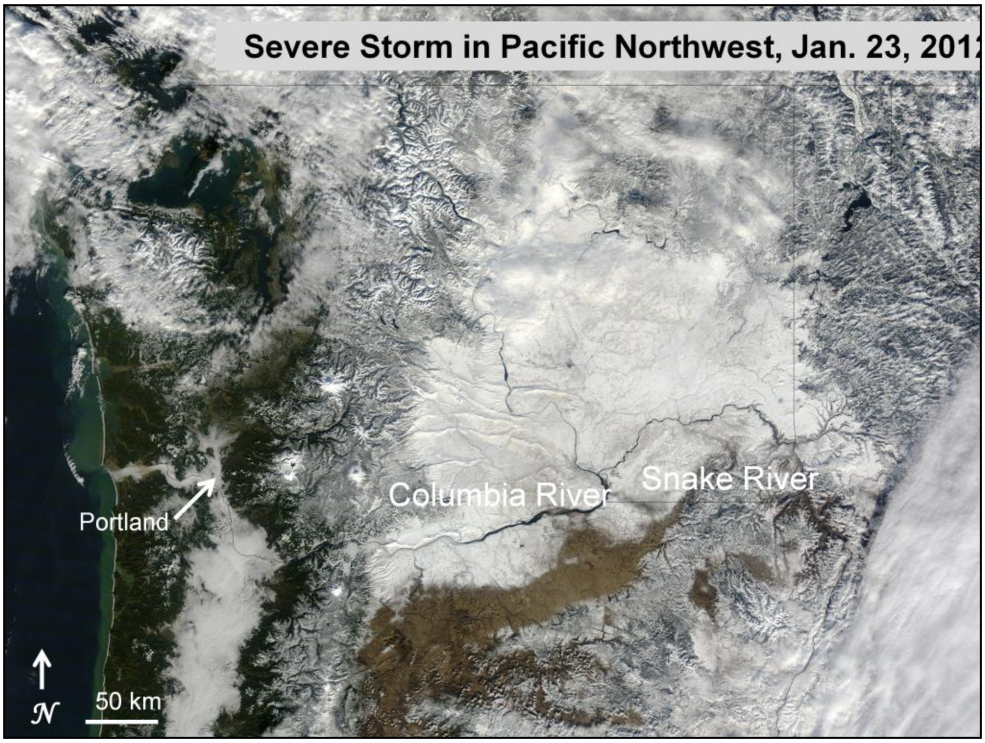


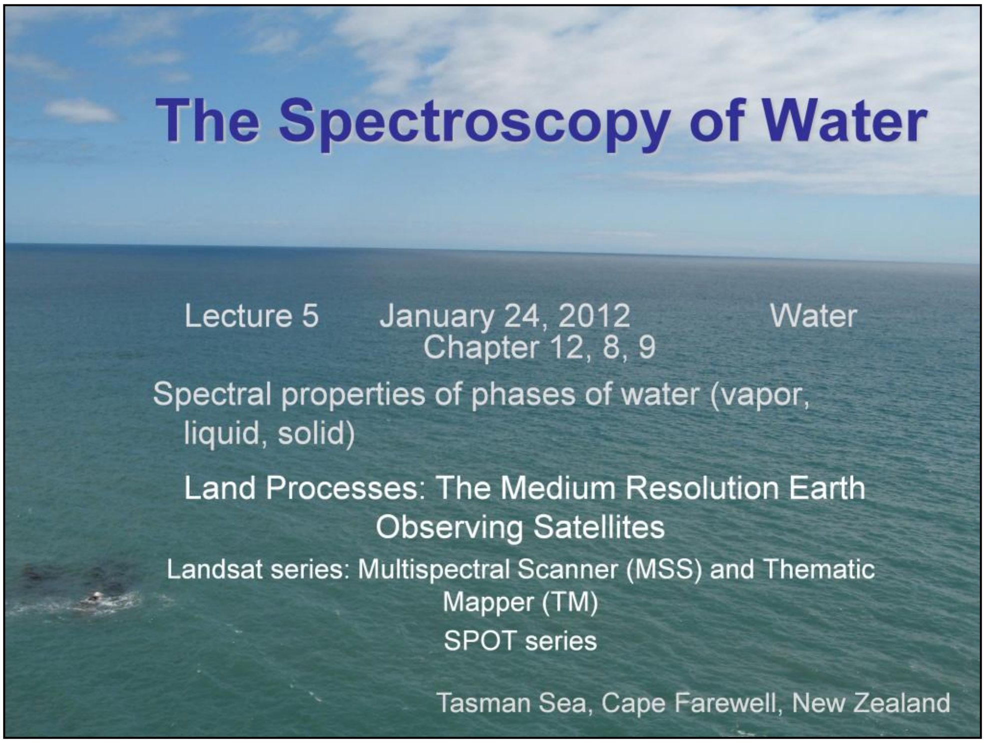
A severe winter storm pummeled the Pacific Northwest in late January 2012, icing roads, downing power lines, and prompting avalanche warnings. On January 20, more than 250,000 customers were without electricity, as utility crews struggled to restore power, news sources said. Rising temperatures and potential new rainfall raised the possibility of flooding in the days that followed.

Snow still blanketed much of Washington state on January 23, 2012, when the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite captured these images. The top image is a natural-color scene similar to what our eyes would see from the sky. The bottom image is a false-color scene that better distinguishes between snow and clouds. Ice and snow are red. Liquid-water clouds are white, and ice clouds are peach. Vegetation is bright green.

Snow blankets the region east of Seattle and Portland, stretching all the way to the Idaho border. In the band of forest along the Pacific Coast, snow may be more prevalent than it appears, as it is sometimes hidden from satellite imagers by trees.

Warmer air blew into the region soon after the storm, adding to hazardous conditions. Flooding closed roads and forced some residents into emergency shelters. On January 23, KVAL reported that a fresh storm was approaching the region and might drop several inches of rain. The National Weather Service issued a flood warning for the Portland area, as the new round of rain had the potential to push rivers into flood stage.

References



The Spectroscopy of Water

Lecture 5 January 24, 2012 Water
Chapter 12, 8, 9

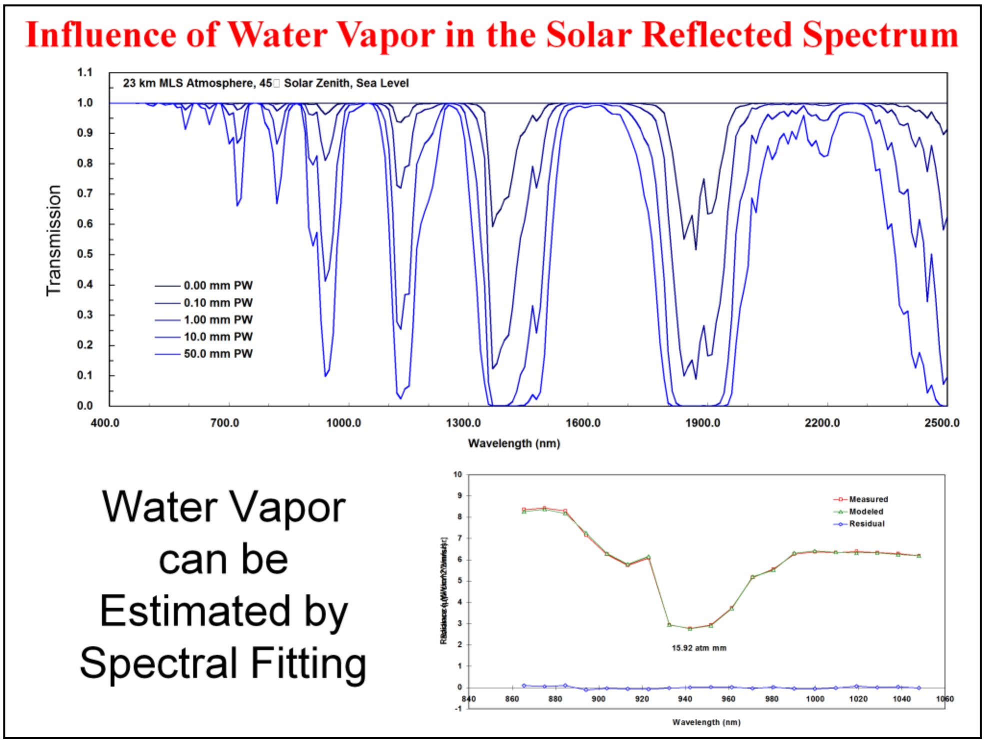
Spectral properties of phases of water (vapor, liquid, solid)

Land Processes: The Medium Resolution Earth Observing Satellites

Landsat series: Multispectral Scanner (MSS) and Thematic Mapper (TM)

SPOT series

Tasman Sea, Cape Farewell, New Zealand



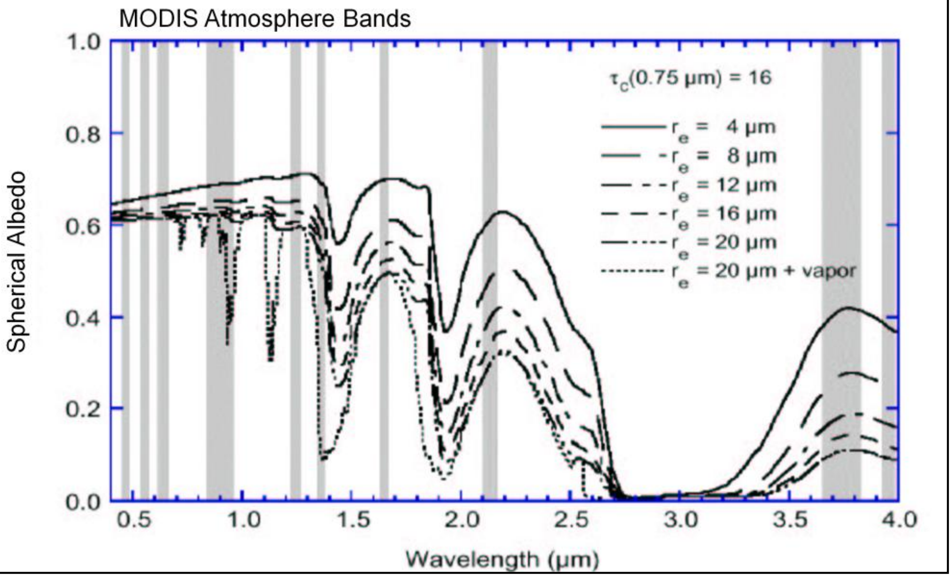
Influence of Water Vapor in the Solar Reflected Spectrum

Water Vapor can be Estimated by Spectral Fitting

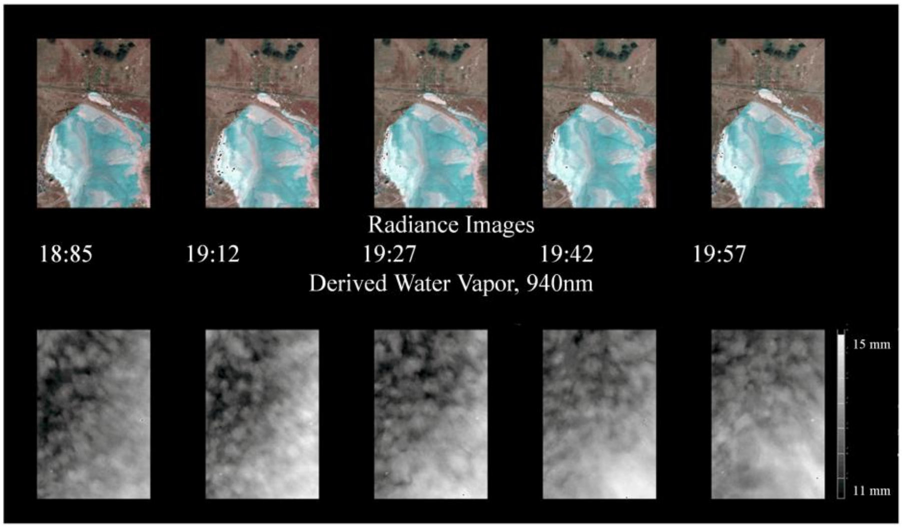
Note that the absorption features become deeper and broader (more wavelengths involved) as water vapor in the atmosphere increases.

Reflectance of Clouds…

— *increases* with *decreasing* droplet size - why?



AVIRIS Water Vapor at Rogers Dry Lake, CA



Robert O. Green

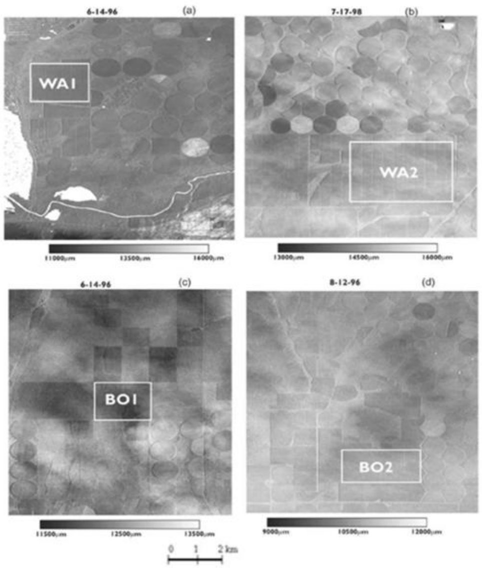
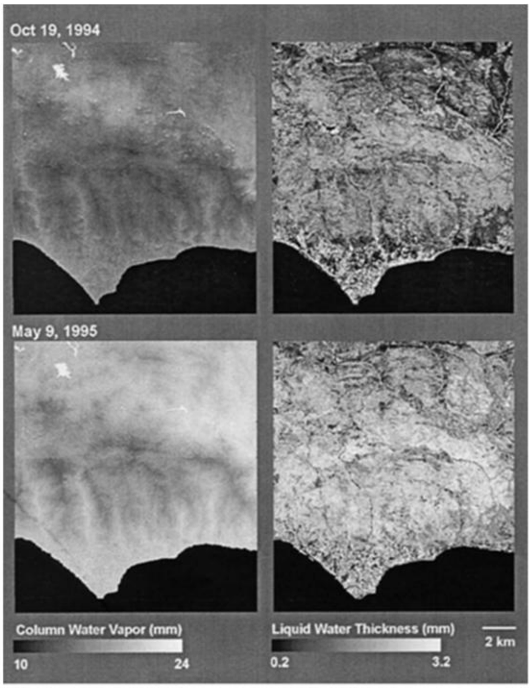


Figure 5. Spatial subset of AVIRIS derived water vapor images of the study sites showing the delineated patches. (a, b, c, d) Column water vapor images corresponding to the false color images shown in Figures 3a, 3b, 3c and 3d, respectively. The dark areas indicate low values of column water vapor while the bright areas indicate high values.

