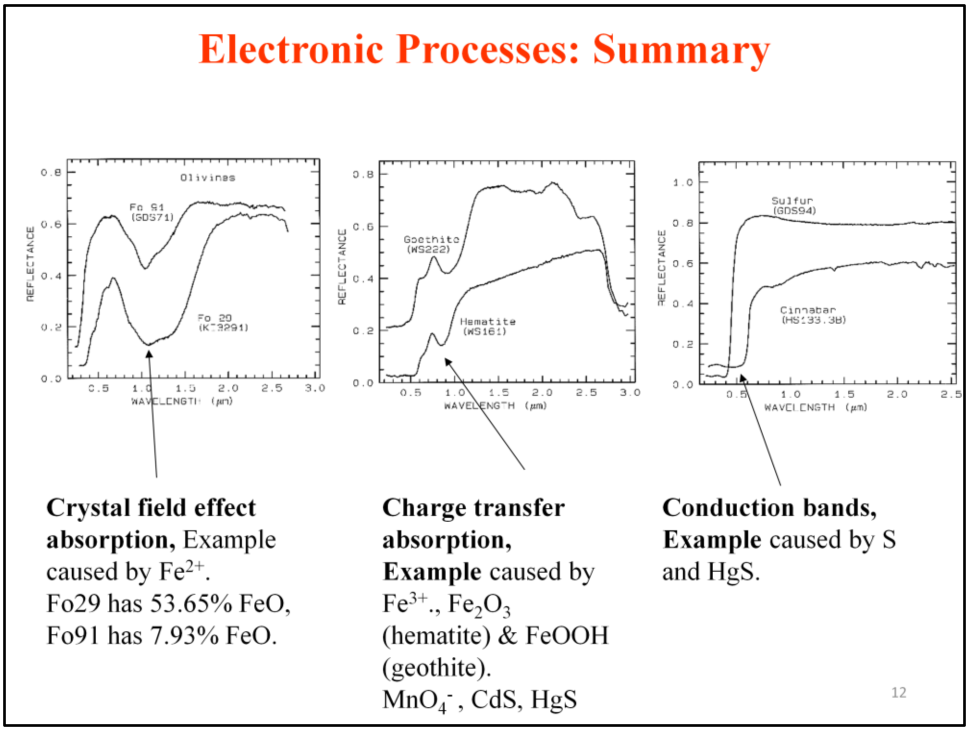
5. Color Centers: irradiation by UV light on an imperfect crystal (with “defects” i.e., impurities) changes the periodicity of the crystal and causes an electron to shift into the defect.

Calcium Fluoride CaF_2 The most colorful mineral:

purple, blue, green, yellow, colorless, brown, pink, black and reddish orange (in order of decreasing energy)

THERMOLUMINESCENCE

Thermoluminescence is a property of some minerals (E.G., FLUORIDE COMPOUNDS) to glow when heated. The minerals contain chemical bonds that emit light when thermal energy (heat) is applied to them. Activator elements must be present in these minerals just like in UV fluorescence.



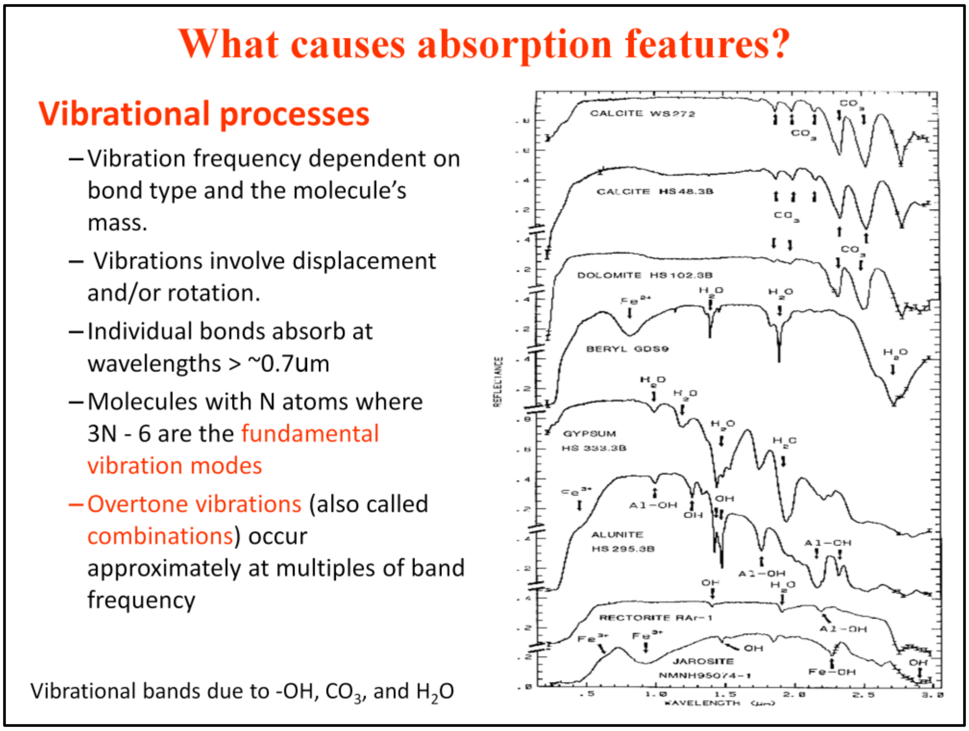
Electronic Processes: Summary

Crystal field effect absorption, Example caused by Fe^{2+}.
Fo29 has 53.65% FeO,
Fo91 has 7.93% FeO.

Charge transfer absorption,
Example caused by Fe^{3+}., Fe_2O_3 (hematite) & FeOOH (geothite).
MnO_4^-, CdS, HgS

Conduction bands,
Example caused by S and HgS.

Mn manganese
O oxygen
Cd cadmium
S sulfur
Hg mercury
Fe iron



What causes absorption features?

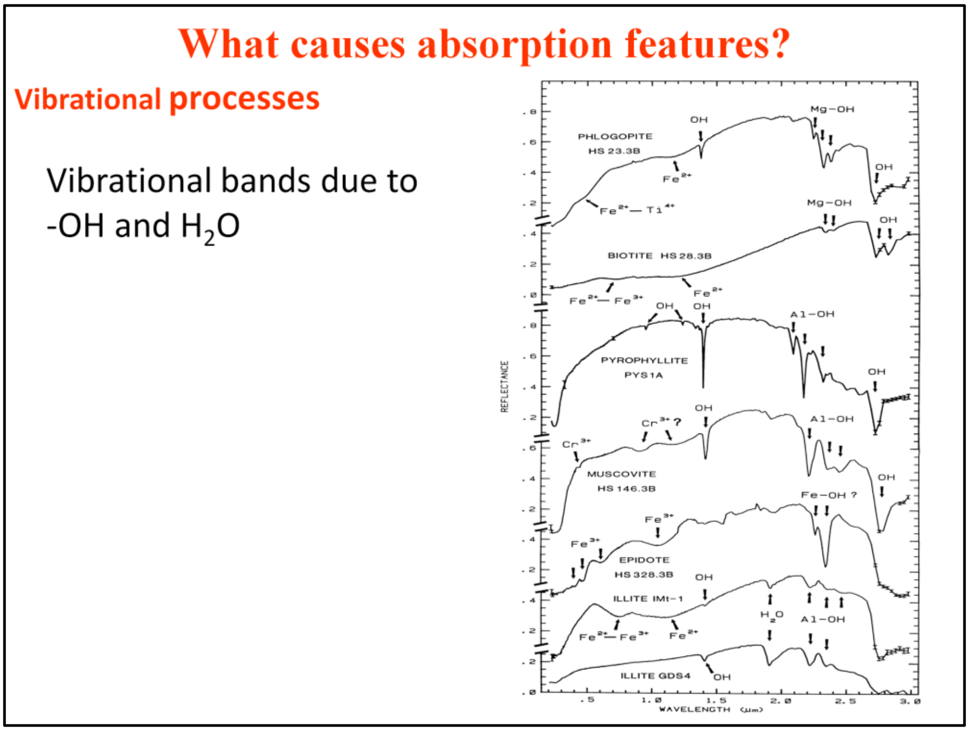
Vibrational processes

- Vibration frequency dependent on bond type and the molecule’s mass.
- Vibrations involve displacement and/or rotation.
- Individual bonds absorb at wavelengths > ~0.7um
- Molecules with N atoms where 3N - 6 are the fundamental vibration modes
- Overtone vibrations (also called combinations) occur approximately at multiples of band frequency

Vibrational bands due to -OH, CO_3, and H_2O

Vibrational bands due to OH, CO3, and H2O

Some materials have important vibrational absorptions: water, hydroxyl, carbonates, phosphates, borates, arsenates, vanadates (metallic elements that combine with vanadium (VO4)-3 (VO3)-1 radicals)

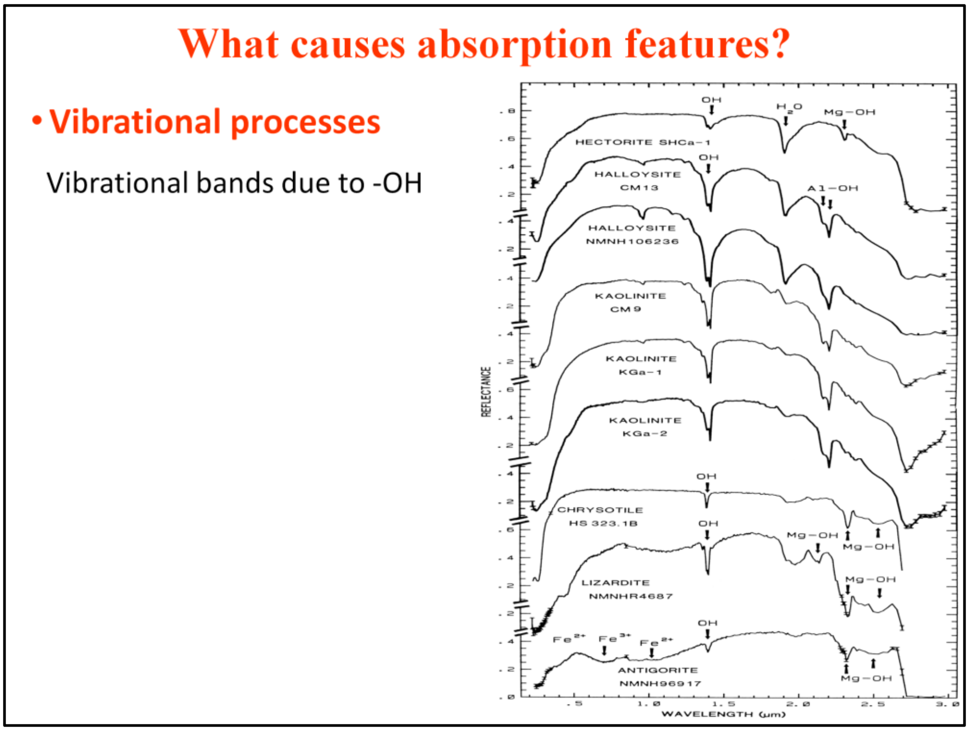


What causes absorption features?

Vibrational processes

Vibrational bands due to -OH and H_2O

Vibrational bands due to OH and H2O



What causes absorption features?

