Visible to Thermal Infrared Remote Sensing for Earth Science Applications

By

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NASA/JPL

Electromagnetic Spectrum

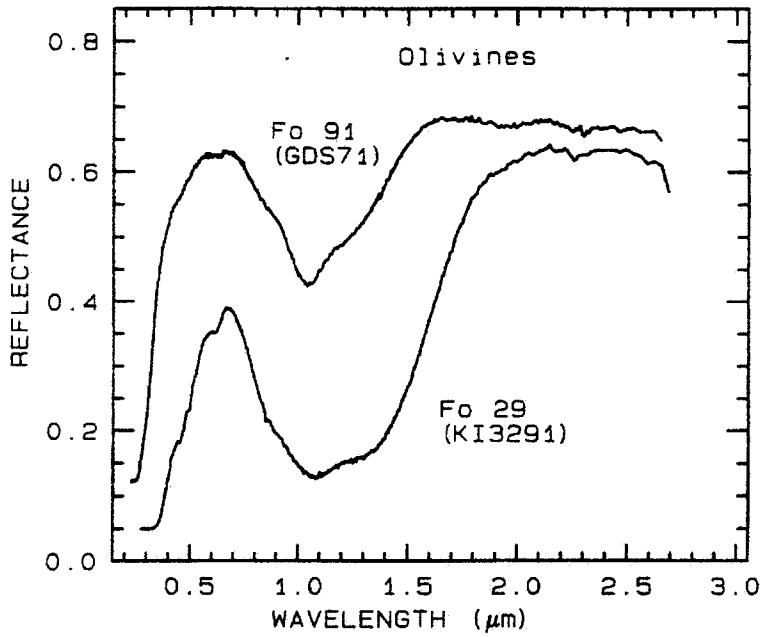
- The electromagnetic spectrum may be defined as the ordering of the radiation according to wavelength, frequency, or energy.

Physical Basis

Minerals exhibit diagnostic features at various wavelengths which provide a means for their remote identification. These features are produced by **electronic** or **vibrational** processes resulting from the interaction of electromagnetic energy with the atoms and molecules which comprise the minerals that make up a rock.

Physical Basis

- **Electronic Processes**
  - Crystal field effects, Charge Transfer Bands Conduction Bands, Color Centers
- **Vibration Processes**
  - Fundamentals, Water and Hydroxl, Carbonates Other groups, e.g phosphates



Charge Transfer Absorptions

- Inter-element transitions where the absorption of a photon causes an electron to move between ions or between ions and ligands.
- Very strong compared with crystal field effects. Typically centered in the ultra violet with wings extending into the visible.

Vibrational Processes

- The bonds in a molecule or crystal lattice act like springs with attached weights. The frequency of the vibration depends on the strength of the bond and mass of the elements.
- For a molecule with N atoms, there are 3N -6 normal modes of vibration called fundamentals.
- The fundamental vibration modes of silicate minerals occur near 10 um.

Vibrational Processes

- Also vibrations can occur at multiples of the fundamental frequency.
- The additional vibrations are called overtones when they involve multiples of a single fundamental mode, and combinations when they involve different modes of vibration.

Other Minerals

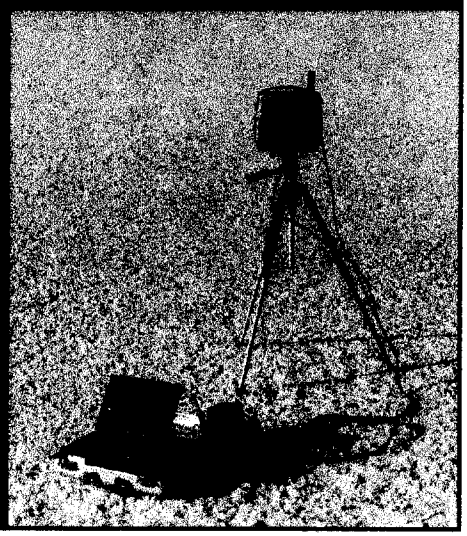
- Carbonates, phosphates, borates, arsenates and vandates also have diagnostic spectral features.
- For example the feature around 11.2 um in carbonate minerals shifts to longer wavelengths as the atomic weight of the cation increases.