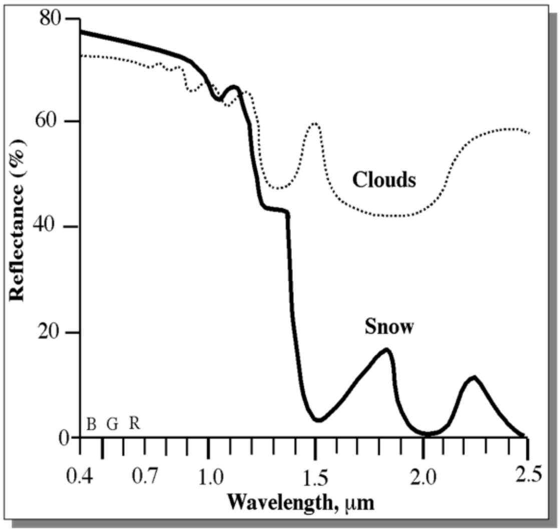
Ogunjemiyo, S., Roberts, D.A., K. Keightley, S.L. Ustin, T. Hinckley, and B. Lamb. 2002. Evaluating the relationship between AVIRIS water vapor and forested land cover. Journal of Geophysical Research-Atmosphere 107 (D23): 4719.

Water vapor
In Fall, Spring
Over Santa Monica
Mts.

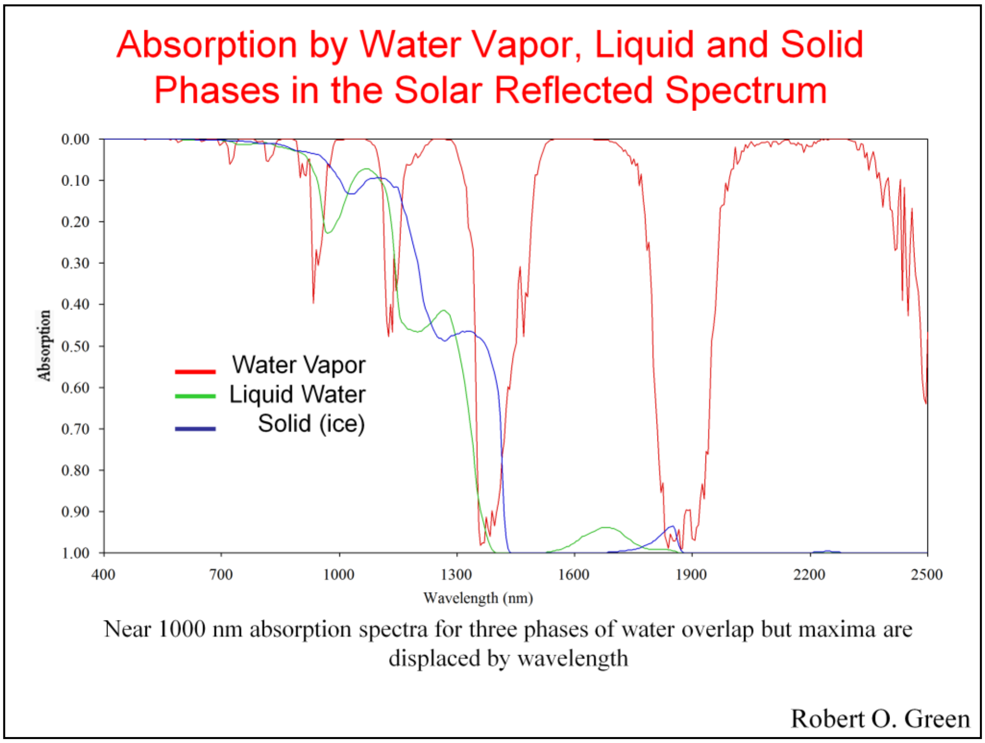


Santa Monica Mountains, CA Measured with AVIRIS

Discriminating Clouds and Snow In Bands Between 1.5 - 2.5 mm



Jensen, 2000



Absorption by Water Vapor, Liquid and Solid Phases in the Solar Reflected Spectrum

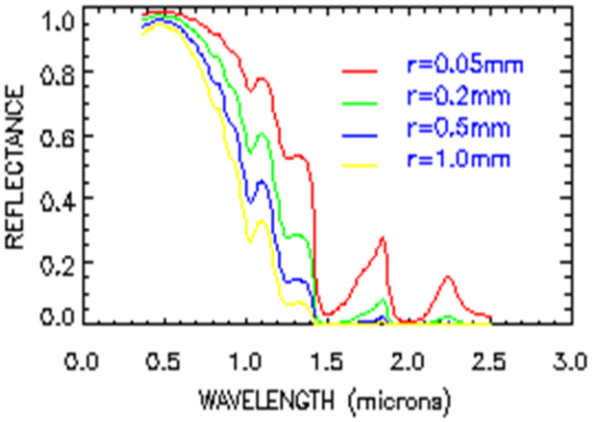
Near 1000 nm absorption spectra for three phases of water overlap but maxima are displaced by wavelength

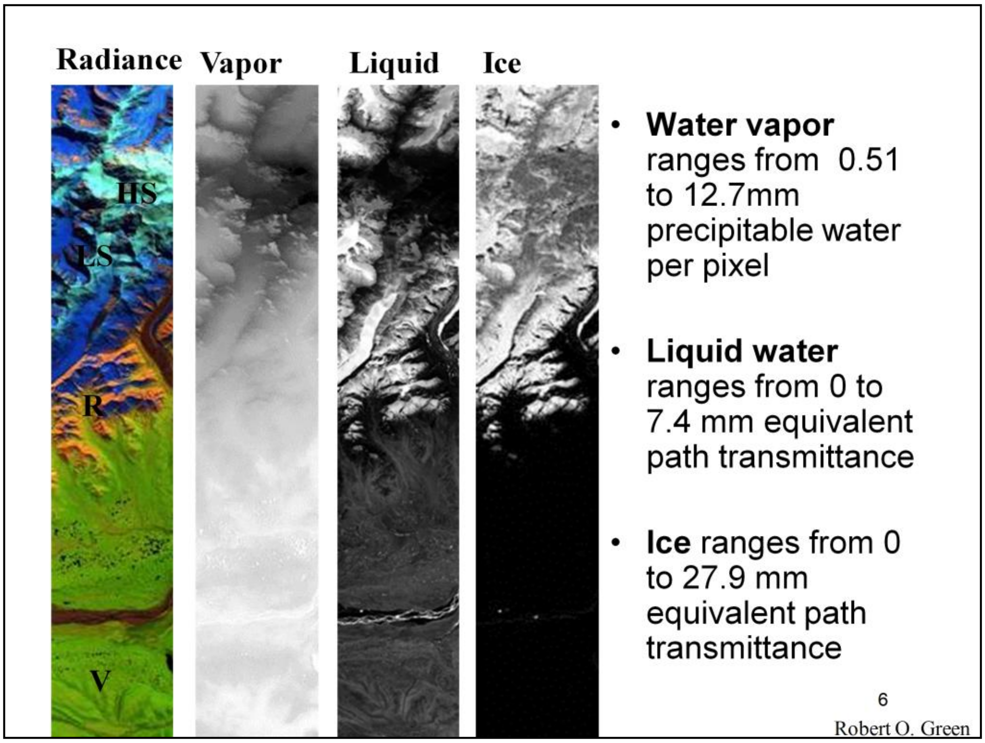
Robert O. Green

Note that near 1000 nm, that the wavelength of maximum absorption for water vapor is at the shortest wavelength, then liquid water and frozen water at the longest wavelength.

Refectance of Snow

— Reflectance ***increases*** **as grain size** ***decreases*** **- why?**



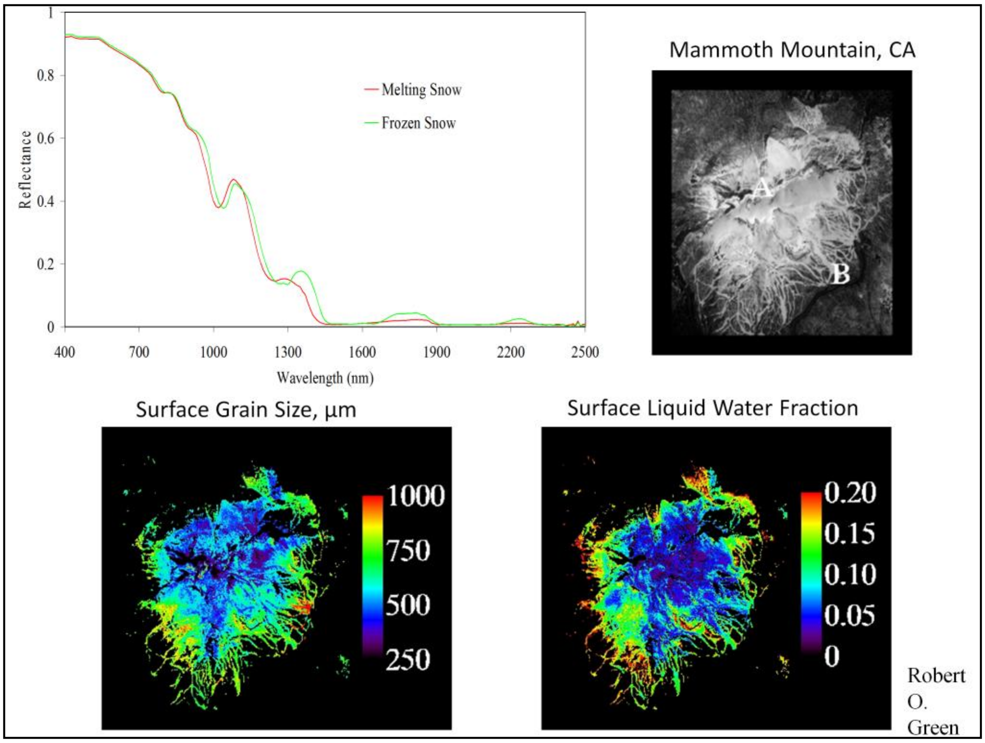


- **Water vapor** ranges from 0.51 to 12.7mm precipitable water per pixel
- **Liquid water** ranges from 0 to 7.4 mm equivalent path transmittance
- **Ice** ranges from 0 to 27.9 mm equivalent path transmittance

Robert O. Green

Forward Inversion results for:

V=vegetation
R=rock
LS=low altitude snow
HS= high altitude snow

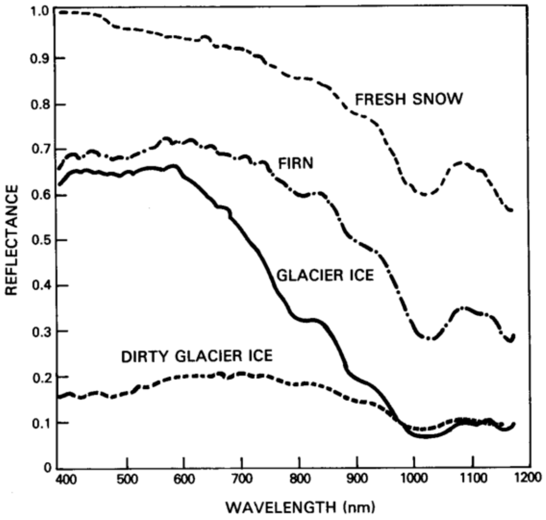


Mammoth Mountain, CA

Surface Grain Size, µm

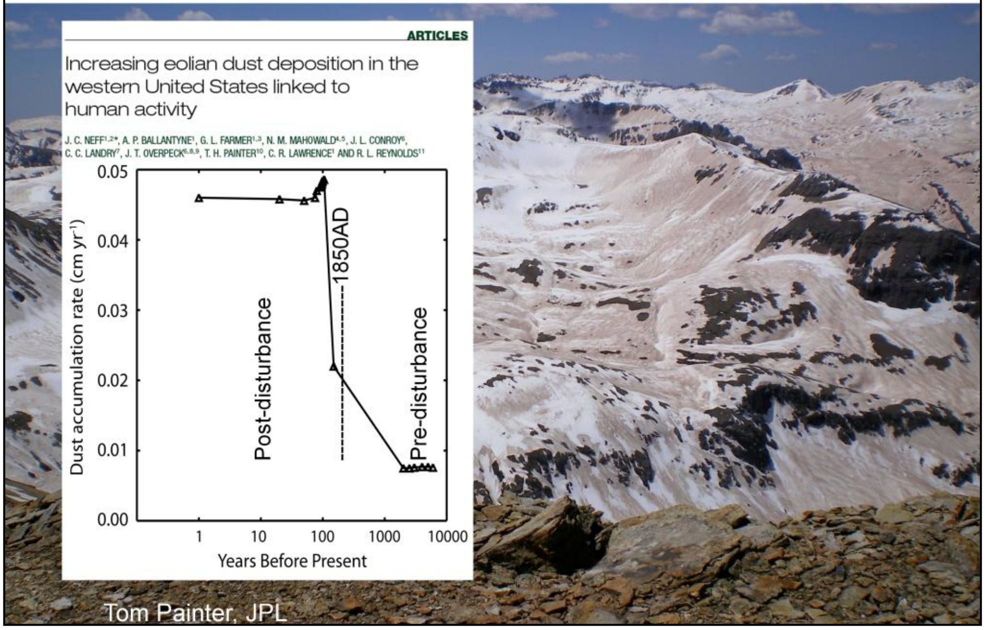
Surface Liquid Water Fraction

Robert O. Green



REFLECTANCE
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
400
500
600
700
800
900
1000
1100
1200
WAVELENGTH (nm)
FRESH SNOW
FIRN
GLACIER ICE
DIRTY GLACIER ICE