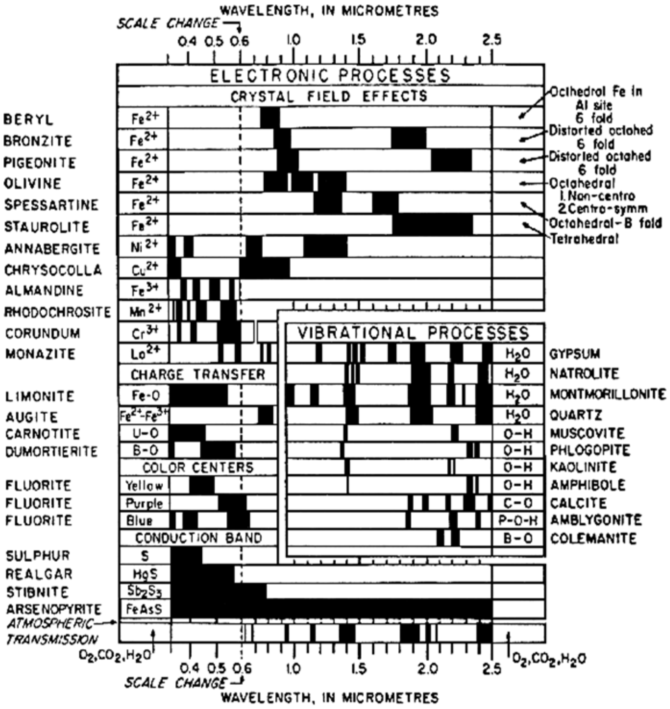
- **Vibrational processes**

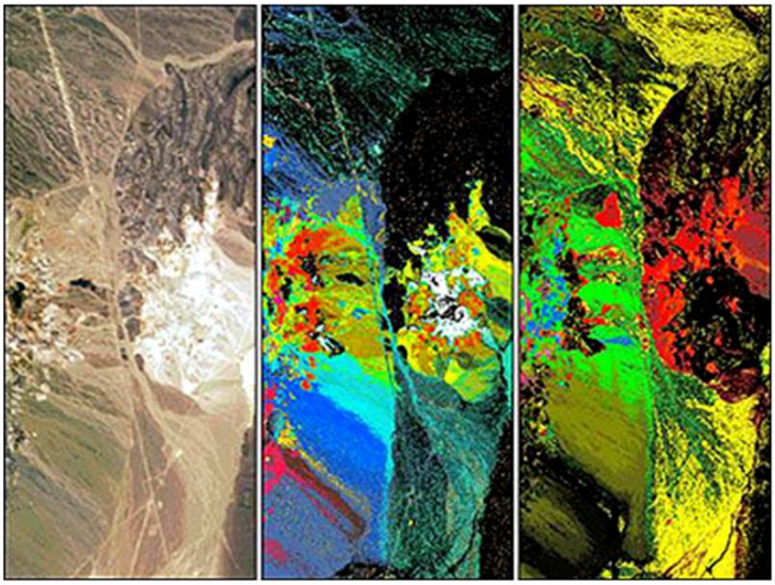
Vibrational bands due to -OH

Vibrational bands due to OH

Identifying Minerals with Spectroscopy

Absorption features used to determine the chemical composition of materials from a spectral reflectance curve.

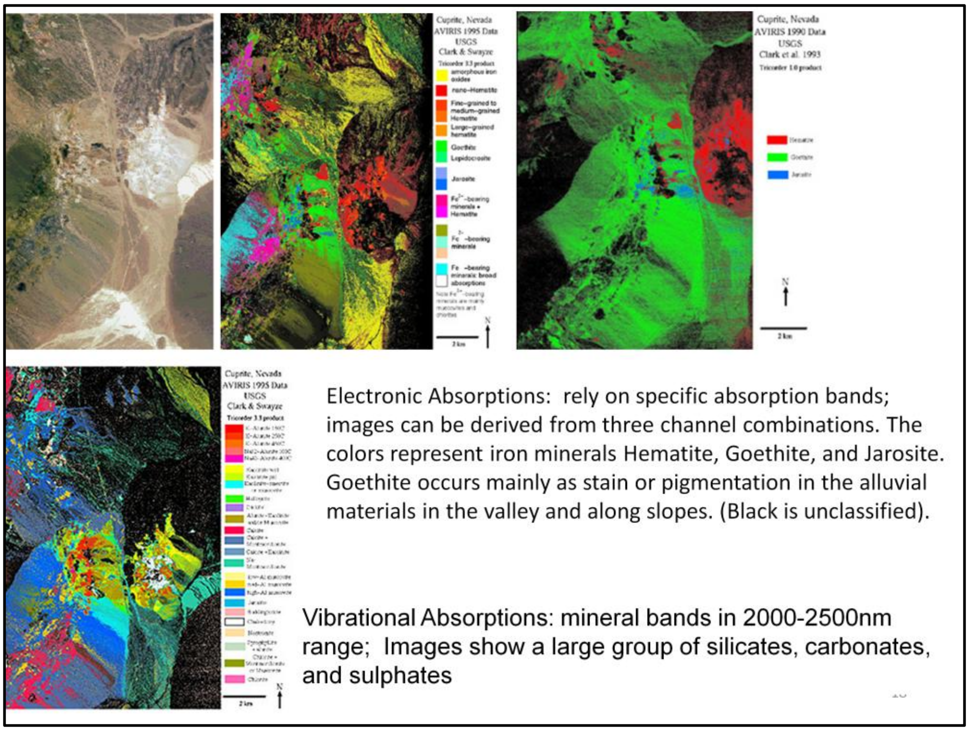




True Color

Minerals
(vibrational absorption)

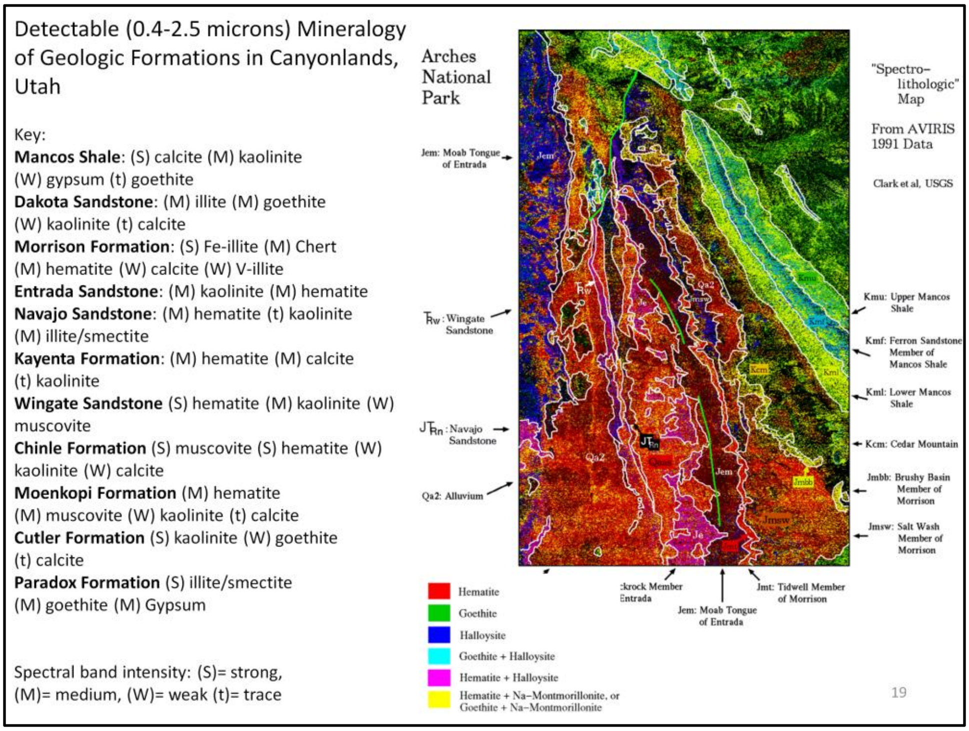
Minerals
(electronic absorption)



Electronic Absorptions: rely on specific absorption bands; images can be derived from three channel combinations. The colors represent iron minerals Hematite, Goethite, and Jarosite. Goethite occurs mainly as stain or pigmentation in the alluvial materials in the valley and along slopes. (Black is unclassified).

Vibrational Absorptions: mineral bands in 2000-2500nm range; Images show a large group of silicates, carbonates, and sulphates

three AVIRIS channels in pseudo-true color of the main area displaying significant alteration. The area shown is approximately 17 by 10 km.



Detectable (0.4-2.5 microns) Mineralogy of Geologic Formations in Canyonlands, Utah

Key:
Mancos Shale: (S) calcite (M) kaolinite (W) gypsum (t) goethite
Dakota Sandstone: (M) illite (M) goethite (W) kaolinite (t) calcite
Morrison Formation: (S) Fe-illite (M) Chert (M) hematite (W) calcite (W) V-illite
Entrada Sandstone: (M) kaolinite (M) hematite
Navajo Sandstone: (M) hematite (t) kaolinite (M) illite/smectite
Kayenta Formation: (M) hematite (M) calcite (t) kaolinite
Wingate Sandstone (S) hematite (M) kaolinite (W) muscovite
Chinle Formation (S) muscovite (S) hematite (W) kaolinite (W) calcite
Moenkopi Formation (M) hematite (M) muscovite (W) kaolinite (t) calcite
Cutler Formation (S) kaolinite (W) goethite (t) calcite
Paradox Formation (S) illite/smectite (M) goethite (M) Gypsum

Spectral band intensity: (S)= strong, (M)= medium, (W)= weak (t)= trace

An example of "spectrolithologic mapping" using only 4 minerals: hematite, goethite, halloysite, and montmorillonite. The minerals in their various compositions allow each formation to be distinguished and mapped. The outlines were derived based on the mineralogic boundaries, and agree well with published geologic maps.

Clark, R.N., A.J. Gallagher, and G.A. Swayze, Material Absorption Band Depth Mapping of Imaging Spectrometer Data Using a Complete Band Shape Least-Squares Fit with Library Reference Spectra, *Proceedings of the Second Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) Workshop.* JPL Publication 90-54, 176-186, 1990.

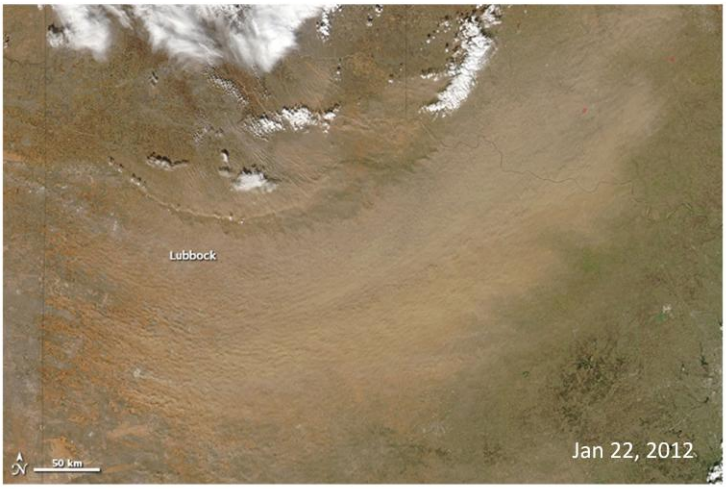
Clark, R.N., G.A. Swayze, A. Gallagher, N. Gorelick, and F. Kruse, Mapping with Imaging Spectrometer Data Using the Complete Band Shape Least-Squares Algorithm Simultaneously Fit to Multiple Spectral Features from Multiple Materials, *Proceedings of the Third Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) Workshop,* JPL Publication 91-28, 2-3, 1991.