Atmospheric Effects

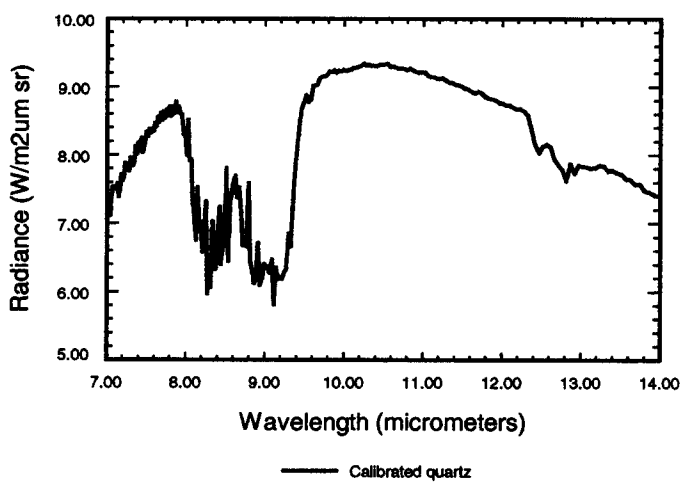
- The gases of the atmosphere selectively scatter, absorb, and emit electromagnetic radiation. The wavelength intervals where radiation is absorbed are referred to as absorption bands and the intervening regions of high-energy transmittance as *atmospheric transmission bands* or *windows*

Designs and Prototypes
of THR

Death Valley, CA



Calibrated Data



AVIRIS

The AVIRIS instrument contains 224 different detectors, each with a wavelength sensitive range of approximately 10 nanometers (nm), allowing it to cover the entire range between 380 nm and 2500 nm. When the data from each detector is plotted on a graph, it yields a spectrum. Comparing the resulting spectrum with those of known substances reveals information about the composition of the area being viewed by the instrument.

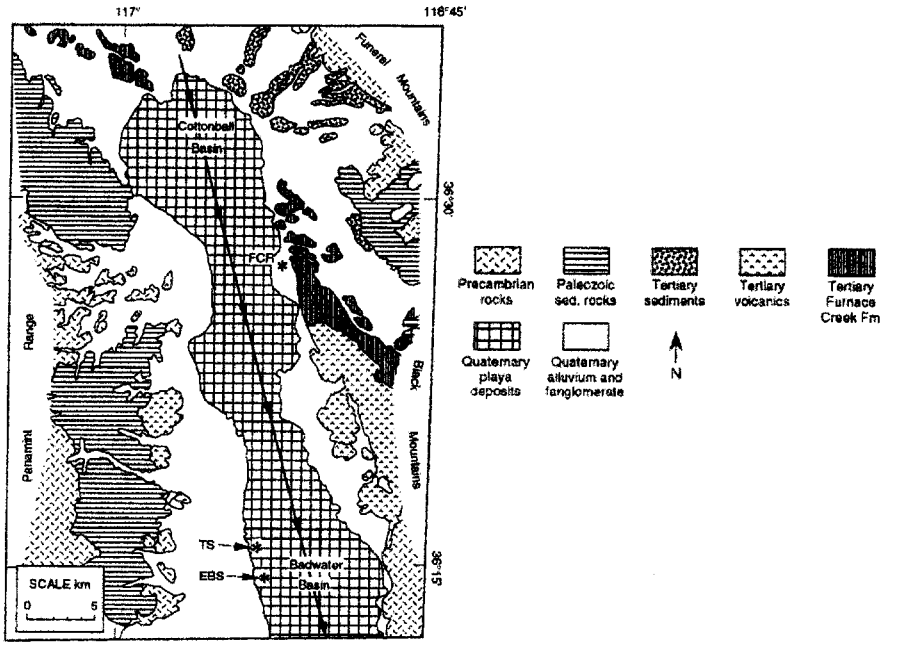
AVIRIS uses a scanning mirror to sweep back and forth ("whisk broom" fashion), producing 614 pixels for the 224 detectors each scan. Each pixel produced by the instrument covers an approximately 20 meter square area on the ground.