Upper Colorado River Basin



ARTICLES

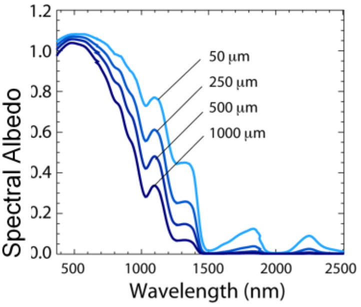
Increasing eolian dust deposition in the western United States linked to human activity

J. C. NEFF[1,2]*, A. P. BALLANTYNE[1], G. L. FARMER[1,3], N. M. MAHOWALD[4,5], J. L. CONROY[6], C. C. LANDRY[7], J. T. OVERPECK[6,8,9], T. H. PAINTER[10], C. R. LAWRENCE[1] AND R. L. REYNOLDS[11]

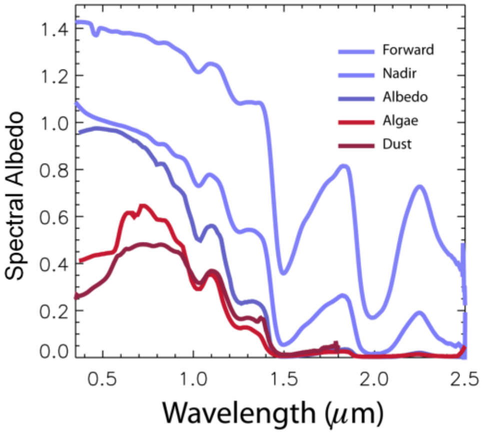
Tom Painter, JPL

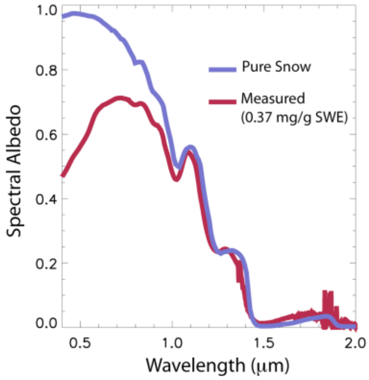
Tien Shan, Kazakhstan

Tom Painter, JPL



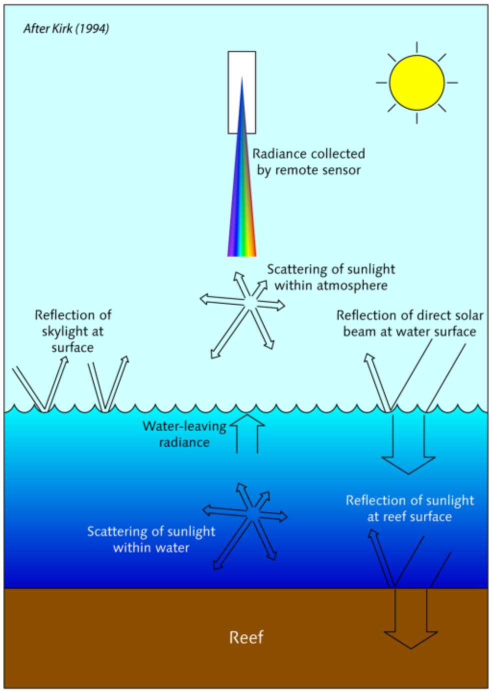
Impact of Dust and Impurities on Snow Reflectance

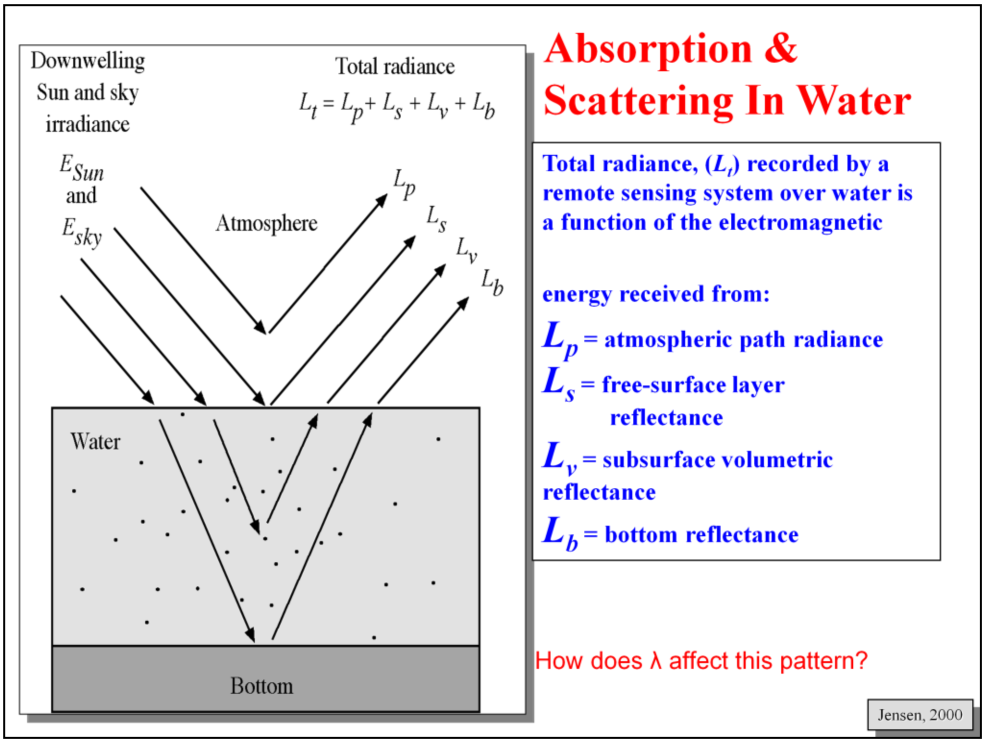




Grain size from integral of ice absorption feature (Clark and Roush 1984; Nolin and Dozier 2000)
- Gives clean snow spectrum against which radiative forcing is determined.

Sources of light contributing to the remotely sensed signal





Absorption & Scattering In Water

Total radiance, (L_t) recorded by a remote sensing system over water is a function of the electromagnetic

energy received from:

L_p = atmospheric path radiance

L_s = free-surface layer reflectance

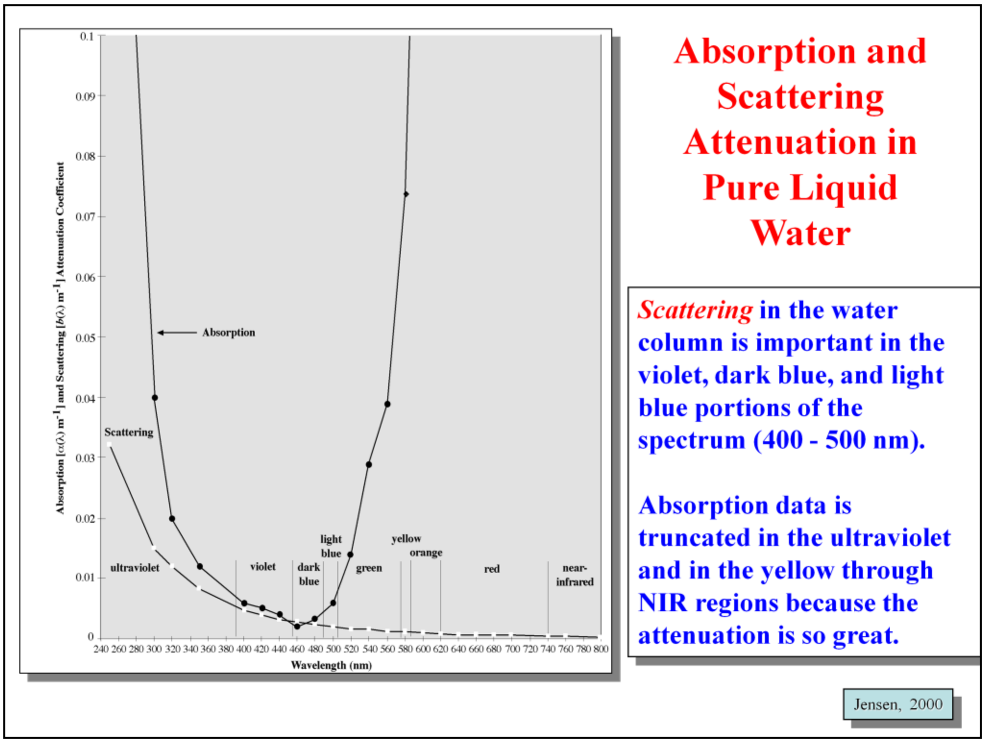
L_v = subsurface volumetric reflectance

L_b = bottom reflectance

How does λ affect this pattern?

Jensen, 2000

Shorter Wavelengtrhs penetrate to deeper depths. Some light can be reflected from bottom. Note refraction between air and water.



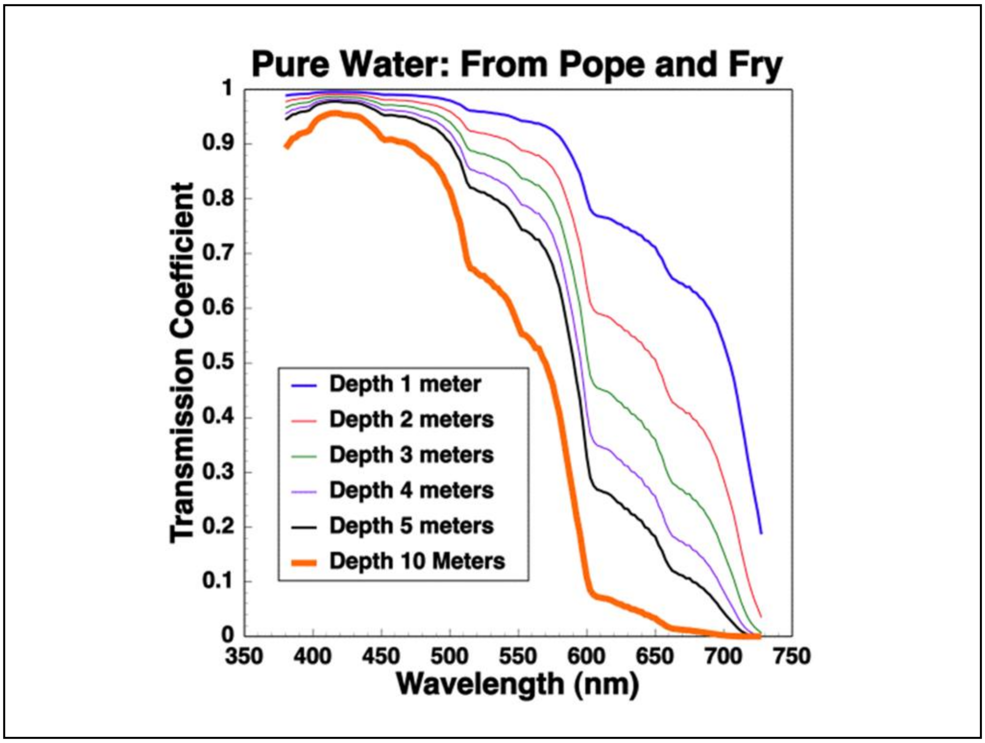
Absorption and Scattering Attenuation in Pure Liquid Water

Scattering in the water column is important in the violet, dark blue, and light blue portions of the spectrum (400 - 500 nm).

Absorption data is truncated in the ultraviolet and in the yellow through NIR regions because the attenuation is so great.

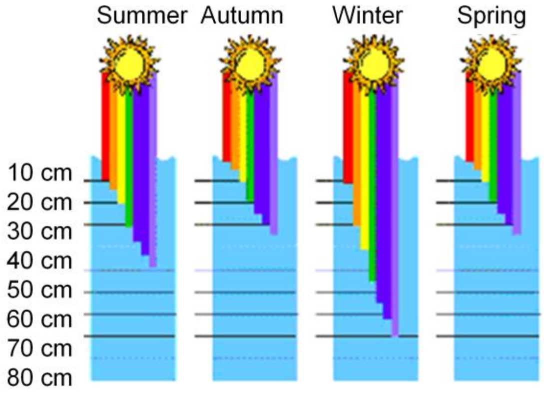
Jensen, 2000

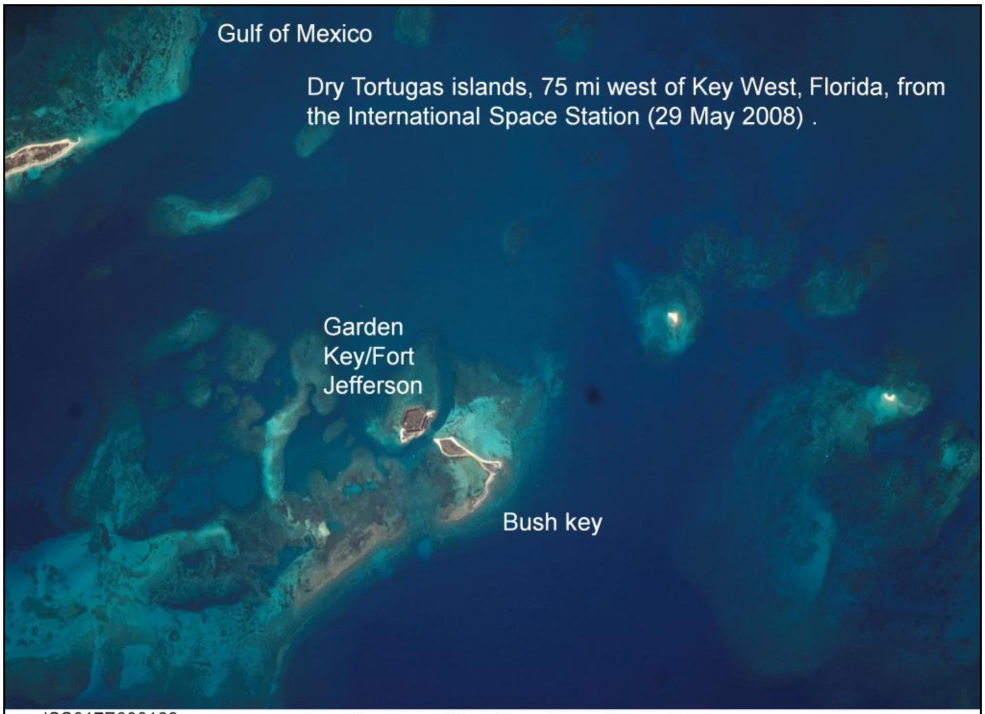
Scattering in the blue is why water appears blue to our eyes.