Lecture 7 What you should know

Geologic Mineralogy:

1. Unique spectral features are due to wide range of mineral chemistry
2. Many require narrow bands to measure
3. Grain size affects scattering, where smaller increases scattering/reflectance
4. What causes absorptions:
   Electronic transitions: crystal field effects, charge transfer absorptions, conduction bands, color centers
   Vibrational modes: fundamental and overtones

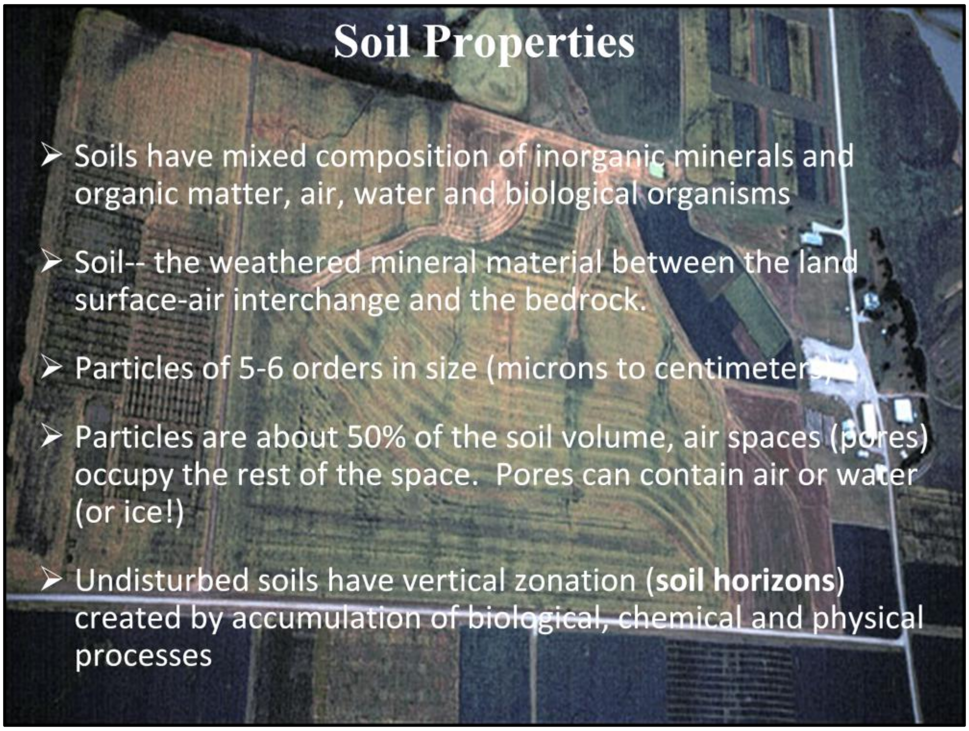
Lecture 7 Feb 2: Soils and Soil Properties



Jan 22, 2012

Soil moisture, soil mineralogy   Chapter 14, 2, 7

Texture, Organic matter, Soil moisture, Soil Erosion:
    wind, water, Drought, Soil salinity



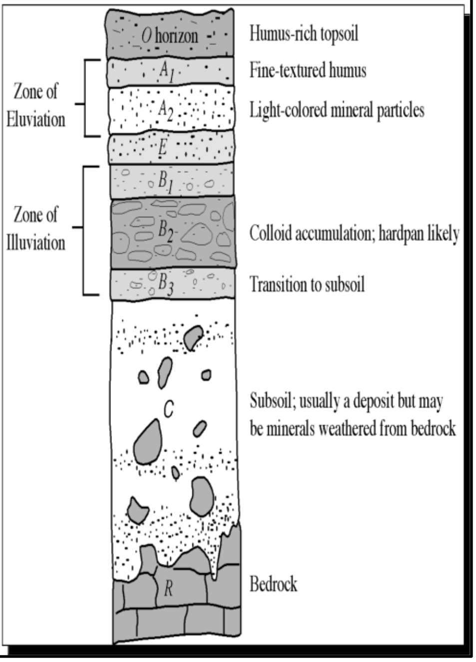
Soil Properties

- Soils have mixed composition of inorganic minerals and organic matter, air, water and biological organisms
- Soil-- the weathered mineral material between the land surface-air interchange and the bedrock.
- Particles of 5-6 orders in size (microns to centimeters)
- Particles are about 50% of the soil volume, air spaces (pores) occupy the rest of the space. Pores can contain air or water (or ice!)
- Undisturbed soils have vertical zonation (**soil horizons**) created by accumulation of biological, chemical and physical processes

This image captures a portion of the Grand Erg Oriental (Eastern Sand Sea) in Algeria. Astronaut photograph ISS010-E-10124 was acquired December 11, 2004, with a Kodak 760C digital camera with a 400 mm lens.

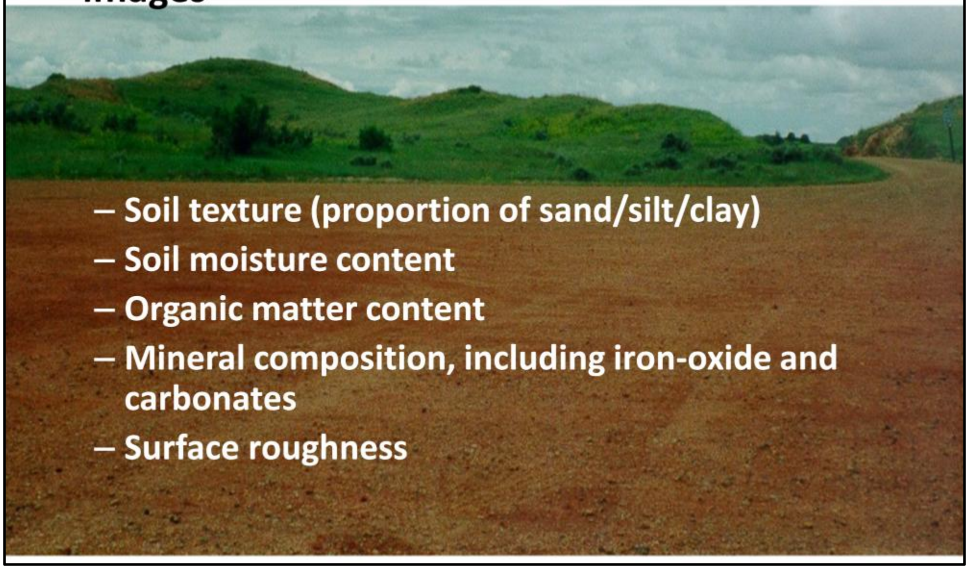
Soil Horizons: Terminology

- **O horizon**: > 20% partially decayed organic matter “humus”
- **A horizon**: zone of eluviation & leaching; water leaches many minerals; often pale and sandy
- **E horizon**: mineral layer; some loss of silicate clay, iron, & aluminum
- **B horizon**: zone of illuviation; materials leached from other zones accumulate; high clay and iron oxide concentrations
- **C horizon**: weathered parent material; mostly mineral composition
- **W horizon**: water layer; Wf if permanently frozen
- **R horizon**: bedrock

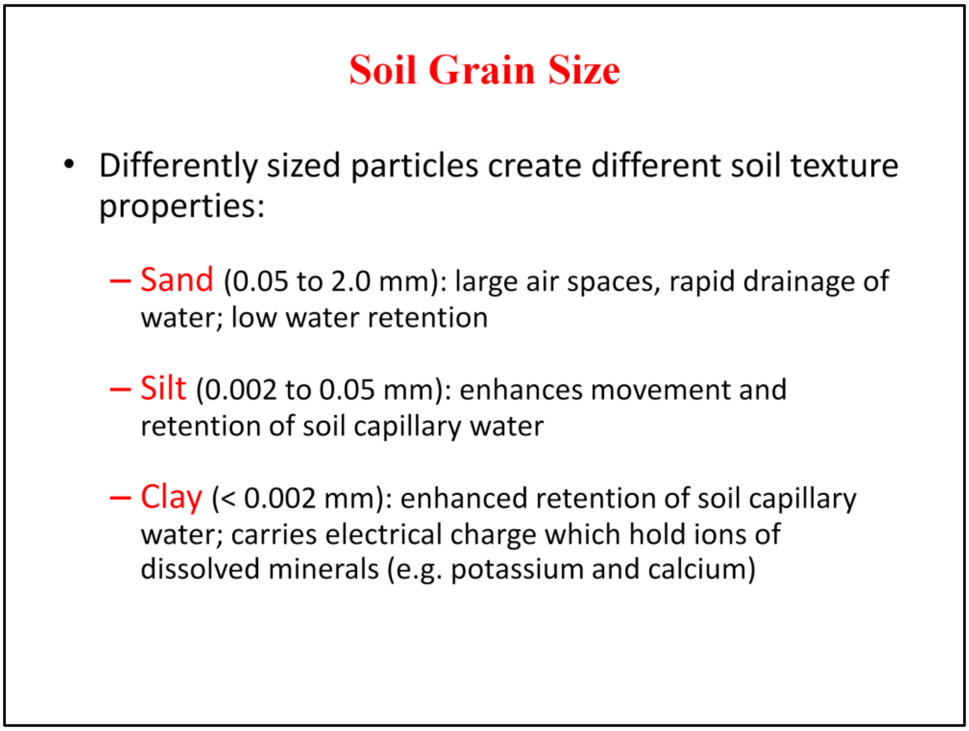


Remote Sensing of Soils

Important properties of soils detected in RS images



- Soil texture (proportion of sand/silt/clay)
- Soil moisture content
- Organic matter content
- Mineral composition, including iron-oxide and carbonates
- Surface roughness

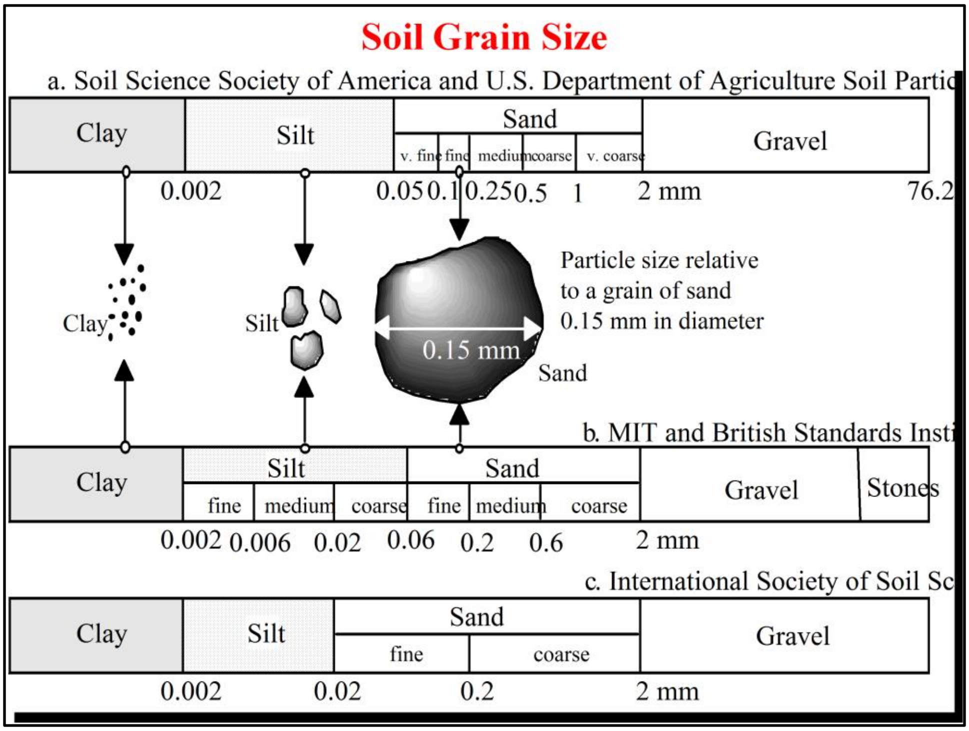


Soil Grain Size

- Differently sized particles create different soil texture properties:
  - Sand (0.05 to 2.0 mm): large air spaces, rapid drainage of water; low water retention
  - Silt (0.002 to 0.05 mm): enhances movement and retention of soil capillary water
  - Clay (< 0.002 mm): enhanced retention of soil capillary water; carries electrical charge which hold ions of dissolved minerals (e.g. potassium and calcium)

What do these particles do to reflectance:
Reflectance increases particle size gets smaller
Reflectance increases with the sand content

Silt has high organic matter and soil is darker; concave in visible



Soil Grain Size

a. Soil Science Society of America and U.S. Department of Agriculture Soil Partic

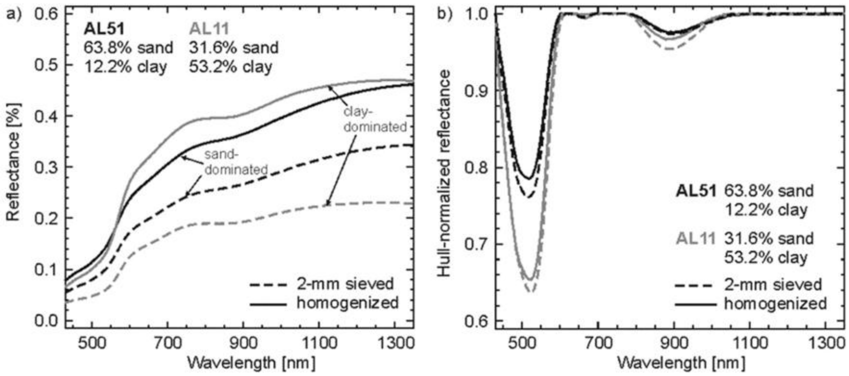
Particle size relative to a grain of sand 0.15 mm in diameter

b. MIT and British Standards Insti

c. International Society of Soil Sc

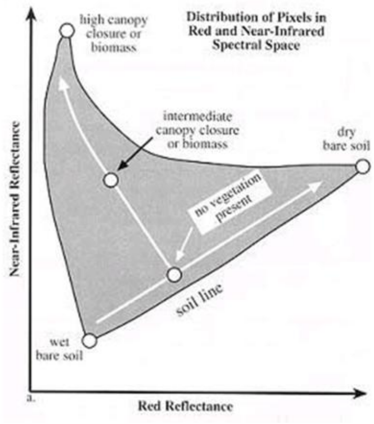
Who remembers how particle size affects reflectance?