MASTER Instrument Characteristics

Wavelength range	0.4-13 micrometers
Number of channels	50
Number of pixels	716
Instantaneous Field of View	2.5 milliradians
Total Field of View	85.92 degrees
Platforms	Department of Energy KingAir Beachcraft B200 NASA ER-2 NASA DC8
Pixel size DC-8	10-30 m
Pixel size ER-2	50 m
Pixel size B200	5-20 m
ER-2 Range (without refueling)	3700 statute miles
B200 Range (without refueling)	700 statute miles
DC-8 Range (without refueling)	5400 nautical miles
Scan speeds	6.25/12.5/25 rps
Products	Radiance at sensor (Level 1B)
Calibration VIS-SWIR	Laboratory Integrating Sphere
Calibration MIR-TIR	2 On-board Blackbodies
Data Format	Hierarchical Data Format (HDF)
Digitization	16-bit

Outline

- Introduction
- Physical Basis
- Atmospheric Effects
- Instruments: AVIRIS and TIMS/MASTER
- Case Studies
  - **Death Valley**
  - Gold Butte
- Future Instruments: ASTER
- Summary and Conclusions

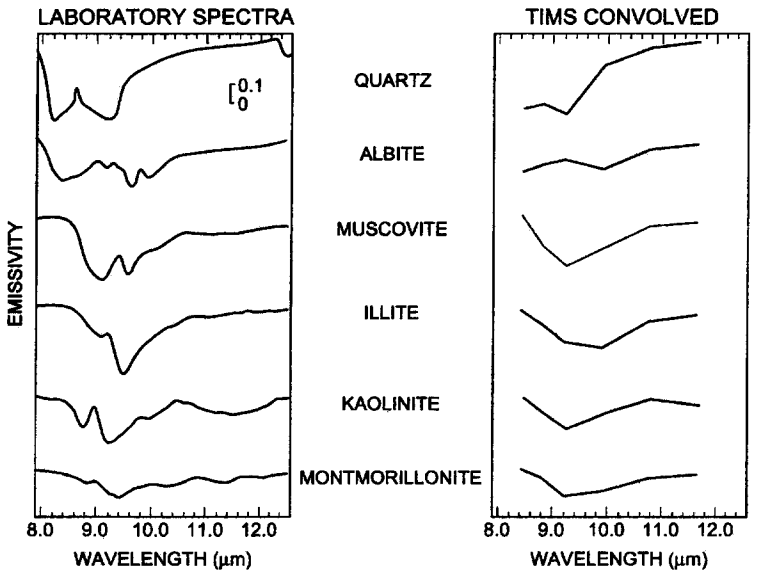


Badwater Basin

The evaporite mineral distributions reflect a brine concentration gradient, with salinities increasing from the salt pan margins inward towards the pan center. Less soluble minerals (Gypsum, Mg-borates) precipitate around the margins, whereas more soluble minerals (e.g. Halite) occur in the center. In the lowest portion of the salt pan (dark blue on image) virtually pure halite remains damp from previous winter-spring runoff. Illitic clay of detrital origin occurs along the distributory channel network of the Armagosa River, which provides sporadic inflow from the south (upper part of image). Salt-tolerant vegetation, including mesquite and salt bush, occurs near springs located along the western (right) margin of the salt pan.