Note that as the depth of water becomes deeper the maximum transmission wavelengths are shifted toward the blue part of the spectrum

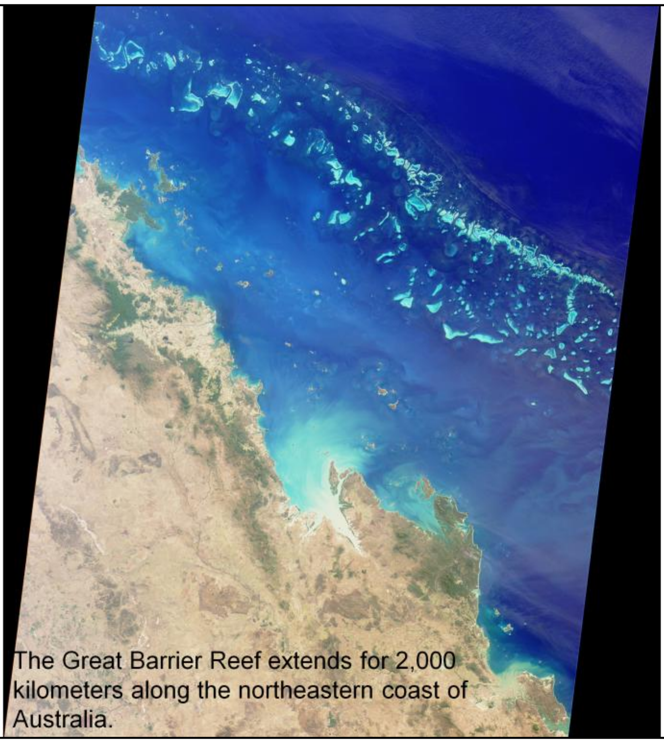
Light Penetration Varies with Season: Sediment, Turbidity, Algae, Aquatic Macrophytes





ISS017E008188 coral reefs over older limestone formations

The islands were named "Dry Tortugas" upon discovery by Ponce de Leon in 1513 -- "tortugas" means turtles in Spanish, and the islands are "dry" as no fresh water is found on them. From the air, the islands present an atoll-like arrangement, however no central volcanic structure is present. The islands are only accessible by boat or seaplane; nevertheless they have been designated the Dry Tortugas National Park, and are visited by hundreds every year. This view highlights three islands in the group; Bush Key, Hospital Key, and Garden Key -- the site of Fort Jefferson. Fort Jefferson is a Civil War era fort, perhaps most notable for being the prison of Dr. Samuel Mudd, who set the broken leg of John Wilkes Booth following Booth's assassination of President Lincoln. The fort itself is currently undergoing extensive restoration to prevent collapse of the hexagonal outer walls (center). The islands stand out due to brown and light tan carbonate sands visible above the Gulf of Mexico water surface. Light blue-green irregular masses in the image surrounding the islands are coral reef tops visible below the water surface.



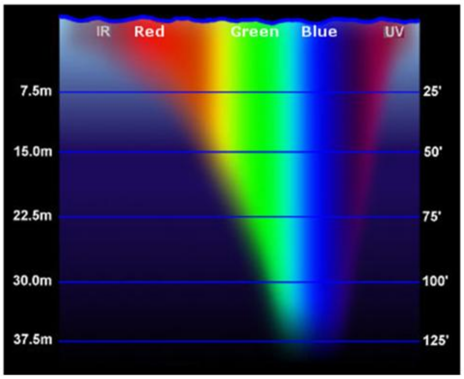
The Great Barrier Reef extends for 2,000 kilometers along the northeastern coast of Australia.

vast maze of reefs, passages, and coral cays (islands that are part of the reef). This nadir true-color image was acquired by the Multi-angle Imaging Spectroradiometer (MISR) instrument on August 26, 2000, and shows part of the southern portion of the reef adjacent to the central Queensland coast. The width of the MISR swath is approximately 380 kilometers, with the reef clearly visible up to approximately 200 kilometers from the coast. It may be difficult to see the myriad details in the browse image, but if you retrieve the higher resolution version, a zoomed display reveals the spectacular structure of the many reefs.

The more northerly coastal area in this image shows the vast extent of sugar cane cultivation, this being the largest sugar producing area in Australia, centered on the city of Mackay. Other industries in the area include coal, cattle, dairying, timber, grain, seafood, and fruit. The large island off the most northerly part of the coast visible in this image is Whitsunday Island, with smaller islands and reefs extending southeast, parallel to the coast. These include some of the better known resort islands such as Hayman, Lindeman, Hamilton, and Brampton Islands.

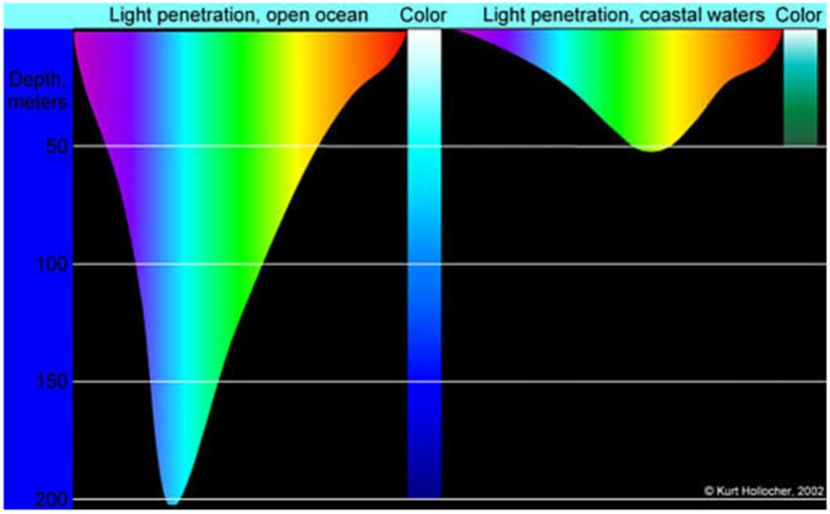
Further south (in the high-resolution version), just inland of the small semicircular bay near the right of the image, is Rockhampton, the largest city along the central Queensland coast, and the regional center for much of central Queensland. Rockhampton is just north of the Tropic of Capricorn. Its hinterland is a rich pastoral, agricultural, and mining region.

Light Penetration in Water

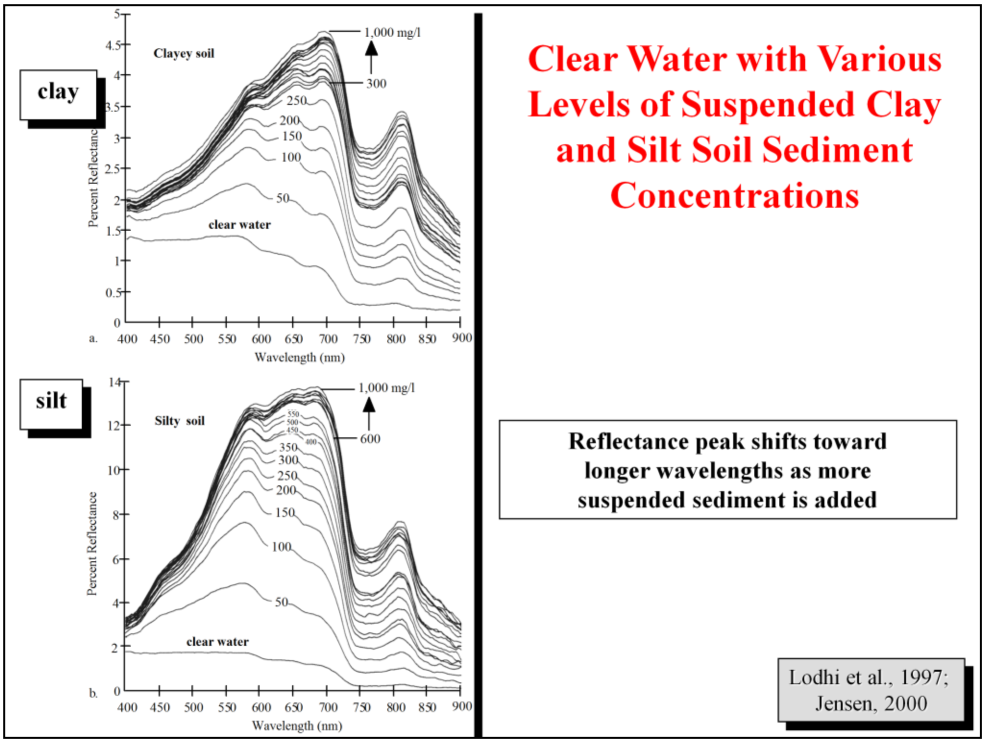


Note Order from long to short wavelengths

Light Penetration in Water



What λ order are these displayed in?

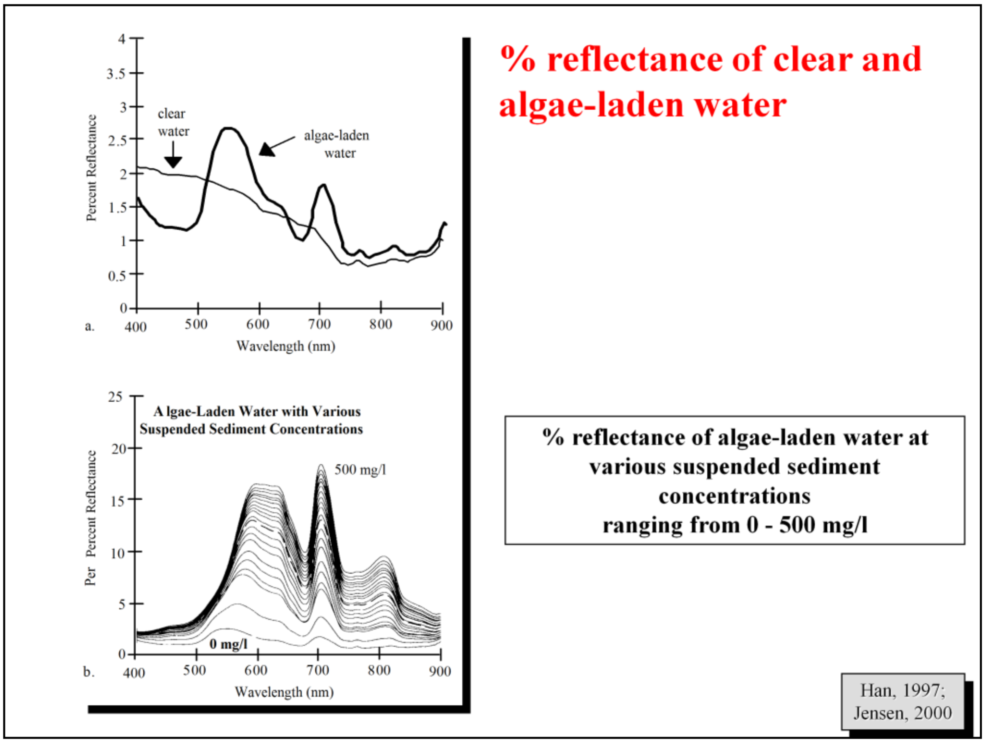


Clear Water with Various Levels of Suspended Clay and Silt Soil Sediment Concentrations

Reflectance peak shifts toward longer wavelengths as more suspended sediment is added

Lodhi et al., 1997;
Jensen, 2000

In situ spectroradiometer Measurements

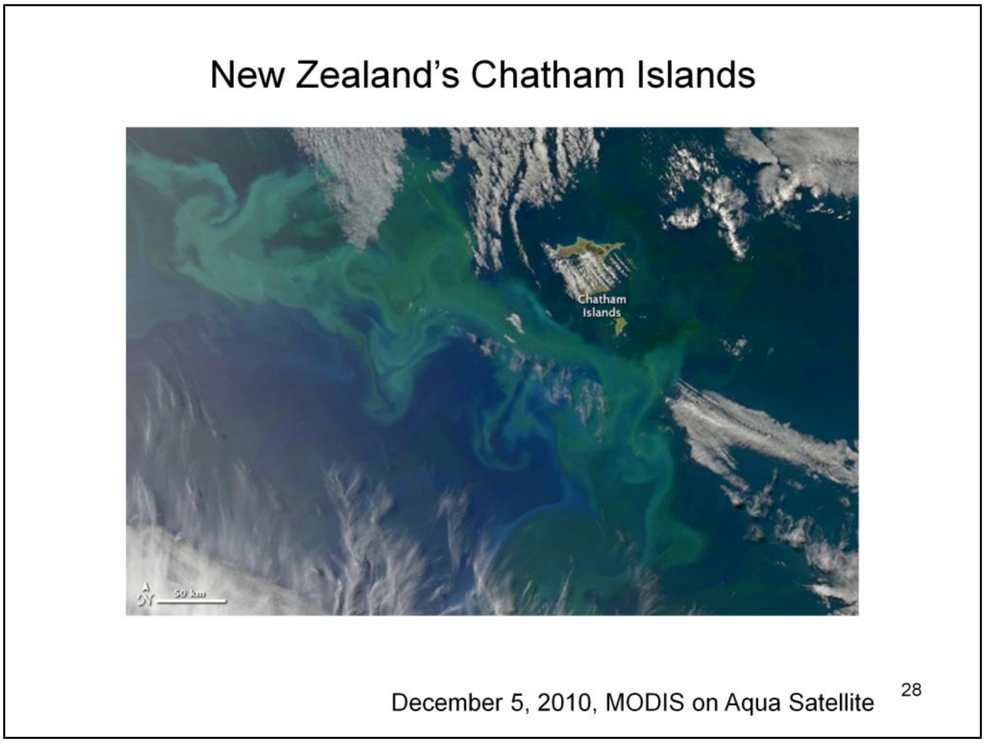


% reflectance of clear and algae-laden water

% reflectance of algae-laden water at various suspended sediment concentrations ranging from 0 - 500 mg/l

Han, 1997;
Jensen, 2000

Note strong *chlorophyll a* absorption of blue light between 400 and 500 nm and strong absorption of red light at ~675 nm