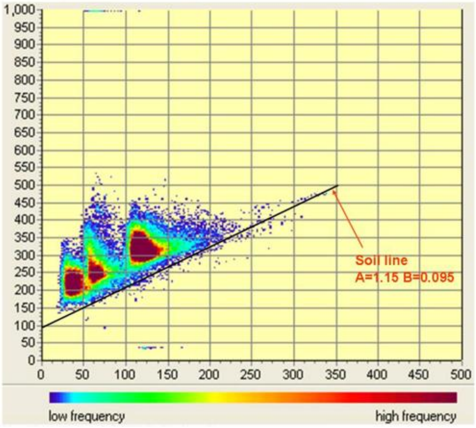
Albedo differences with soil fraction and particle size



N. Richter , T. Jarmer, S. Chabrillat, C. Oyonarte, P. Hostert and H. Kaufmann. 2008. J. Soil Science Am. 73: 72-81.

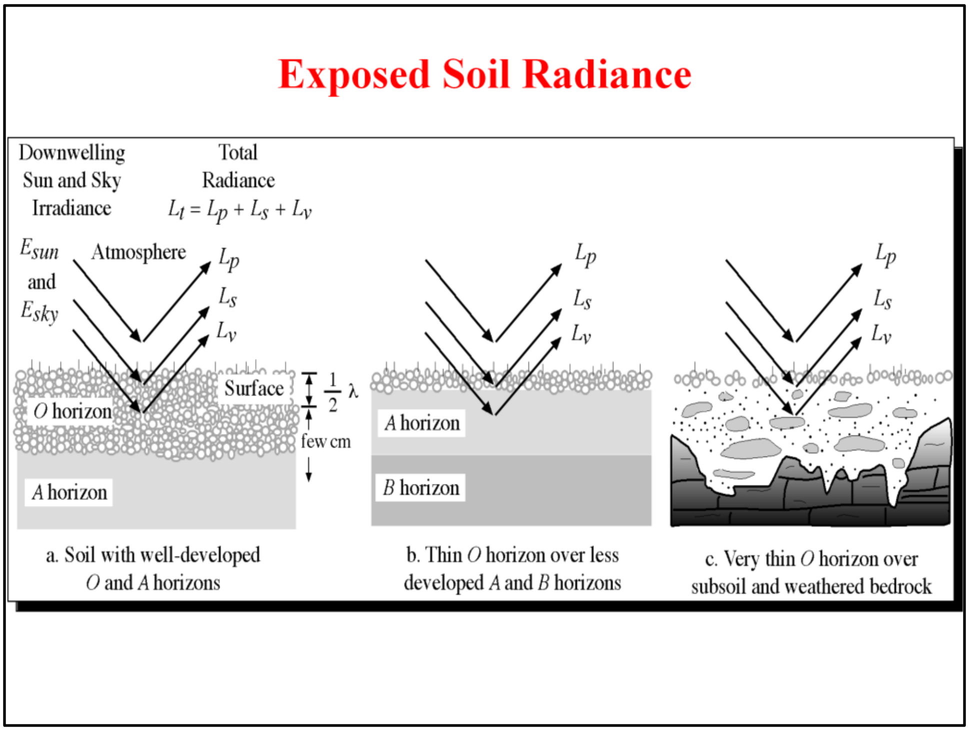
Red and Near-Infrared “Soil Line”





Example of Soil line extracted from NIR vs RED CHRIS-PROBA data

What does a soil line tell you about how soils of different texture vary?



Exposed Soil Radiance

a. Soil with well-developed *O* and *A* horizons

b. Thin *O* horizon over less developed *A* and *B* horizons

c. Very thin *O* horizon over subsoil and weathered bedrock

$L_t = L_p + L_s + L_v$

L_t = at-sensor radiance of a pixel of exposed soil
L_p = atmospheric path radiance, usually removed through atmospheric correction
L_s = radiance reflected off the air-soil interface (boundary layer)

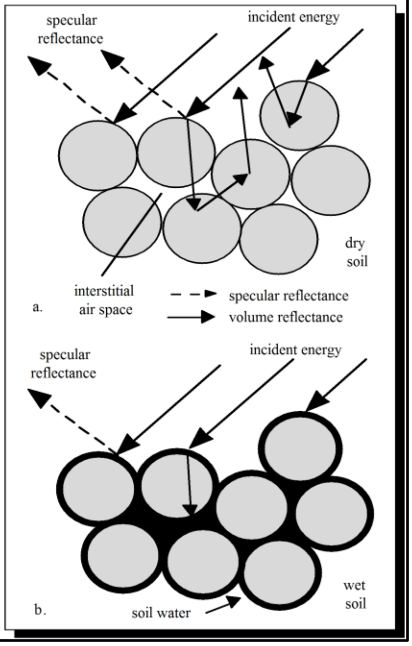
> organic matter and moisture significantly impact L_s; characterize the O and A horizons (if no O), or lower levels if A and O are nonexistant.

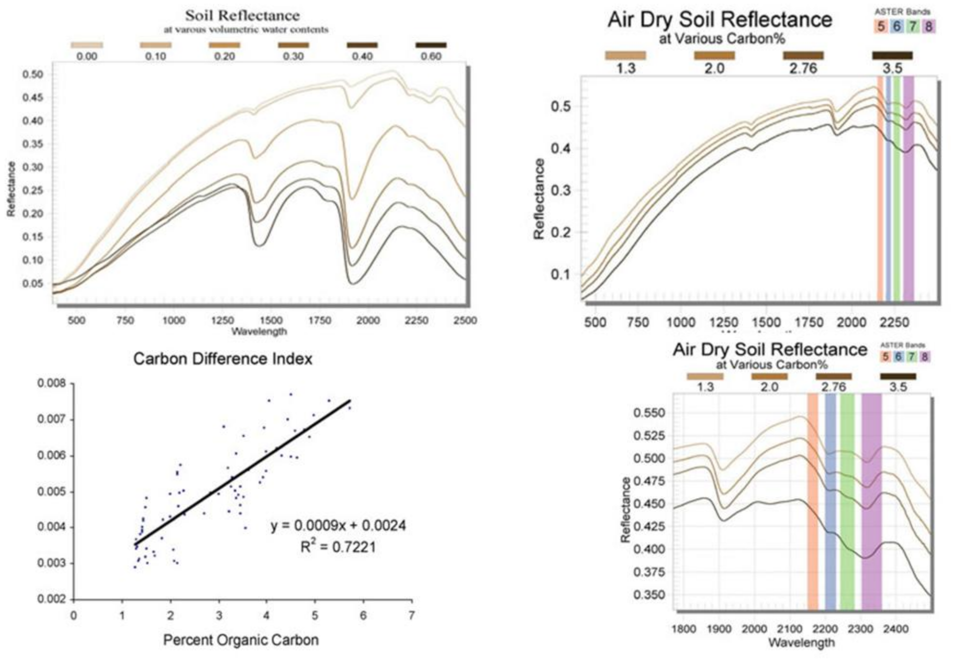
L_v = volume scattering, EMR which penetrates a few mm to cm.

> penetrates approximate 1/2 the wavelength
> Function of the wavelength (so RADAR may penetrate farther), type and amount of organic/inorganic constituents, shape and density of minerals, degree of mineral compaction, and the amount of soil moisture present.

Soil Moisture

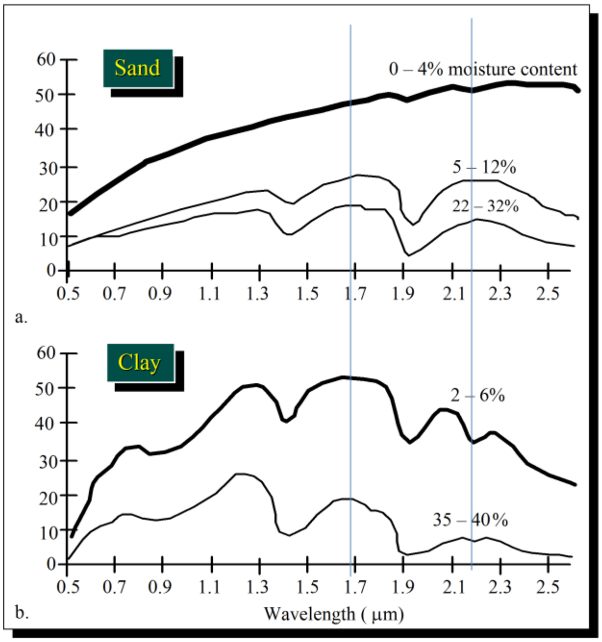
- Water ‘coats’ particles, filling air spaces and reducing the amount of multiply scattered light. Soils with more moisture are darker in the infrared than drier soils.
- Moist soils are darker in the mid-IR at water absorption bands which increase significantly
- The depth of the water absorption bands at 1.4, 1.9 and 2.7 μm can be used to determine soil moisture.





Remote Sensing Organic Carbon in Soil S. Chod Stephens, V. Phil Rasmussen, R. Douglas Ramsey, Ralph E. Whitesides, Gregory S. Searle, Robert L. Newhall, Utah State University, Logan, Utah 84322

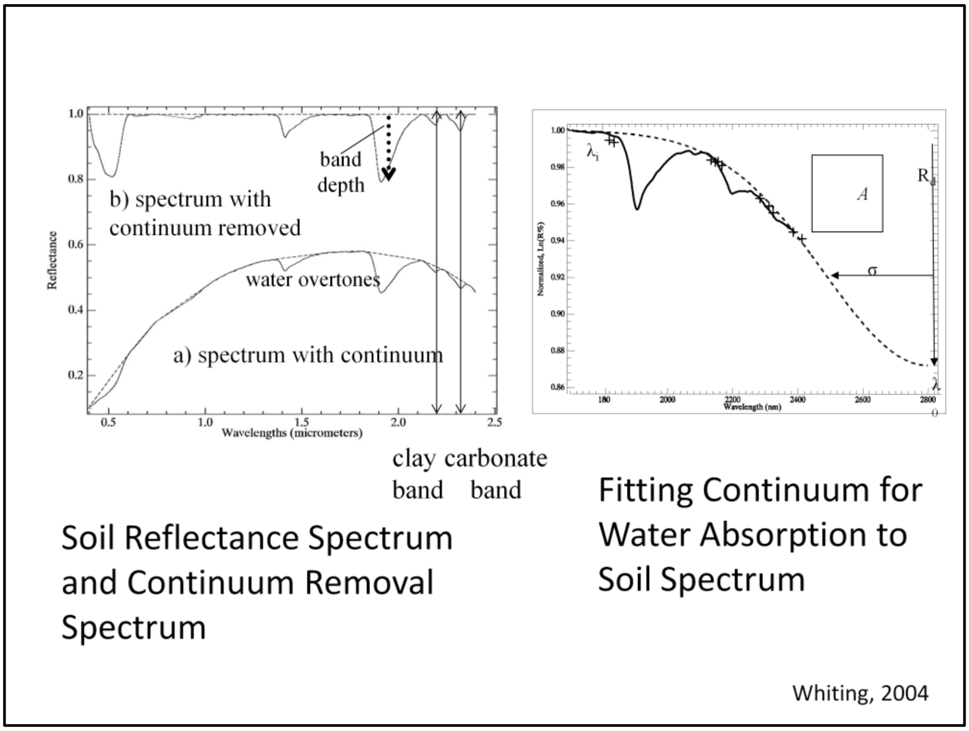
Soil Moisture and Texture



Clays hold water more ‘tightly’ than sand.