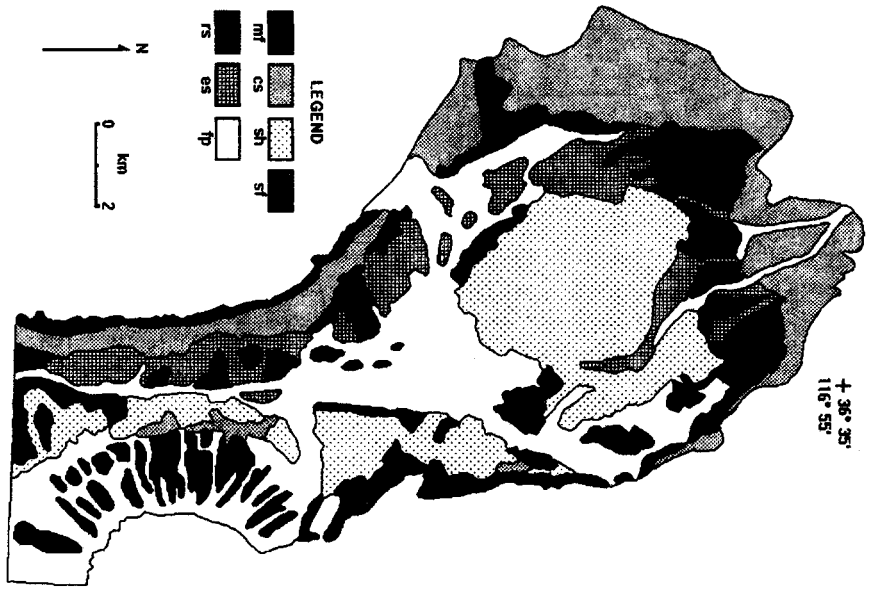
Eagle Borax

The Mg-borates are highly unusual mineral phases discovered at Eagle Borax in the course of AVIRIS remote sensing research in the early 1990's. The Mg-borate minerals pinnoite and rivadavite, highlighted in yellow on the image, are known from only a few other localities in the world. Their occurrence in the Death Valley salt pan has provided important insights into the formation of economic borate mineral deposits, which involve similar evaporative concentration processes.



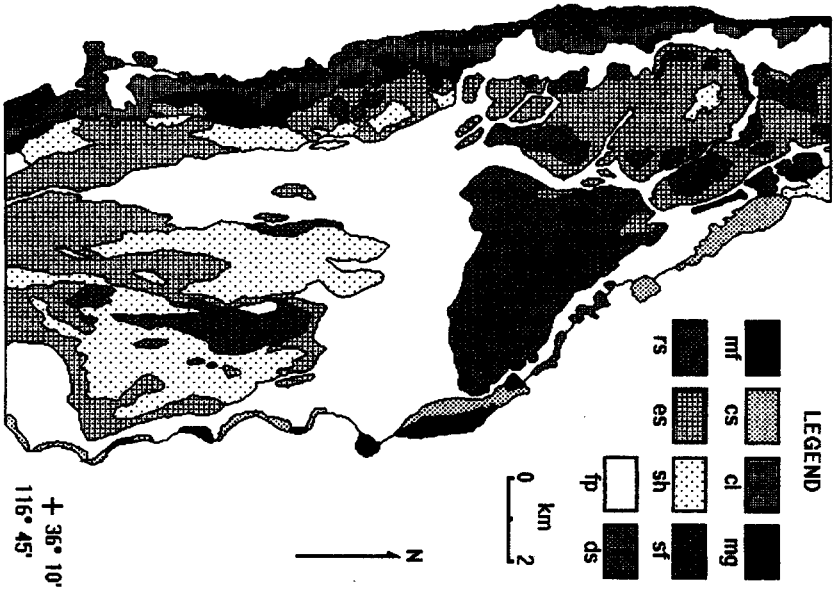
Cottonball Description

Pseudo temperature image of Cottonball Basin with color overlays showing the distribution of different spectral classes. Labels A-G indicate areas used to extract spectra. Surficial units represented by varies colors are A, yellow pixels, thenardite-rich crusts in saline facies of sulfate zone; orange pixels, silty halite, smooth facies, and carbonate zone, silty facies; C, red pixels, gypsum crusts; D, dark blue pixels, illite/muscovite-rich alluvial deposits; E, green pixels, quartz-rich fan gravels and mudflats; F, cyan pixels, massive halite and silty halite, rough facies; and G, light green pixels, mixied silicate and evaporite minerals crusts on floodpains. Unit description modified from Hunt et al. (1966).



Badwater Description

Pseudo-temperature image of the Badwater Basin study area with color overlays showing the distribution of various spectral classes. Labels H-N indicate areas used to extract spectra. The spectrum for site B is shown in Cottonball figure. Surfical units represented by various image colors are: Yellow pixels, thenardite-rich cursts in saline facies of sulfate zone; B, orange pixels, silty halite, smooth facies, and carbonate zone, siltry facies;H, I J,magenta, salmon,and black pixels, smooth halite-rich crusts on floodplains; K, red pixels, gypsum crusts; L, green pixels, quartz-rich alluvial deposits; M, dark blue pixels, illite/muscovite-rich alluvial deposits; and N, light green pixels, mixed silicate and evaporite mineral crusts on floodplains. Cyan pixels, massive halite and silty halite, rough facies. Unit descriptions modefied from Hunt et al. (1966). O indicates a rough-salt area that has changed since the original mapping by Hunt.