New Zealand’s Chatham Islands

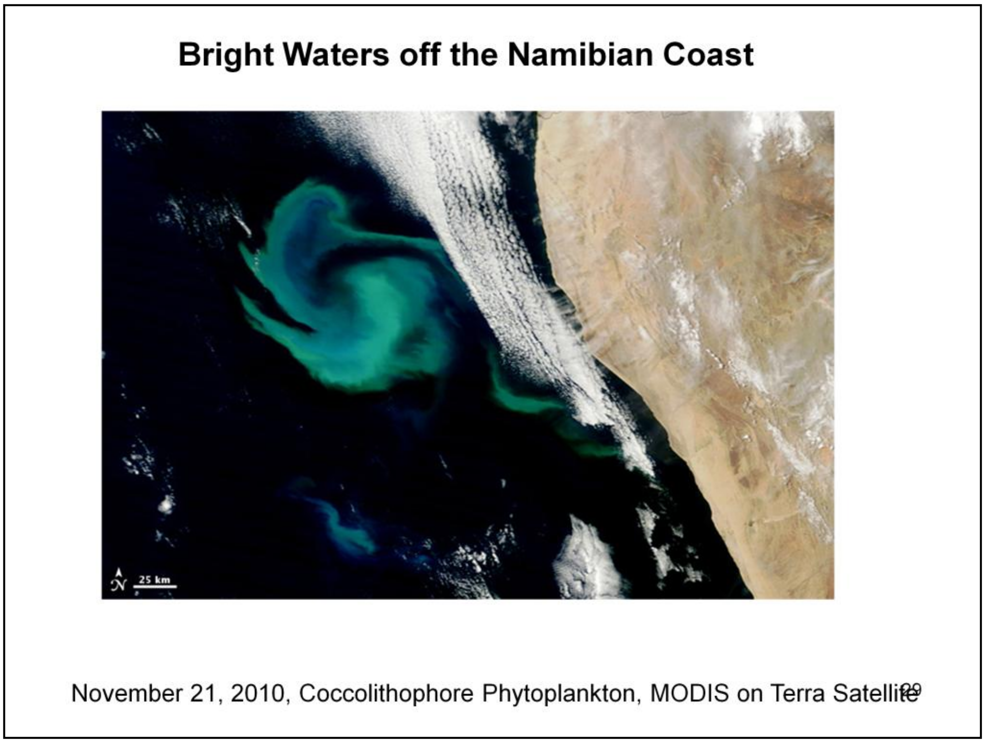
December 5, 2010, MODIS on Aqua Satellite

The waters around New Zealand’s Chatham Islands teem with life. The highly productive waters support massive phytoplankton blooms that sustain valuable stocks of fish. This image, taken by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA’s Aqua satellite on December 5, 2010, shows the large annual spring-time bloom.

The bloom is an array of colors from deep green to electric blue, and is probably made up of many different types of marine life, primarily phytoplankton. The phytoplankton, plant-like organisms, contribute to making the ocean in this region a carbon sink, a place where the ocean takes in more carbon dioxide than it releases into the atmosphere.

The ocean is productive in this region because the topography of the ocean floor brings two currents together around the Chatham Islands. The islands sit on the Chatham Rise, an underwater plateau that stretches from New Zealand’s South Island east to just beyond the Chatham Islands. The water north and south of the plateau is very deep. Cold, nutrient-rich, but iron-poor water from the Antarctic flows south of the Chatham Rise. To the north is mostly warm, nutrient-poor, but iron-rich water from the subtropics.

The two pools of water come together in a current that rides over the plateau, mixing cold water with warm. The mixed water in the current provides both the nutrients and iron fertilizers needed to support large blooms around the Chatham Islands. The current, and therefore, the bloom, is strongest in the spring and fall.



Bright Waters off the Namibian Coast

November 21, 2010, Coccolithophore Phytoplankton, MODIS on Terra Satellite

Ocean waters glowed peacock green off the northern Namibian coast in late November 2010. The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA’s Terra satellite captured this natural-color image on November 21, 2010.

These bright swirls of green occur along a continental shelf bustling with biological activity. Phytoplankton blooms often occur along coastlines where nutrient-rich waters well up from ocean depths. The light color of this ocean water suggests the calcite plating of coccolithophores.

Farther south along the coast of Namibia, hydrogen sulfide eruptions occur fairly frequently. According to a study published in 2009, ocean currents deliver oxygen-poor water from the north, while the bacteria that break down phytoplankton also consume oxygen, depleting the supply even more. In this oxygen-poor environment, anaerobic bacteria produce hydrogen sulfide gas. When the hydrogen sulfide finally reaches oxygen-rich surface waters, pure sulfur precipitates into the water. The sulfur’s yellow mixes with the deep blue ocean to make bright green.

So this swirl of bright green could contain phytoplankton, sulfur, or a combination of the two.

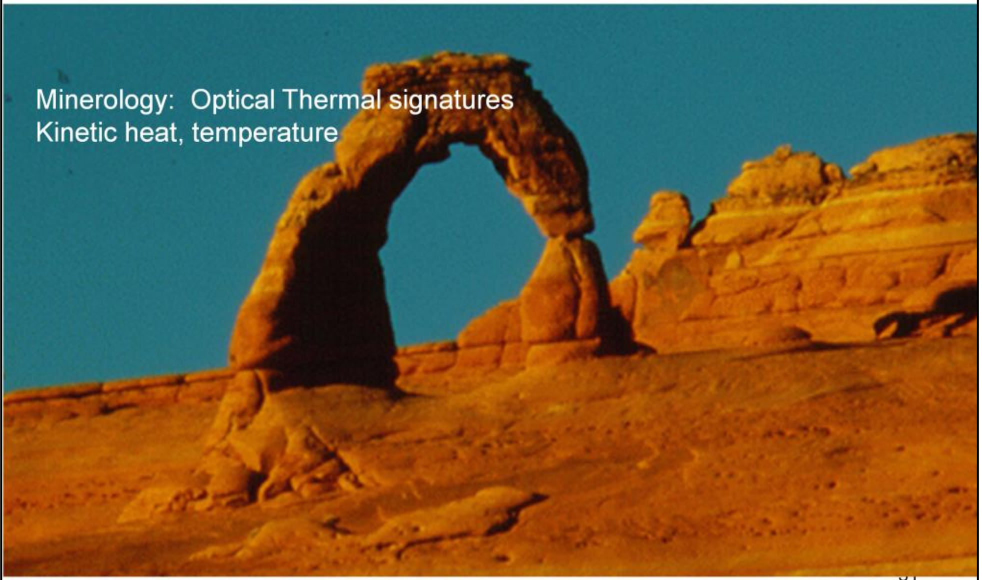
Lecture 5: What you should know about Earth Observing Satellites

1. *Landsat MSS and TM (# bands, approx. λ location, spatial resolution)*
2. SPOT satellites (compared to Landsat *(# bands, approx. λ location, spatial resolution)*
3. Pixel and spatial resolution of Landsat, SPOT
4. Trends: more bands, smaller pixels, more countries, companies flying them, etc.

Lecture 5: What you should know about water

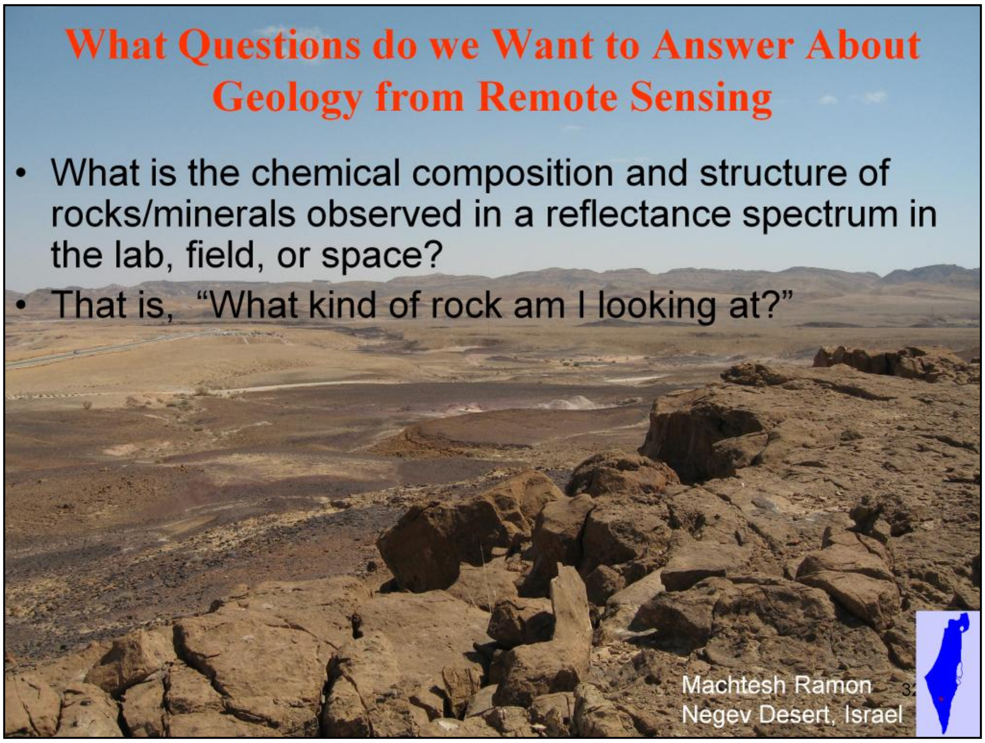
1. Spectral properties of water in all three phases
2. Causes of absorption and scattering in vapor, liquid, ice
3. Effect of particle size on reflectance of ice & water drops in clouds, snow
4. Impact of algae, black carbon, and sediment on ice/snow reflectance
5. Light penetration into water by wavelength
6. Detection of coral, other things in water

Lecture 6 Spectroscopy of Minerals Chapter 14, 2



Minerology: Optical Thermal signatures
Kinetic heat, temperature

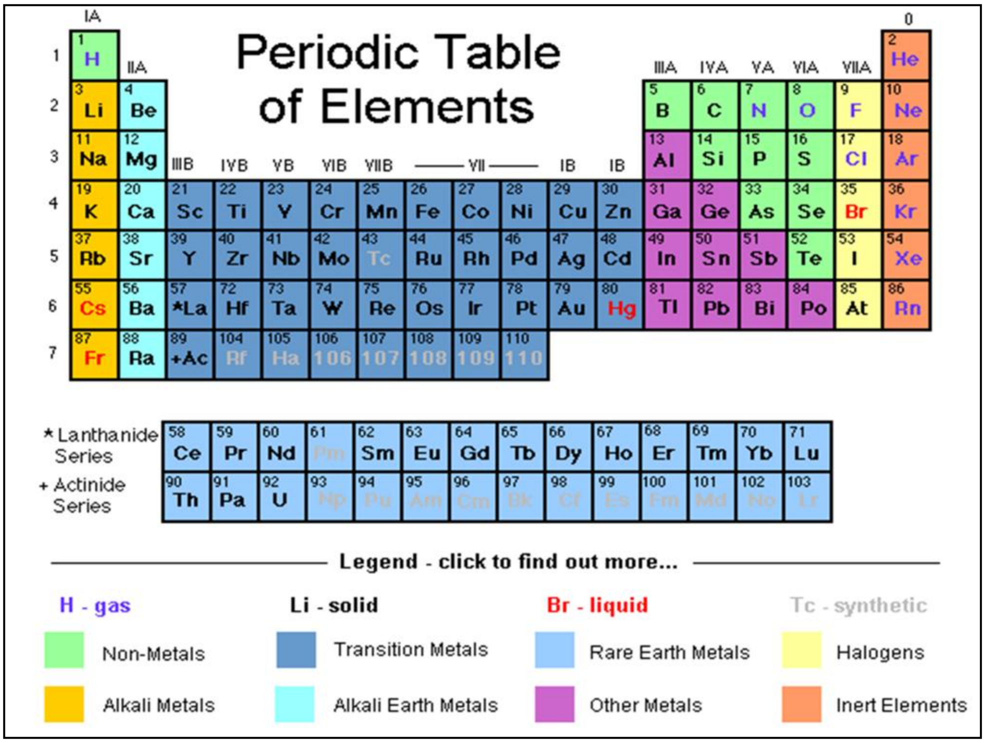
The image above is Delicate Arch in Arches National Park. by Roger N. Clark



What Questions do we Want to Answer About Geology from Remote Sensing

- What is the chemical composition and structure of rocks/minerals observed in a reflectance spectrum in the lab, field, or space?
- That is, “What kind of rock am I looking at?”

Machtesh Ramon
Negev Desert, Israel



Periodic Table of Elements

	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VII			IB	IB	IIIA	IVA	VA	VIA	VIIA	0
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 *La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 +Ac	104 Rf	105 Ha	106 106	107 107	108 108	109 109	110 110								

* Lanthanide Series	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
+ Actinide Series	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

Legend - click to find out more...