Thus, water absorption bands in a clay spectrum are more prominent than in a sand spectrum.

Hyperspectral data can be used to quantify these absorption features.

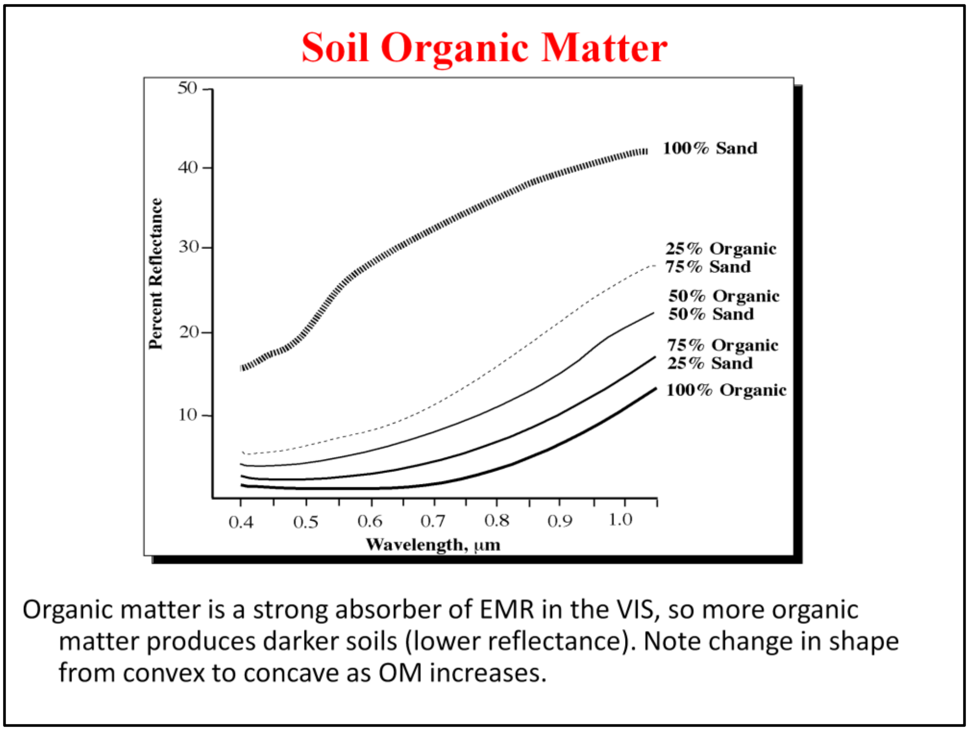


Soil Reflectance Spectrum and Continuum Removal Spectrum

Fitting Continuum for Water Absorption to Soil Spectrum

Whiting, 2004

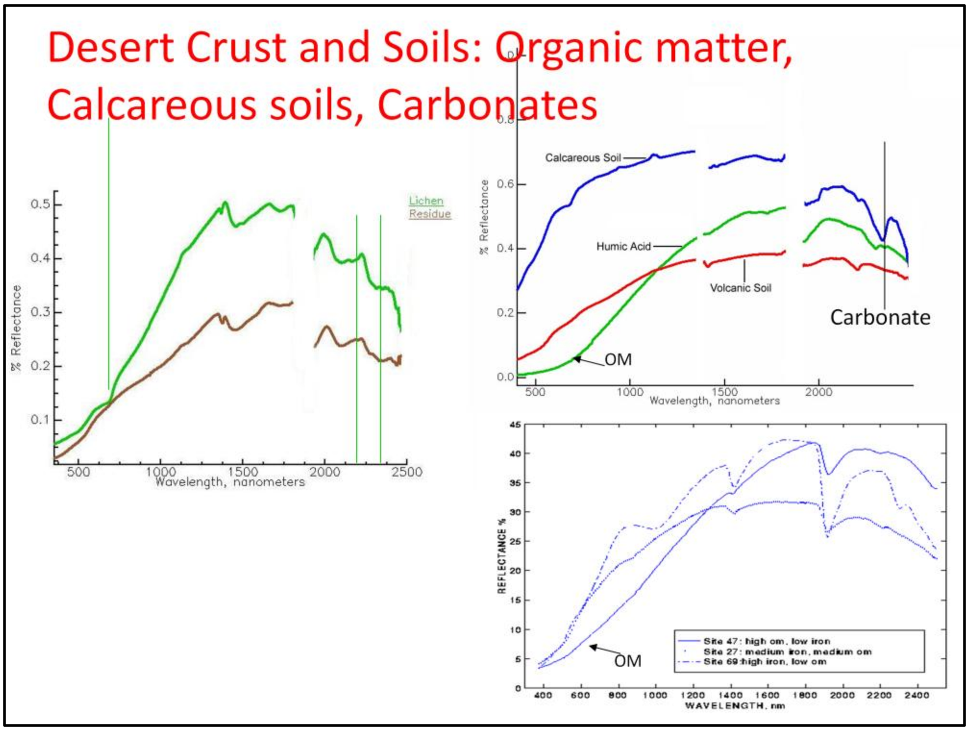
Modeling moisture in soils is critical to extracting biochemical information from them.



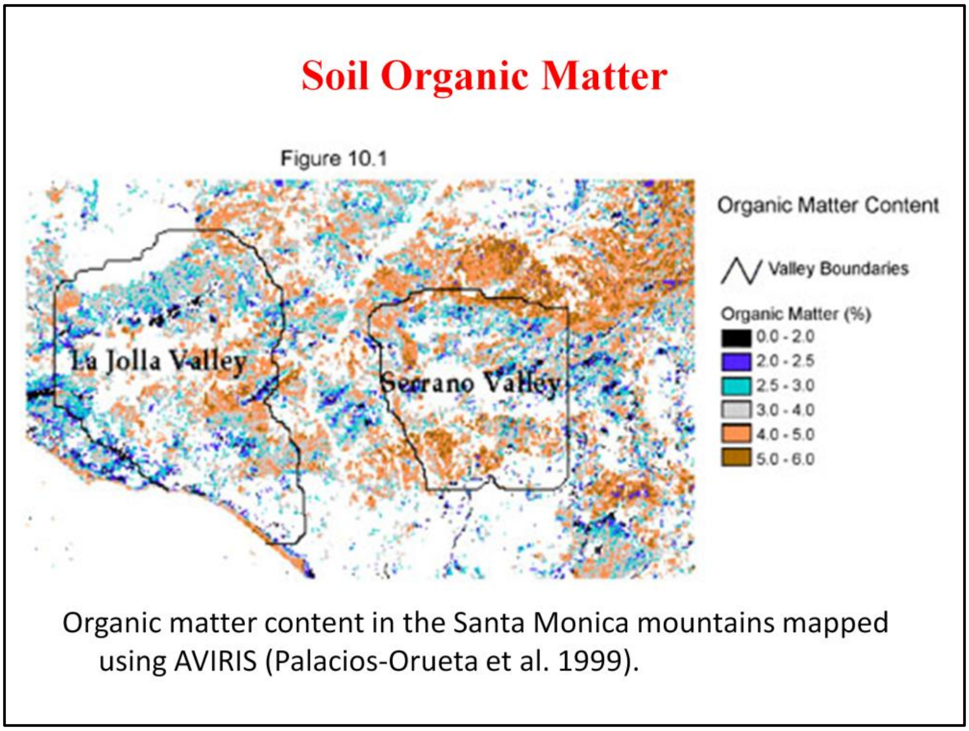
Soil Organic Matter

Organic matter is a strong absorber of EMR in the VIS, so more organic matter produces darker soils (lower reflectance). Note change in shape from convex to concave as OM increases.

Desert Crust and Soils: Organic matter, Calcareous soils, Carbonates



Changes in soils as organic residues degrade. First panel shows degradation resistant residues and lichens (with lines where lichens are reported to absorb energy). Then Humic acid (note presence of OM but not specific SWIR absorptions.
Then two soils one calcareous (with large carbonate feature) and volcanic soils.
Last, three soils of varying OM and iron absorption.



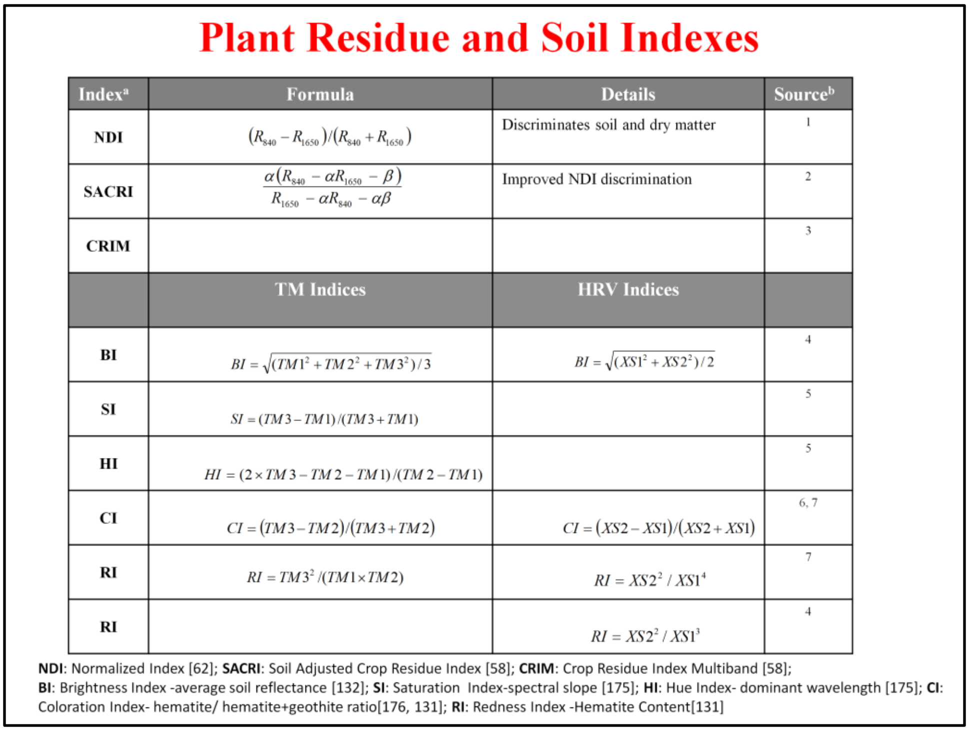
Soil Organic Matter

Figure 10.1

Organic matter content in the Santa Monica mountains mapped using AVIRIS (Palacios-Orueta et al. 1999).

This soil classification was based on prior discriminant function results that showed the soils could be distinguished. Then a supervised classification was imposed on the results of a hierarchical singular value decomposition. The reason for first separating it into different ranges was to reduce the variance at each step.

The valleys are in the Santa Monica Mts. and a wildfire had removed most of the vegetation in the two valleys (areas white are vegetated and masked from the analysis). The two valleys have different parent material and as a result had different ranges of organic matter.