H - gas	Li - solid	Br - liquid	Tc - synthetic
■ Non-Metals	■ Transition Metals	■ Rare Earth Metals	■ Halogens
■ Alkali Metals	■ Alkali Earth Metals	■ Other Metals	■ Inert Elements

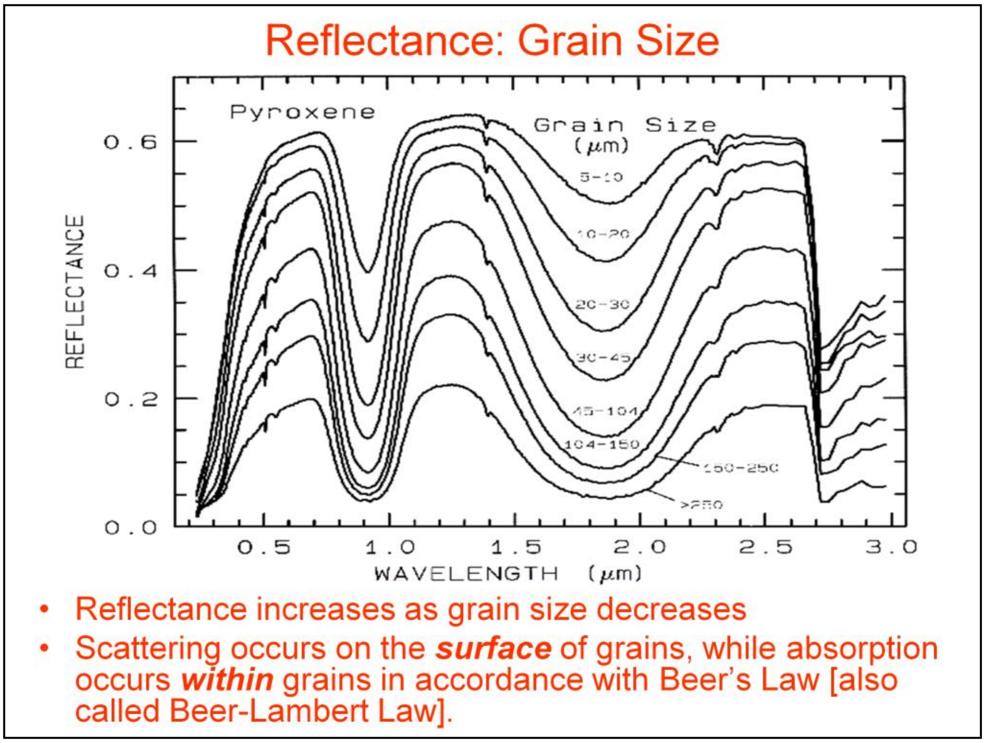
21 Scandium, 22 Titanium, 23 Vanadium, 24 Chromium, 25 Manganese, 26 Iron, 27 Cobalt, 28 Nickel, 29 Copper, 30 Zinc

40 Zirconium, 42 Molybdenum, 43 Technetium, 44 Ruthenium, 45 Rhodium, 46 Lead, 47 Silver, 28 Cadmium

78 Platinum, 79, Gold, 80 Mercury

EMR and Minerals

- What does EMR do when it contacts a rock?
  - Reflects
    - Reflects off grains; scattering either away from the surface (single scattering) or onto other grains (multiple scattering)
  - Transmitted and Refracted through a translucent (semi-transparent) grain onto other grains
  - Absorbed by a grain

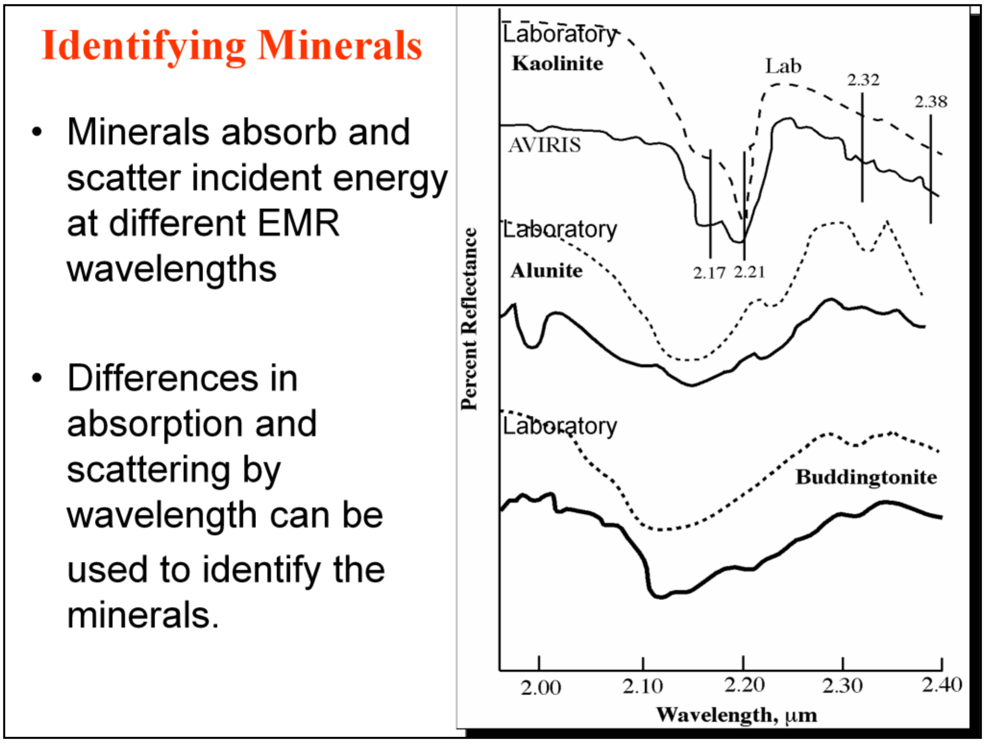


Reflectance: Grain Size

- Reflectance increases as grain size decreases
- Scattering occurs on the ***surface*** of grains, while absorption occurs ***within*** grains in accordance with Beer's Law [also called Beer-Lambert Law].

Surface to volume ratio: smaller grains have higher surface to volume ratio, so usually more scattering occurs in smaller grains vs. larger grains, and reflectance is typically higher in the VNIR.

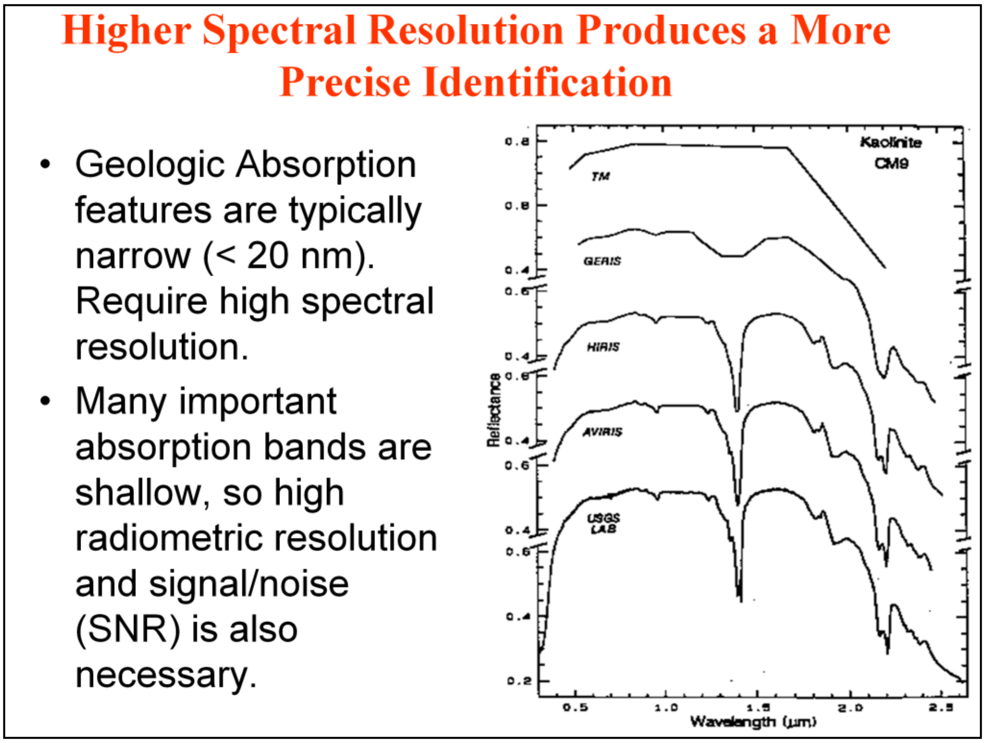
Beer's Law: states that as light is transmitted through a path of a certain length, the absorbance is directly proportional to the concentration of a solution. If you plot absorbance versus concentration, the resulting graph yields a straight line.



Identifying Minerals

- Minerals absorb and scatter incident energy at different EMR wavelengths
- Differences in absorption and scattering by wavelength can be used to identify the minerals.

Comparison of laboratory spectral signatures and airborne hyperspectral imager (AVIRIS) spectra for three minerals: kaolinite (a type of clay), allunite (another type of clay) and buddingtonite (a rare mineral sometimes associated with gold deposits)

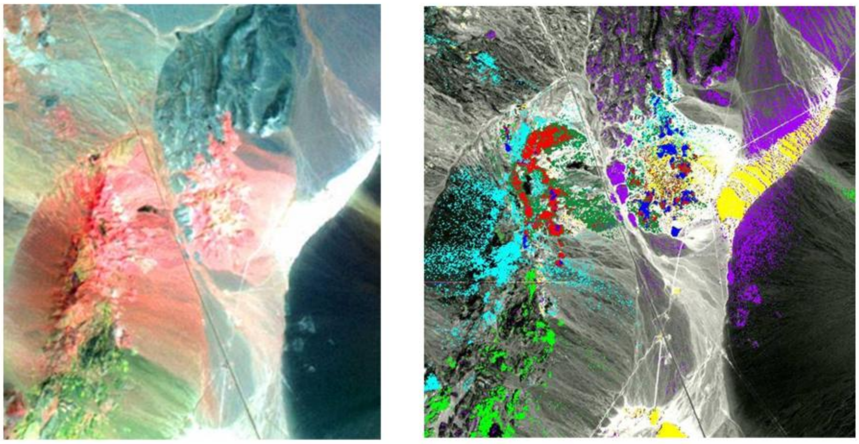


Higher Spectral Resolution Produces a More Precise Identification

- Geologic Absorption features are typically narrow (< 20 nm). Require high spectral resolution.
- Many important absorption bands are shallow, so high radiometric resolution and signal/noise (SNR) is also necessary.

Contrast with soils and plants

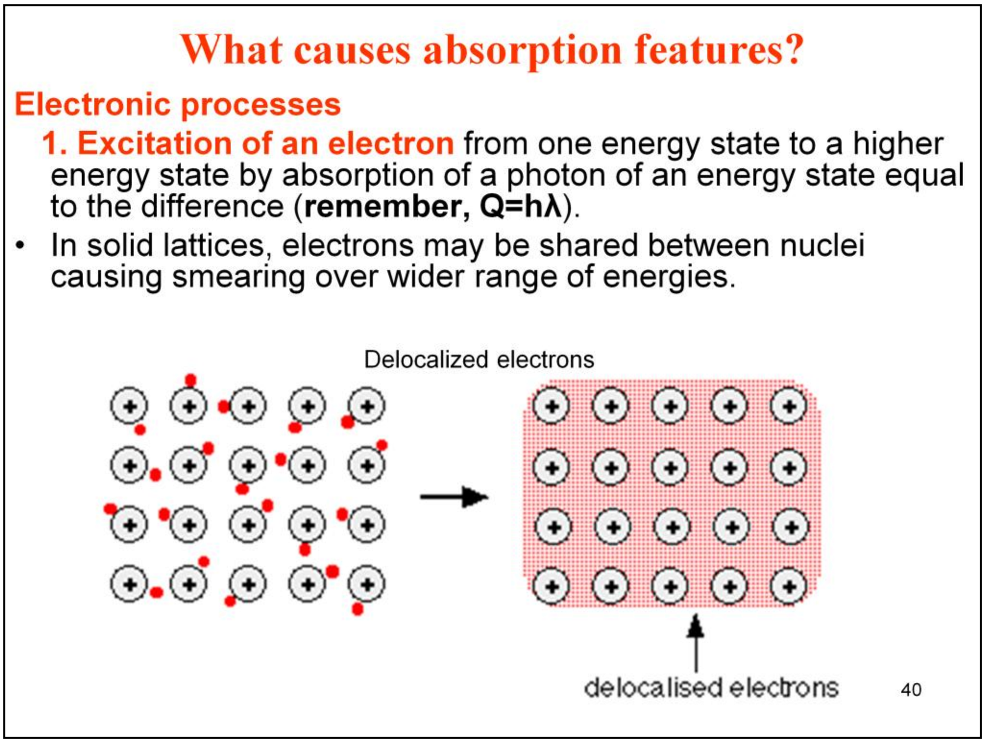
ASTER: Cuprite, NV



ASTER (SWIR bands 4,6,8 on left). Classification (right): Blue=kaolinite, red=alunite, light green=calcite, dark green=alunite+kaolinite, cyan=montmorillonite, purple=unaltered, yellow=silica or dickite.

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.



What causes absorption features?

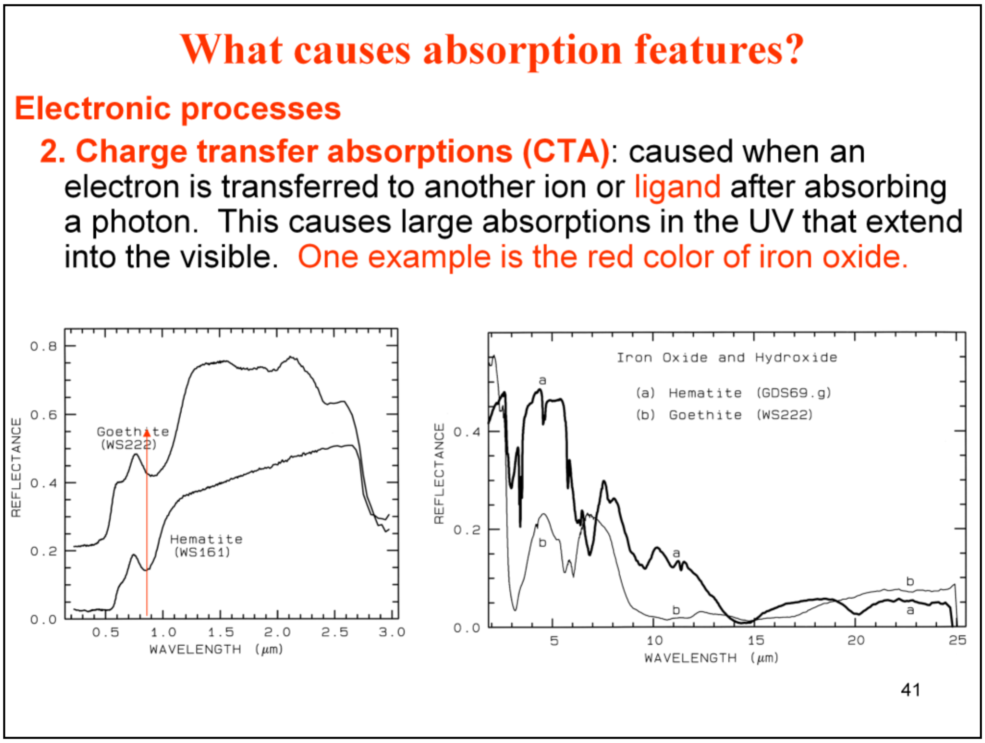
Electronic processes

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.