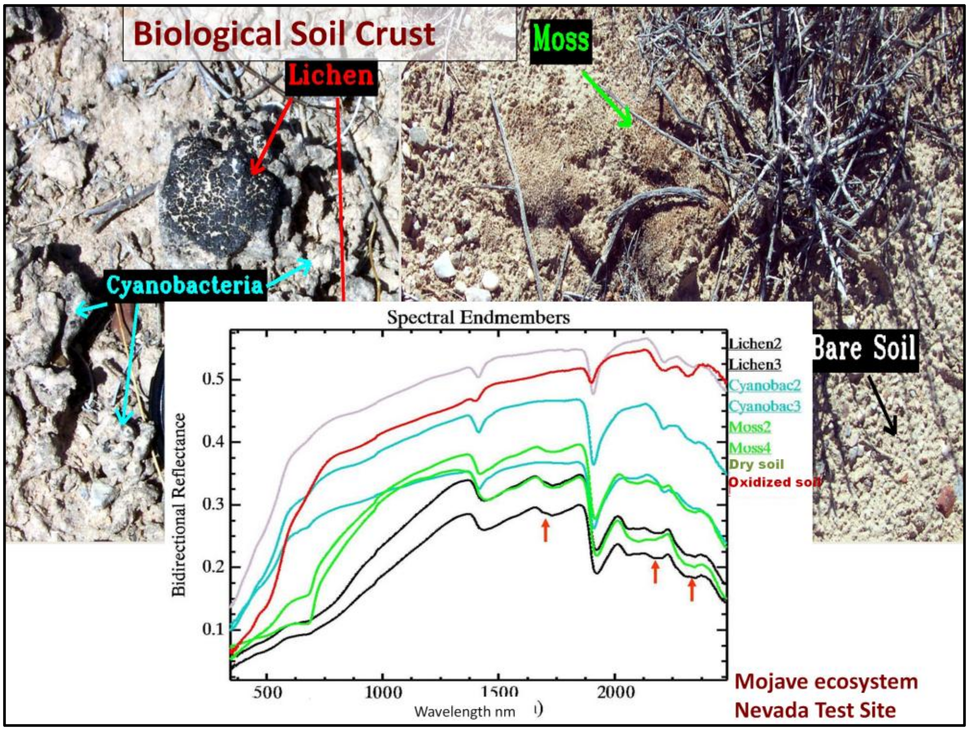


Plant Residue and Soil Indexes

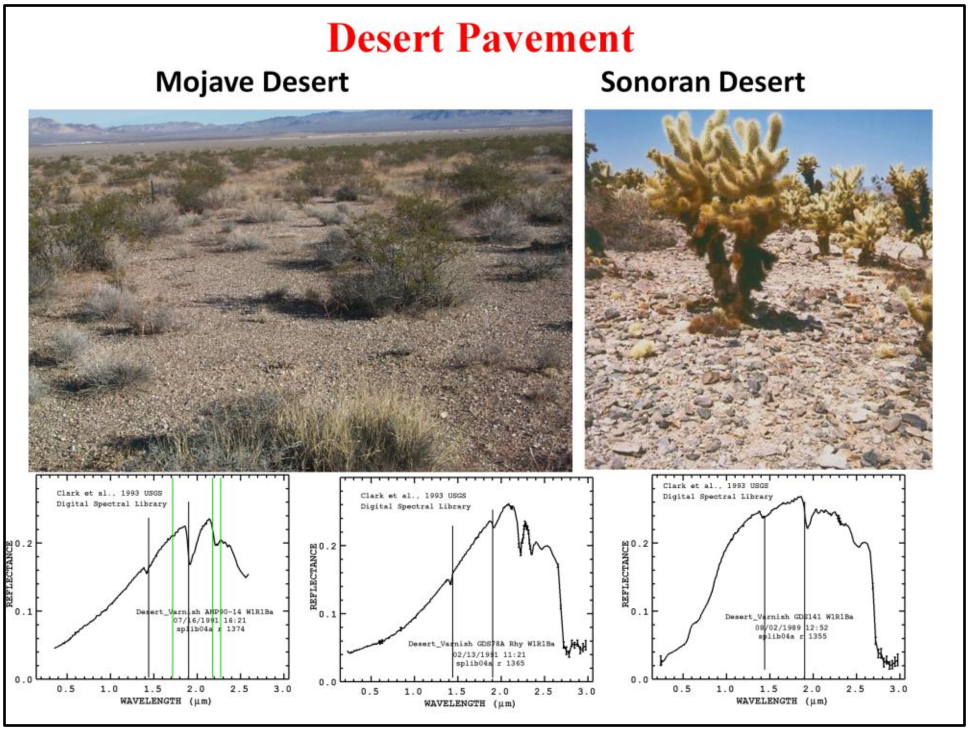
Index[a]	Formula	Details	Source[b]
NDI	$(R_{840} - R_{1650})/(R_{840} + R_{1650})$	Discriminates soil and dry matter	1
SACRI	$\frac{\alpha(R_{840} - \alpha R_{1650} - \beta)}{R_{1650} - \alpha R_{840} - \alpha\beta}$	Improved NDI discrimination	2
CRIM			3
	TM Indices	**HRV Indices**	
BI	$BI = \sqrt{(TM1^2 + TM2^2 + TM3^2)/3}$	$BI = \sqrt{(XS1^2 + XS2^2)/2}$	4
SI	$SI = (TM3 - TM1)/(TM3 + TM1)$		5
HI	$HI = (2 \times TM3 - TM2 - TM1)/(TM2 - TM1)$		5
CI	$CI = (TM3 - TM2)/(TM3 + TM2)$	$CI = (XS2 - XS1)/(XS2 + XS1)$	6, 7
RI	$RI = TM3^2/(TM1 \times TM2)$	$RI = XS2^2 / XS1^4$	7
RI		$RI = XS2^2 / XS1^3$	4

NDI: Normalized Index [62]; **SACRI**: Soil Adjusted Crop Residue Index [58]; **CRIM**: Crop Residue Index Multiband [58]; **BI**: Brightness Index -average soil reflectance [132]; **SI**: Saturation Index-spectral slope [175]; **HI**: Hue Index- dominant wavelength [175]; **CI**: Coloration Index- hematite/ hematite+geothite ratio[176, 131]; **RI**: Redness Index -Hematite Content[131]

Similarly to plants, several soil and plant residue indexes have been developed. These have been less widely tested than the vegetation indexes.



Biologic Soil Crust is a major compoinent of the soil in most desert ecosystems. These organisms are often credited with a large fraction of ecosystem productivity, nitrogen fixation and also serve other functions, including soil stabilization and prevention of erosion. The wavelengths identified by the red arrows are reported diagnostic of lichens.



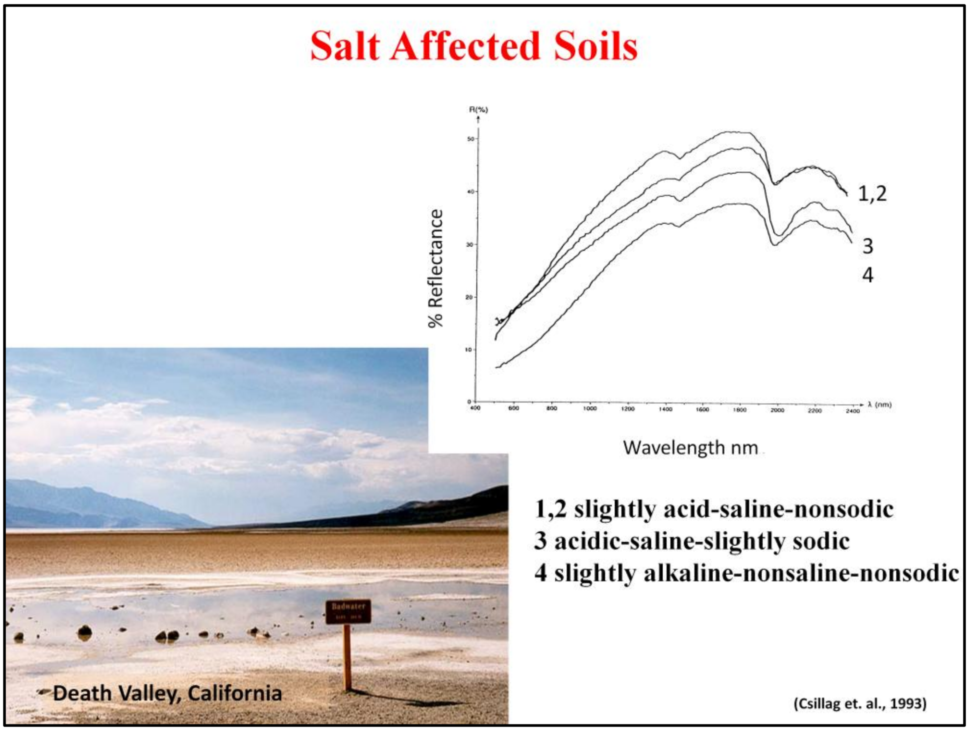
Desert Pavement

Mojave Desert

Sonoran Desert

Desert pavement is another land cover type critical to interpretation of site condition. The pavement takes 1000s years to develop and loss provides direct evidence of disturbance.

The rocks weather and acquire a dark patina developed by bacterial metabolism acting on the minerals and clays that coat the rocks. Note they do not have the lichen signature even though both processes lower albedo.



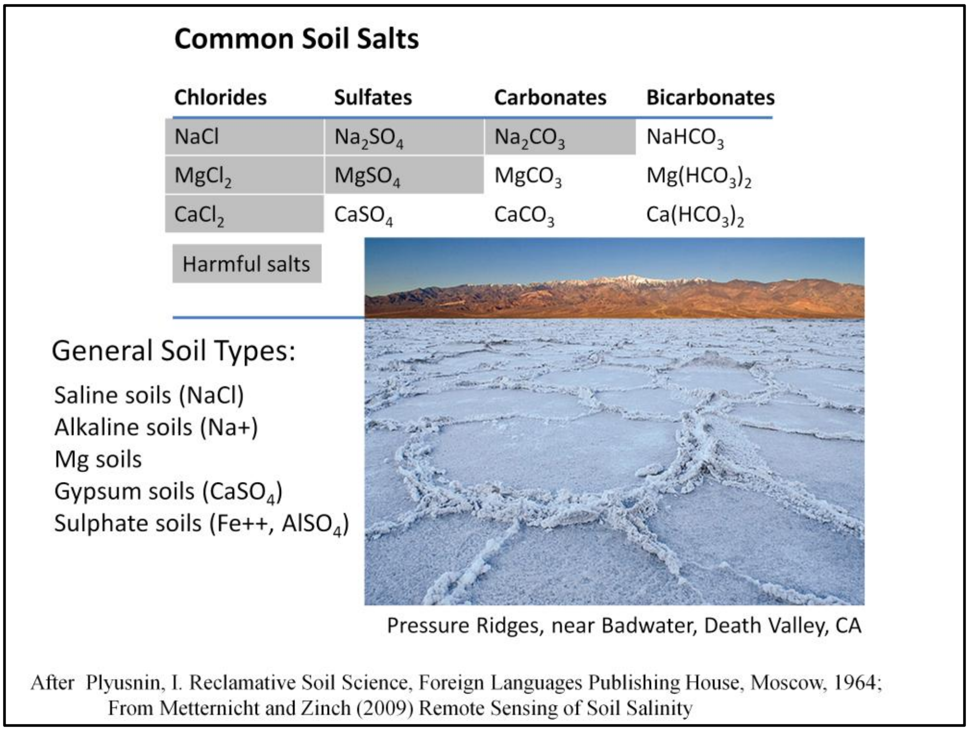
Salt Affected Soils

1,2 slightly acid-saline-nonsodic
3 acidic-saline-slightly sodic
4 slightly alkaline-nonsaline-nonsodic

Death Valley, California

(Csillag et. al., 1993)

Saline and alkaline affected soils are another biophysical property of interest in arid regions. However, it has not been easy to spectrally quantify the presence unless a distinct crust is formed.