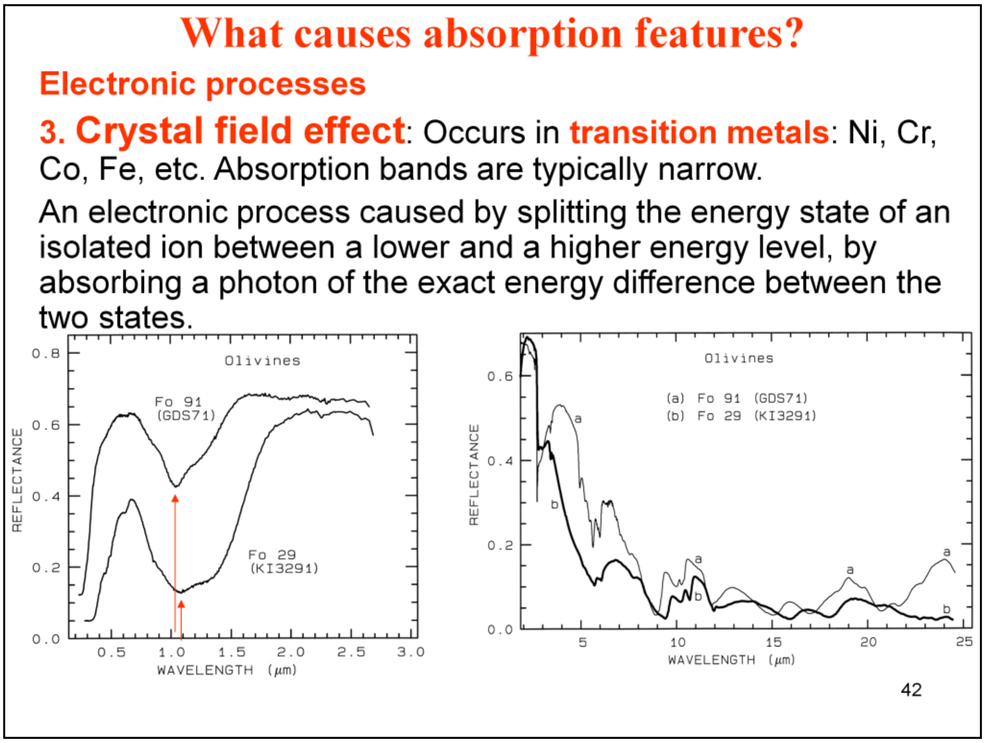
Transfer of an electron between ions or between ions and ligands. Can occur with different valence states in a metal (e.g., Fe^{+2} and Fe^{+3}).

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.

(Left) 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.

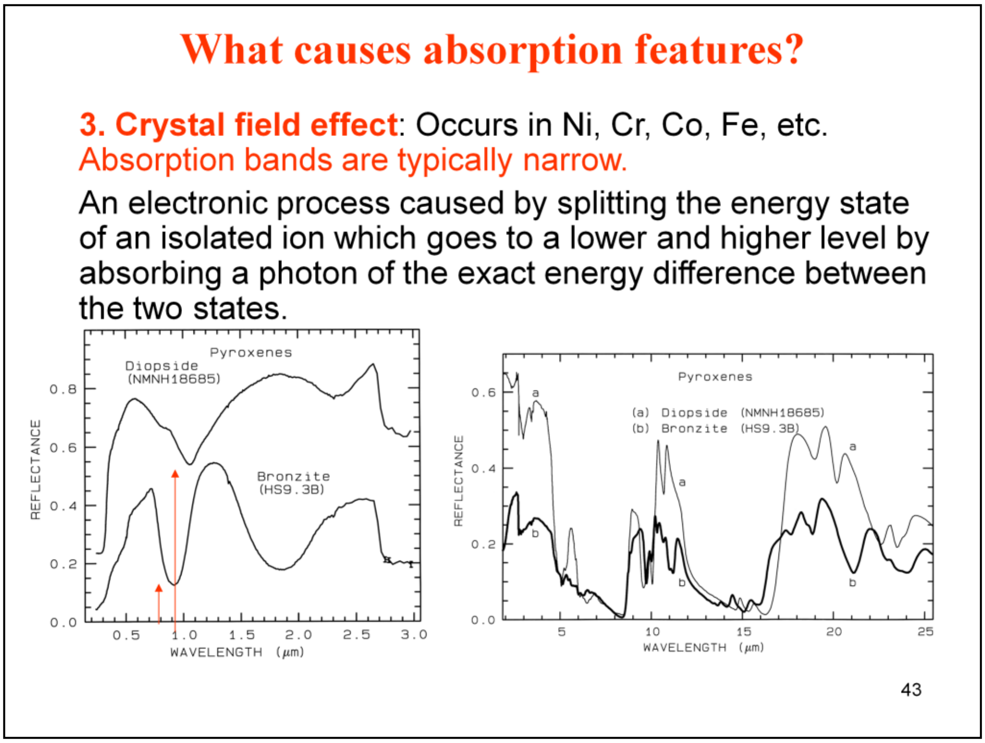
An electronic process caused by splitting the energy state of an isolated ion between a lower and a higher energy level, by absorbing a photon of the exact energy difference between the two states.

42

(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 Fe2+.** "Fo" stands for forsterite (Mg2SiO4) in the forsterite-fayalite (Fe22+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.



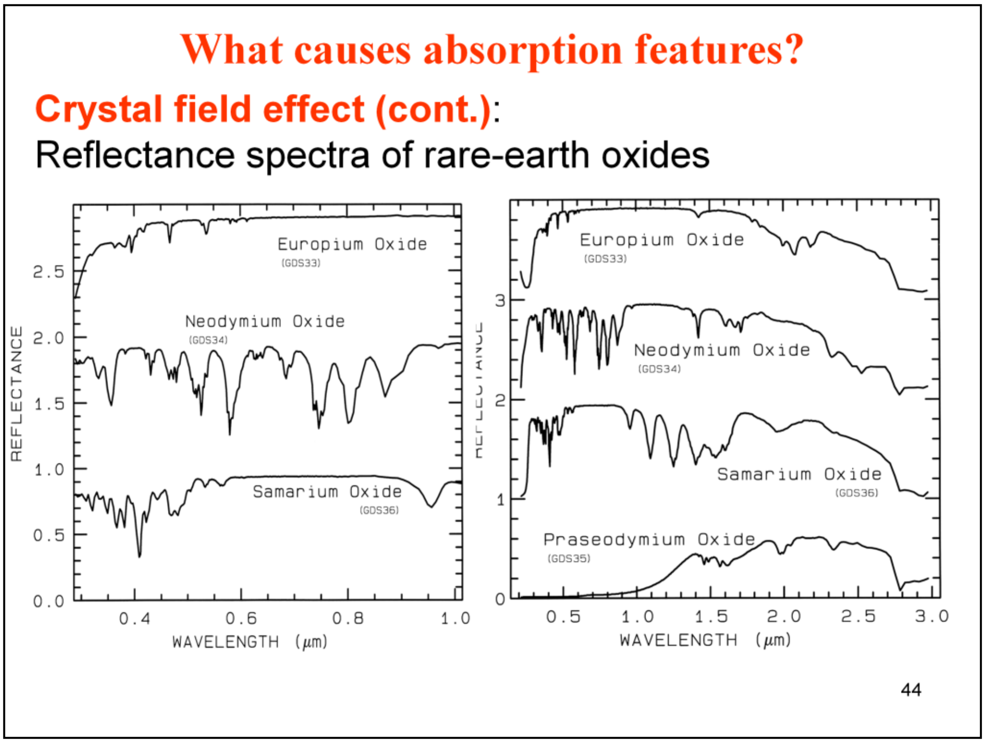
What causes absorption features?

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.

43

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

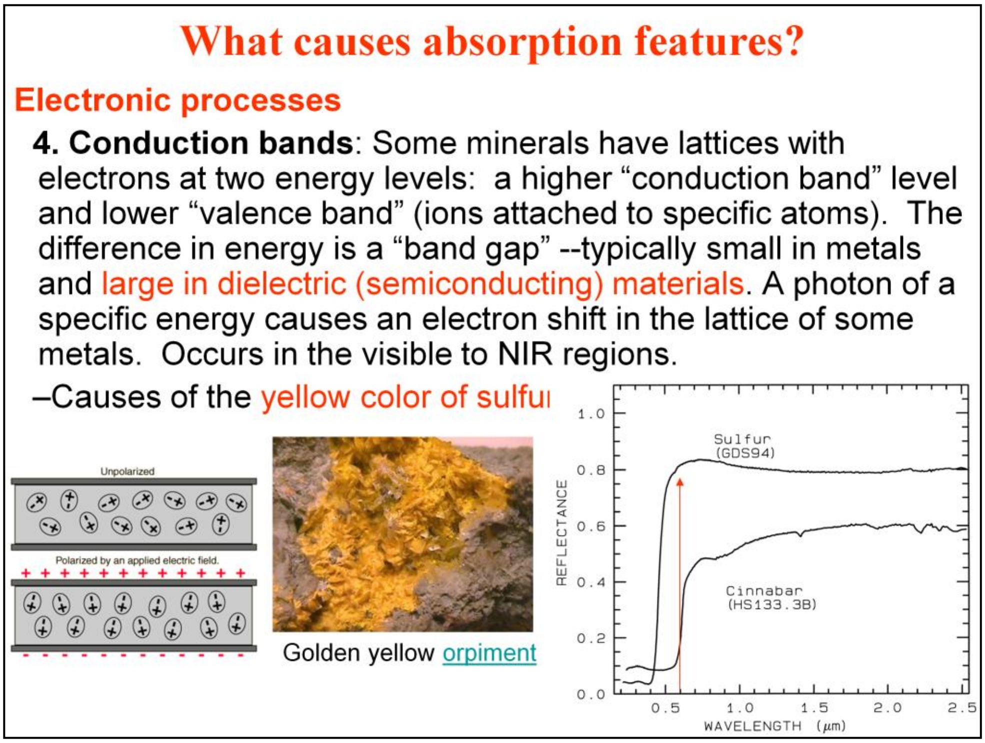
99% White Reflecting Panels

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 sulfu

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)

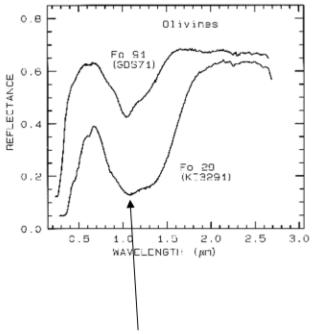
Amethyst

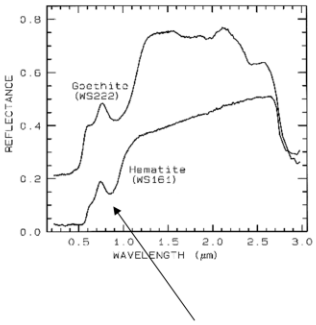
47

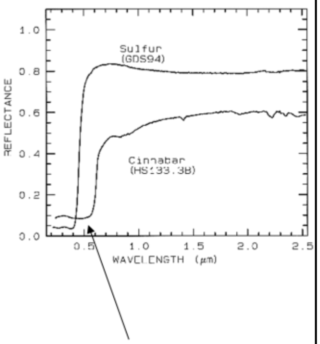
THERMOLUMINESCENCE

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



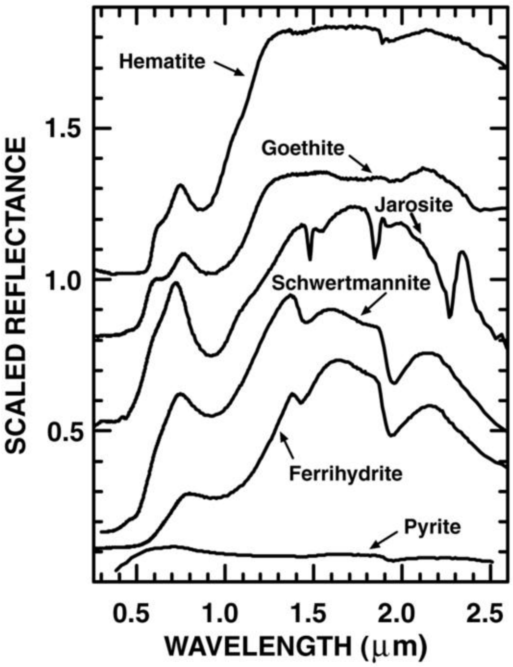


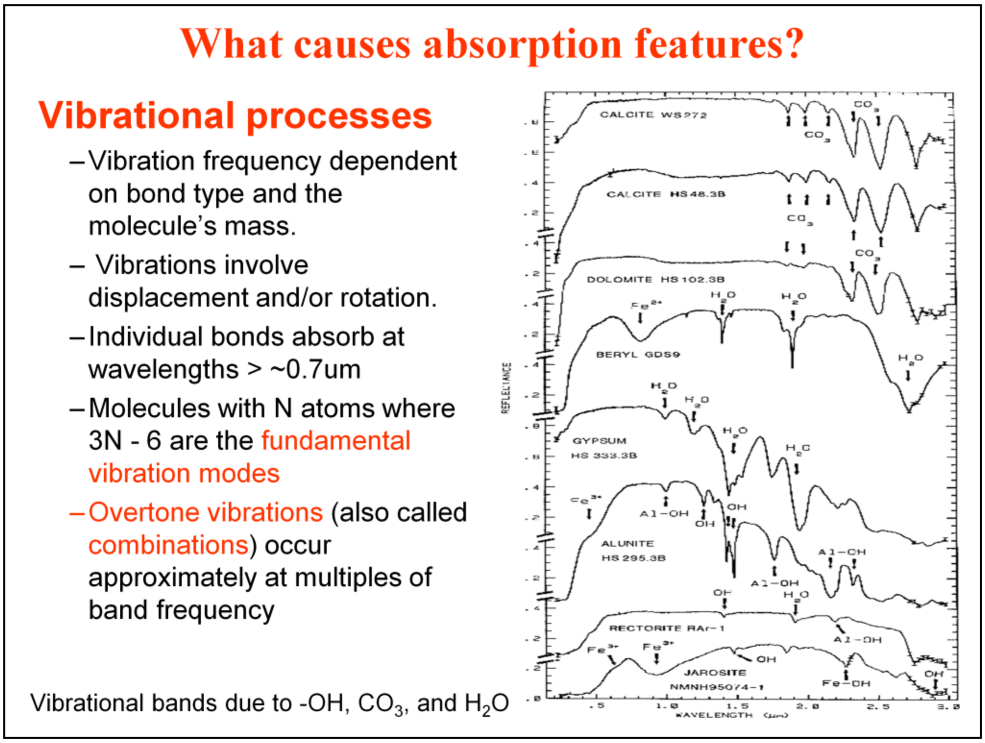


Crystal field effect absorption, Example caused by Fe^{2+}.
Fo29 has 53.65% FeO,
Fo91 has 7.93% FeO.