Common Soil Salts

Chlorides	Sulfates	Carbonates	Bicarbonates
▨ NaCl	▨ Na_2SO_4	▨ Na_2CO_3	$NaHCO_3$
▨ $MgCl_2$	▨ $MgSO_4$	$MgCO_3$	$Mg(HCO_3)_2$
▨ $CaCl_2$	$CaSO_4$	$CaCO_3$	$Ca(HCO_3)_2$

▨ Harmful salts

General Soil Types:

- Saline soils (NaCl)
- Alkaline soils (Na+)
- Mg soils
- Gypsum soils ($CaSO_4$)
- Sulphate soils (Fe++, $AlSO_4$)

Pressure Ridges, near Badwater, Death Valley, CA

After Plyusnin, I. Reclamative Soil Science, Foreign Languages Publishing House, Moscow, 1964;
From Metternicht and Zinch (2009) Remote Sensing of Soil Salinity

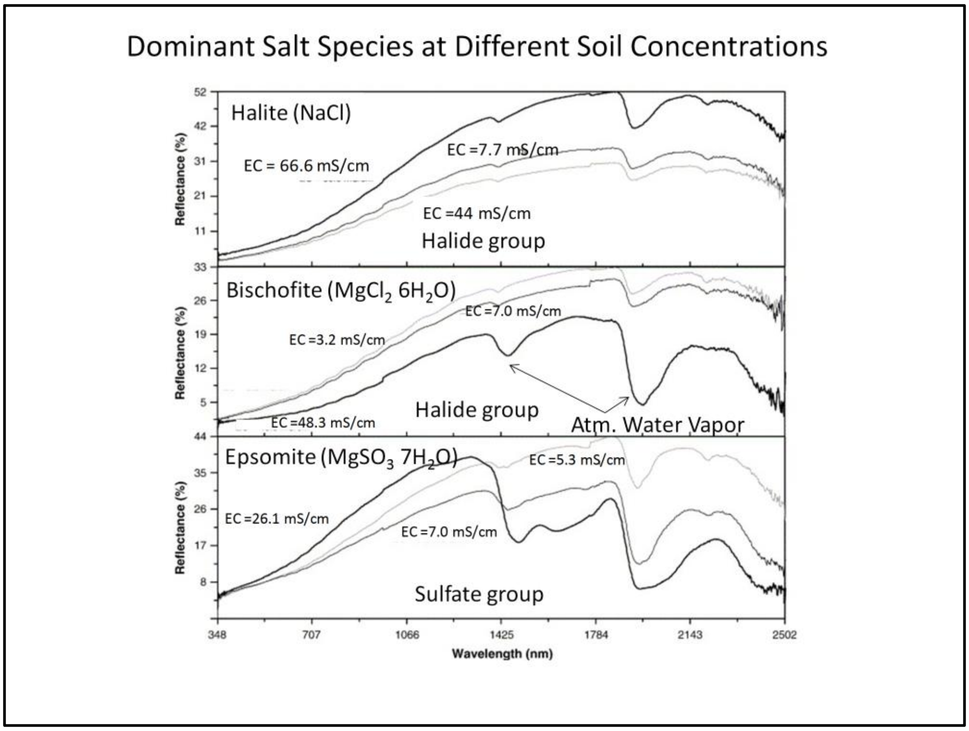
Salt affected soil can be divided into five main groups: Saline soil (Solonchak) with high amount of water soluble soils.

Alkaline soil (Solonetz), high alkalinity and high exchangeable sodium percentage (ESP).

Magnesium soil: high magnesium content in the soil solution.

Gypsiferous soil: strong gypsum (calcium sulphate $CaSO_4$) accumulation.

Acid sulphate soil: highly acidic iron or aluminium sulphate accumulation.



Dominant Salt Species at Different Soil Concentrations

Fig. 1. Examples of salt-affected soil spectra, obtained in laboratory, from soil materials impregnated by different evaporate minerals.

J. Farifteh, A. Farshad, R.J. George. 2006. Assessing salt-affected soils using remote sensing, solute modelling, and geophysics. Geoderma 130: 191-206.

Halite (NaCl)

Sylvite (KCl)

Bischofite ($MgCl_2 \cdot 6H_2O$)

Borax ($Na_2B_4O_7 \cdot 10H_2O$)

Calcite ($CaCO_3$)

Nathcolite ($NaHCO_3$)

Natron ($Na_2CO_3 \cdot 10H_2O$)

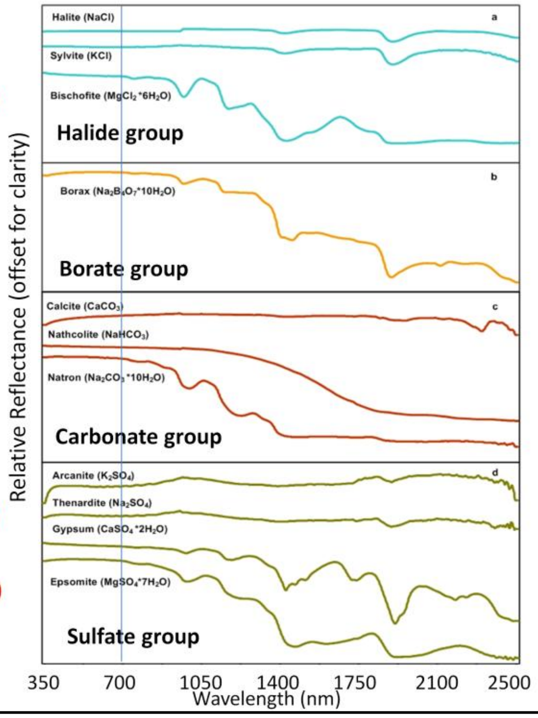
Arcanite (K_2SO_4)

Thenardite (Na_2SO_4)

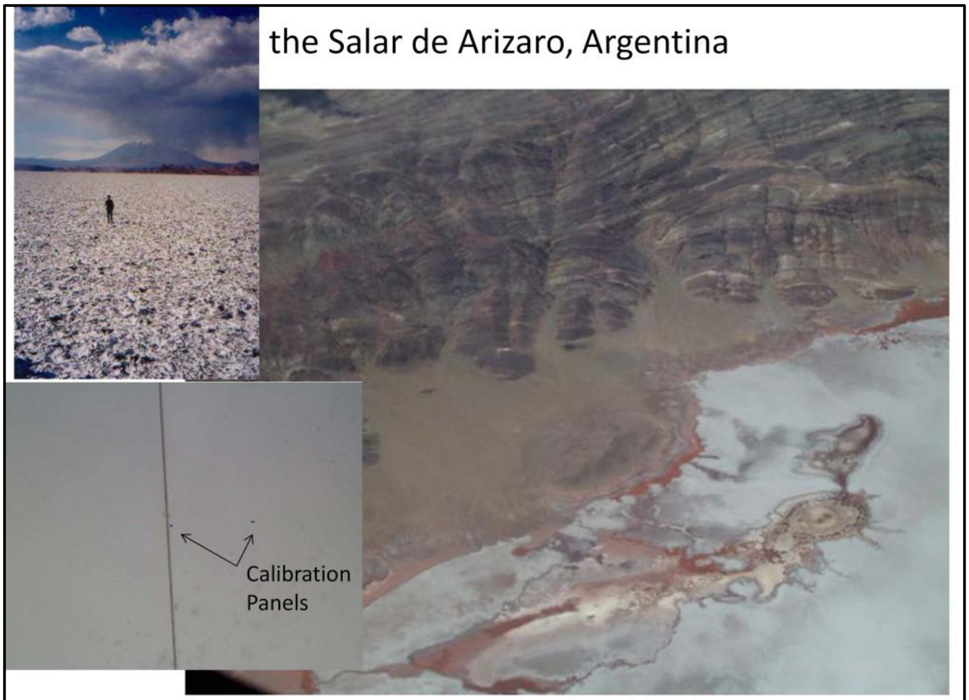
Gypsum ($CaSO_4 \cdot 2H_2O$)

Epsomite ($MgSO_4 \cdot 7H_2O$)