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

Conduction bands, Example caused by S and HgS.


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



What causes absorption features?

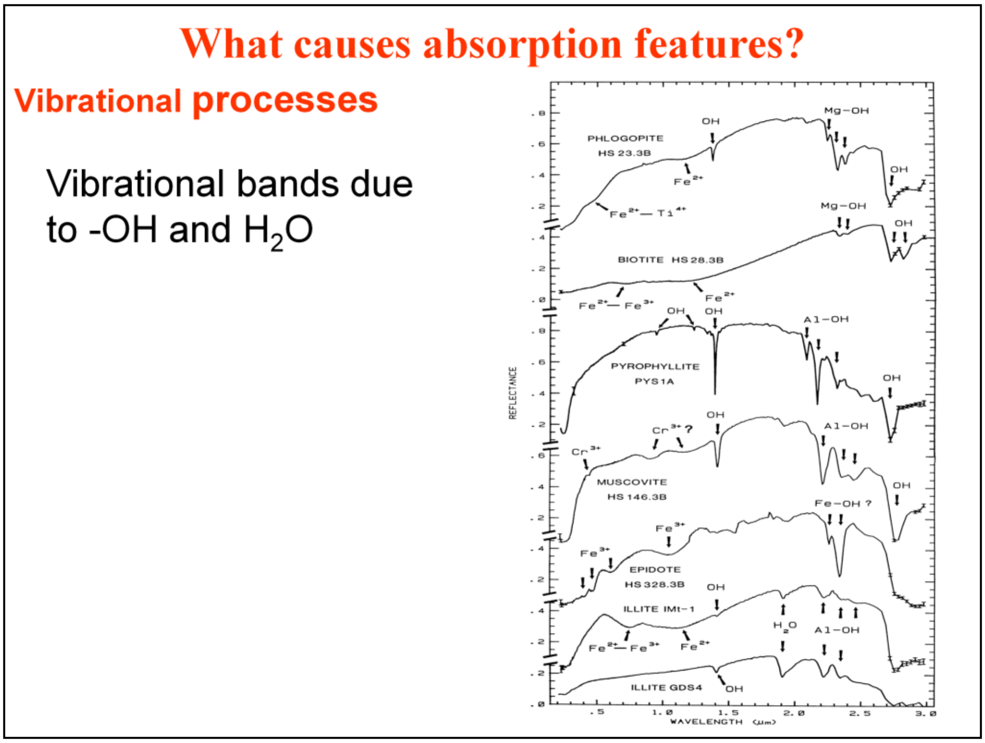
Vibrational processes

- 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)

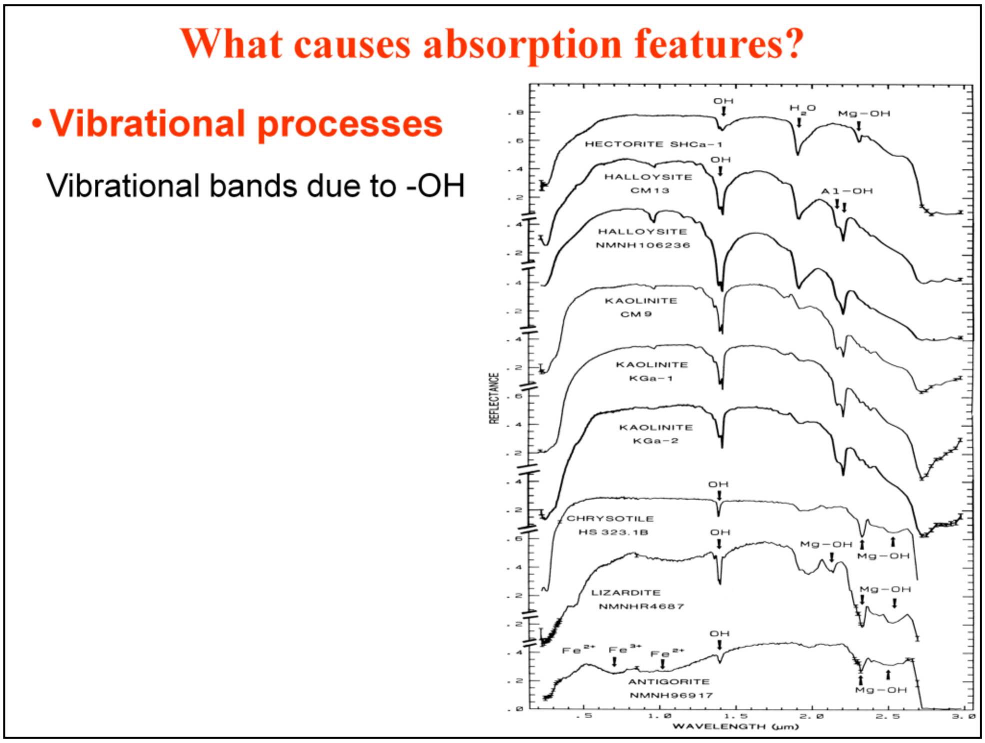


What causes absorption features?

Vibrational processes

Vibrational bands due to -OH and H_2O

Vibrational bands due to OH and H2O



What causes absorption features?

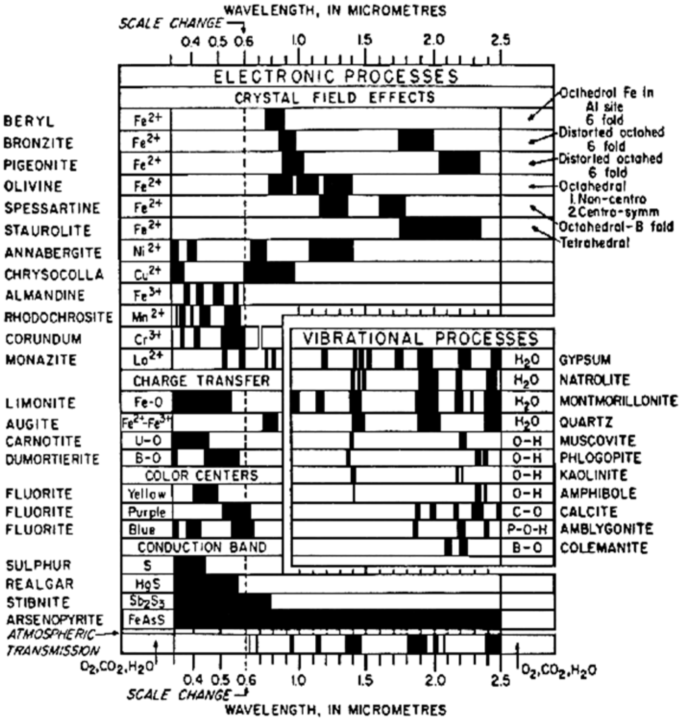
- **Vibrational processes**

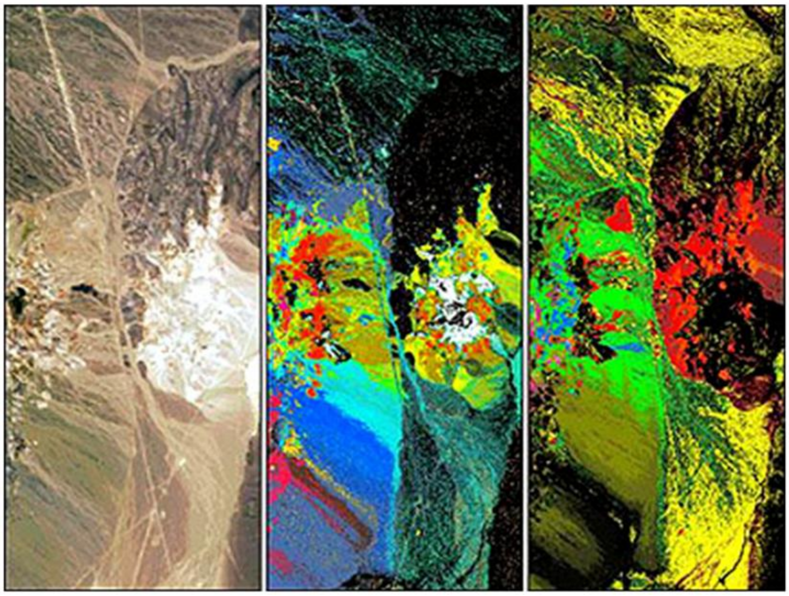
Vibrational bands due to -OH

Vibrational bands due to OH

Identifying Minerals with Spectroscopy

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

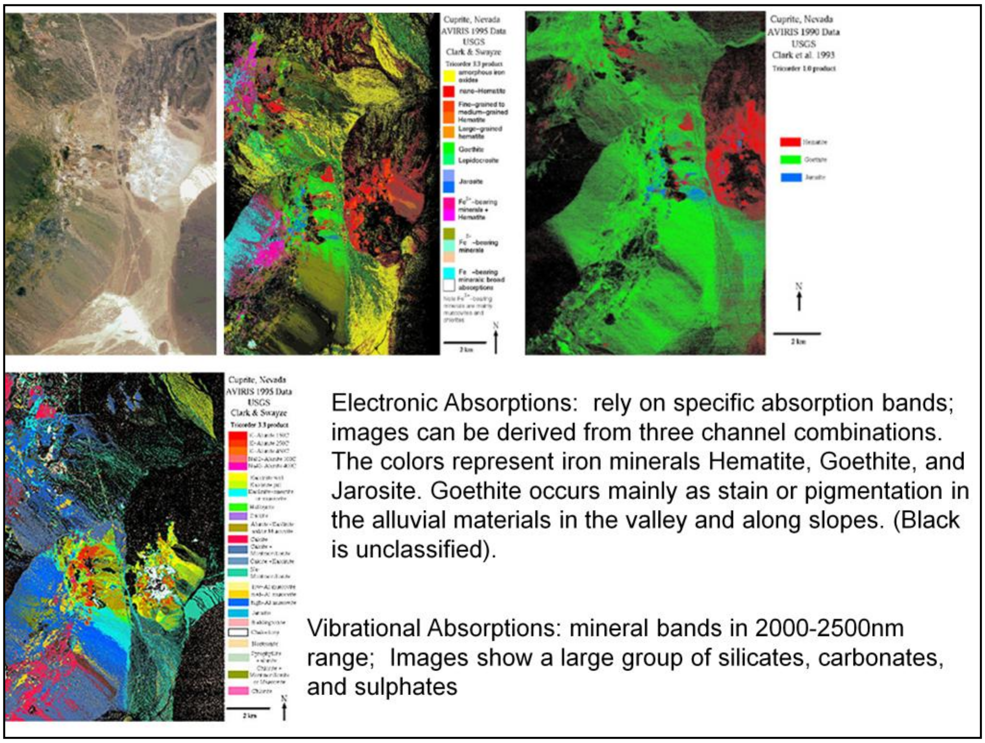




True Color

Minerals (vibrational absorption)

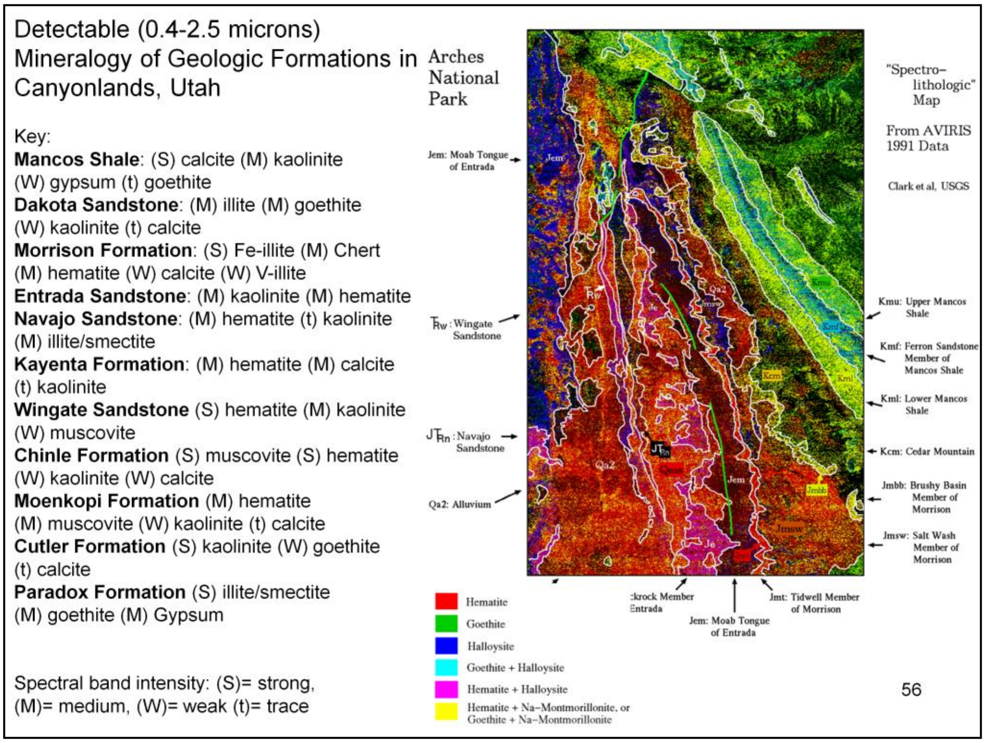
Minerals (electronic absorption)



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 6 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