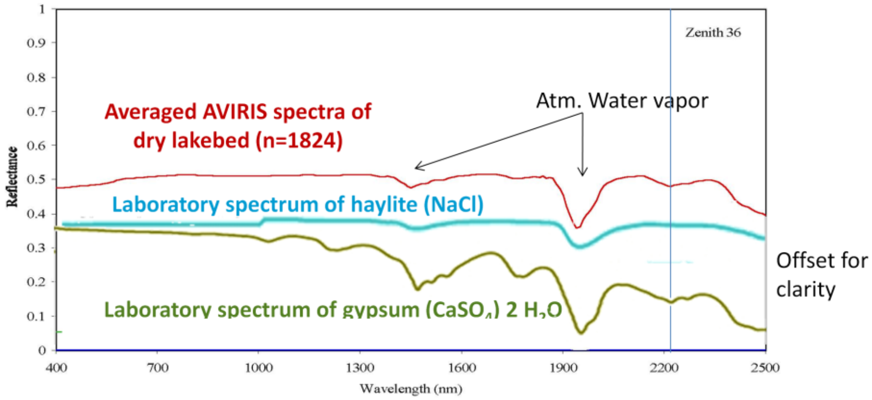
* harmful

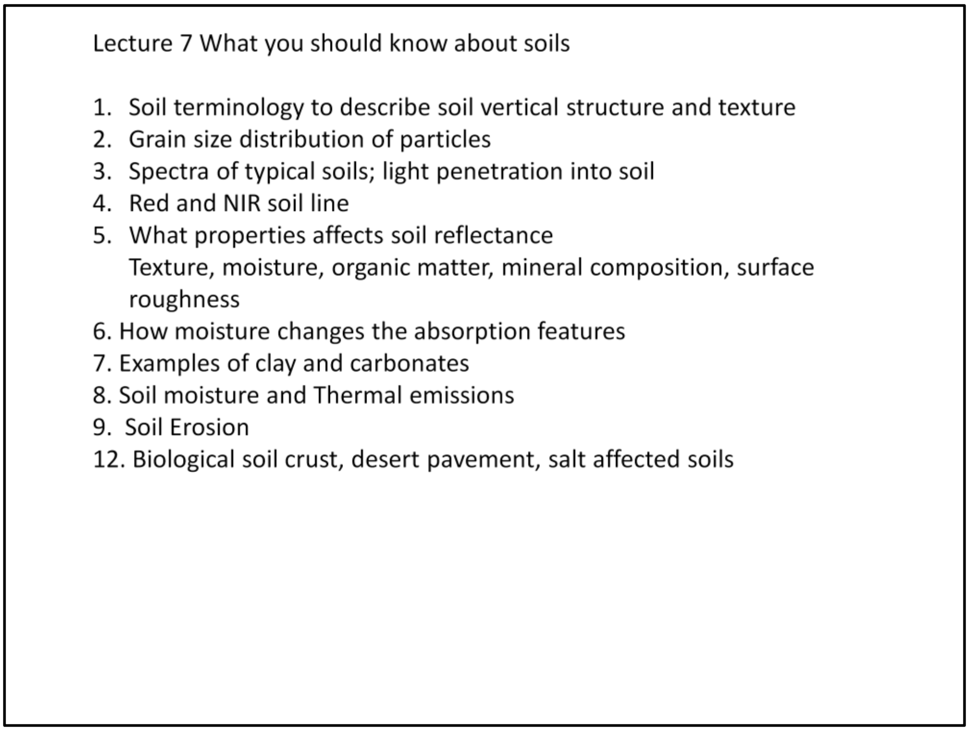


the Salar de Arizaro, Argentina



Arizaro Surface Measured for Hyperion Satellite Calibration

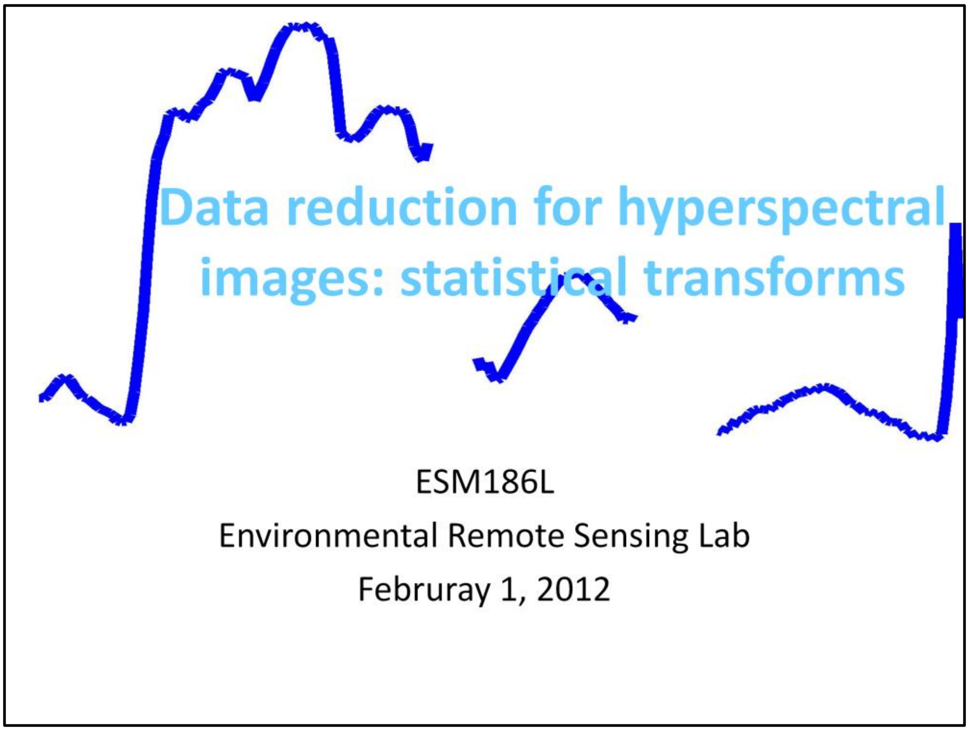




Lecture 7 What you should know about soils

1. Soil terminology to describe soil vertical structure and texture
2. Grain size distribution of particles
3. Spectra of typical soils; light penetration into soil
4. Red and NIR soil line
5. What properties affects soil reflectance
   Texture, moisture, organic matter, mineral composition, surface roughness
6. How moisture changes the absorption features
7. Examples of clay and carbonates
8. Soil moisture and Thermal emissions
9. Soil Erosion
12. Biological soil crust, desert pavement, salt affected soils

What countries are experiencing drought today

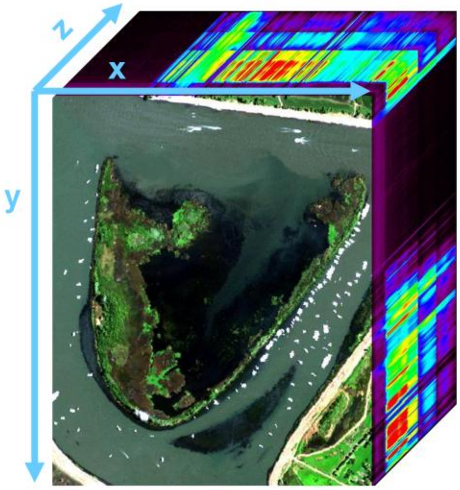


Data reduction for hyperspectral images: statistical transforms

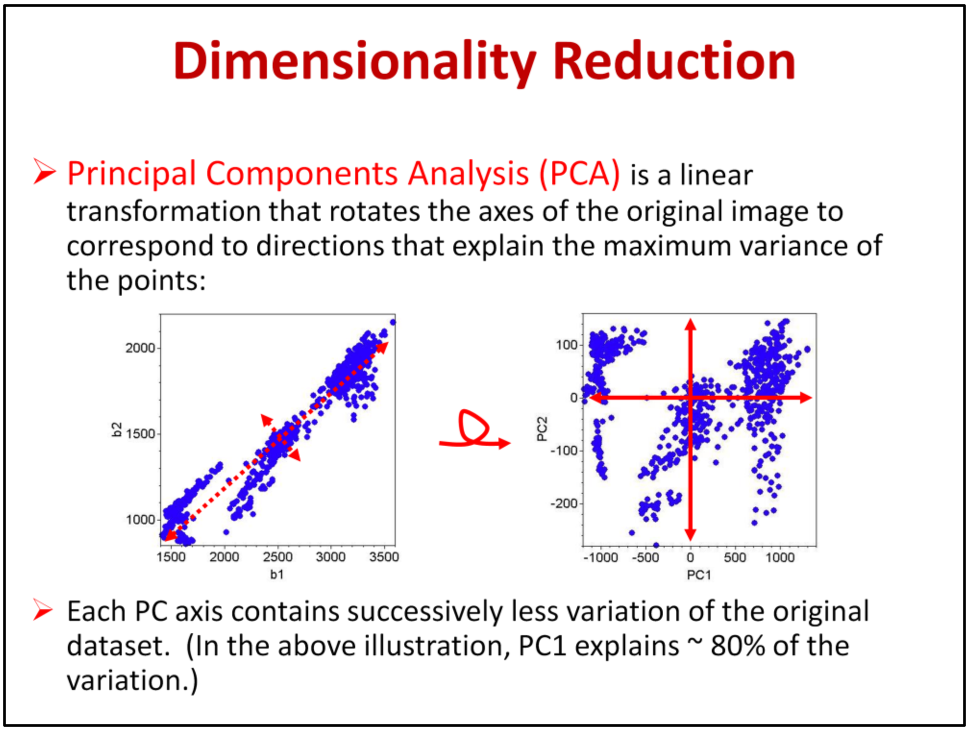
ESM186L
Environmental Remote Sensing Lab
Februray 1, 2012

Hyperspectral Data

Dimensionality Reduction



- Hyperspectral data is very high dimensional.
  - AVIRIS: 224-D
  - HyMap: 126-D
- Not all spectral bands are independent.
- Such high data dimensionality overwhelms traditional processing methods.



Dimensionality Reduction

- **Principal Components Analysis (PCA)** is a linear transformation that rotates the axes of the original image to correspond to directions that explain the maximum variance of the points:

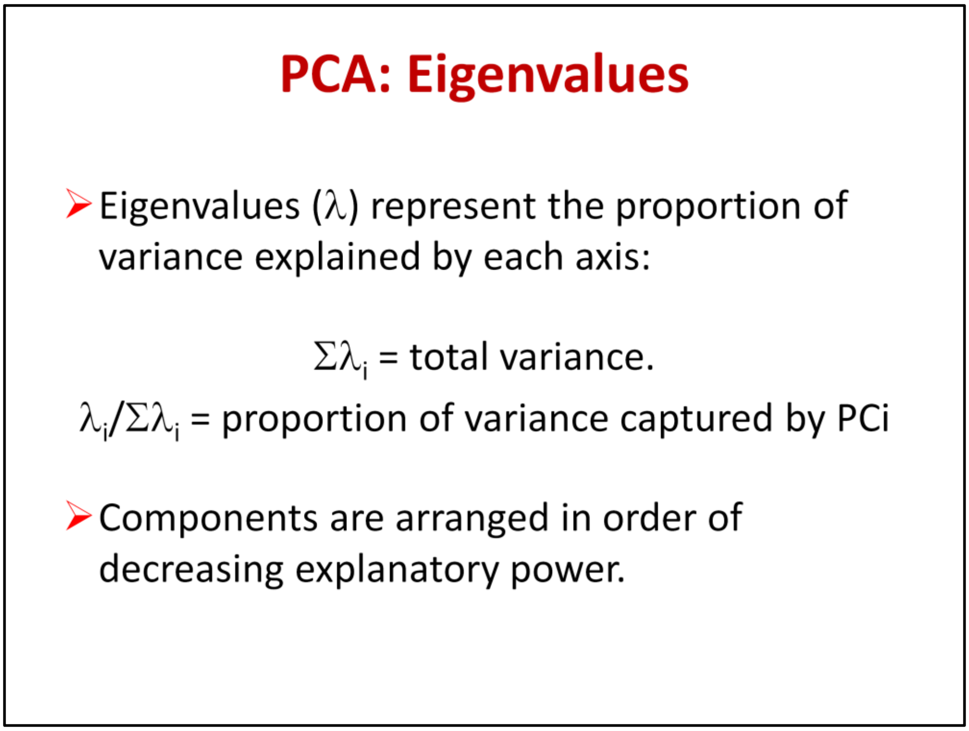
- Each PC axis contains successively less variation of the original dataset. (In the above illustration, PC1 explains ~ 80% of the variation.)

Each eigenvector has a length and a direction.

PCA: Eigenvectors

- PCA performs an *eigenanalysis* of the variance-covariance (or correlation) matrix of the spectral bands.
- The *eigenvectors* are the principal components axes. Each principal component is a linear combination of the original variables. The *i*-th element of each principal component is the loading factor for the *i*-th variable. Thus, variables with high loadings contribute the most to a given axis.

Use the variance-covariance matrix when all variables are in the same scale (ie, on your reflectance or radiance data). With this input, the PCA will emphasize variables with the greatest variance. Use the correlation matrix when variables don't share the same scale or when they vary greatly in range (ie, if you wish to perform a PCA on index data). With the correlation matrix, all variables are weighted equally.



PCA: Eigenvalues

- Eigenvalues (λ) represent the proportion of variance explained by each axis:

$$\Sigma\lambda_i = \text{total variance.}$$

$$\lambda_i/\Sigma\lambda_i = \text{proportion of variance captured by PCi}$$

- Components are arranged in order of decreasing explanatory power.

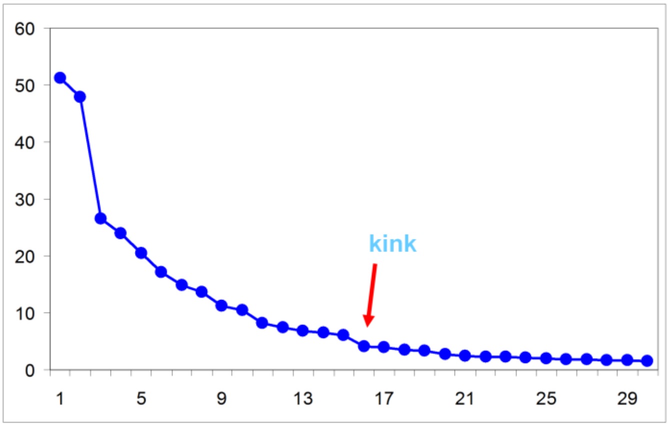
Use the variance-covariance matrix when all variables are in the same scale (ie, on your reflectance or radiance data). With this input, the PCA will emphasize variables with the greatest variance. Use the correlation matrix when variables don't share the same scale or when they vary greatly in range (ie, if you wish to perform a PCA on index data). With the correlation matrix, all variables are weighted equally.

PCA: Selecting PCA Bands

- Your PCA image has the same number of bands as the input image. You must choose which ones are important to reduce dimensionality.
- General rules of thumb:
  - Top PCA bands to include 80% of variation.
  - PCA bands that each have an above average eigenvalue (i.e., all PCA bands that contain more information than a single input band).
  - Select Eigenvalue at which the scree plot flattens.

PCA: Selecting PCA Bands

- Scree plot – Eigenvalue plotted vs. PCA band number:



PCA: Disadvantages

- Eigenvectors are derived from data variance without normalizing noise.
- Noise can contribute significantly to data variance.
- PCA is unable to reliably remove noise
- Because PCA's are calculated on variance in the image, they cannot be transported to other images

Dimensionality Reduction: MNF

- The Minimum Noise Fraction (MNF) transform was developed to address the shortcomings of PCA. It is essentially 2 sequential PCA transformations.
- In the first, noise is decorrelated and rescaled.
- A normal PCA transform is then performed on the noise-whitened data.

MNF: Selecting PCA Bands

- Your MNF image will have the same number of bands as the input image. You must choose which ones are important to reduce dimensionality.
- General rules of thumb:
  - Top MNF bands to include 80% of variation.
  - MNF bands that each have an above average eigenvalue (i.e., all MNF bands that contain more information than a single input band).
  - Eigenvalue at which the scree plot flattens.