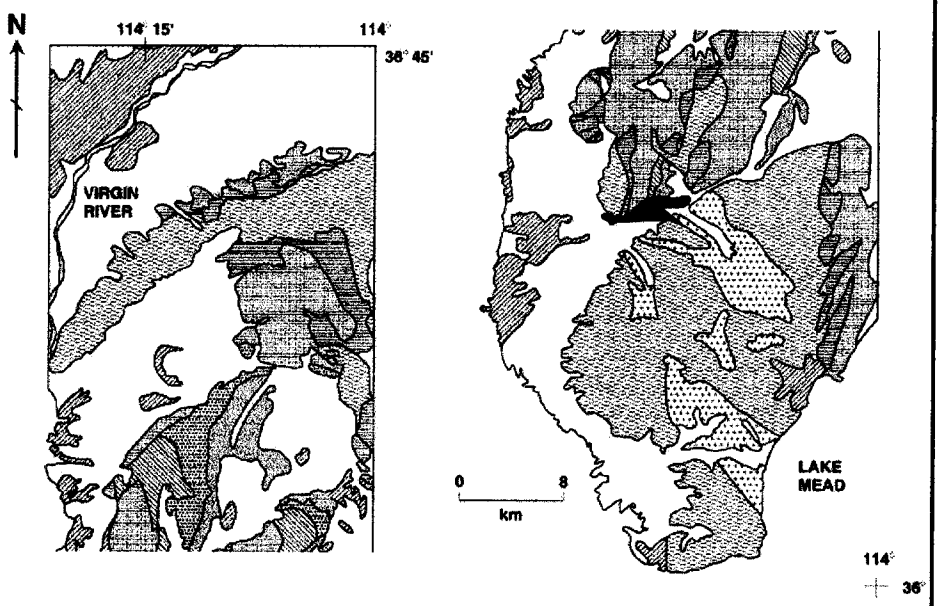


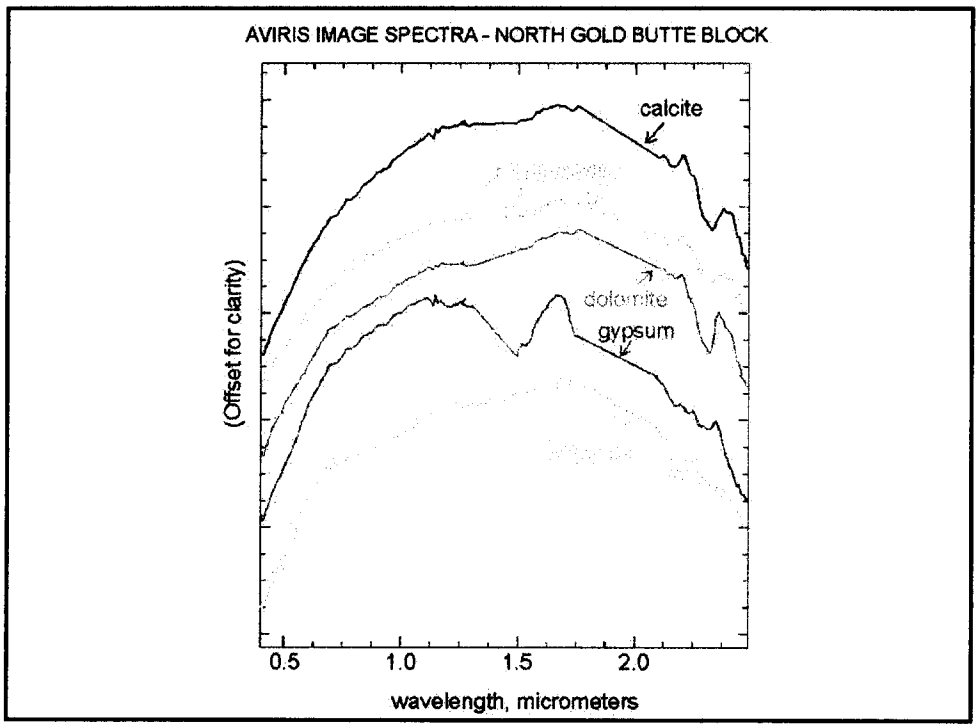
Death Valley - VSWIR

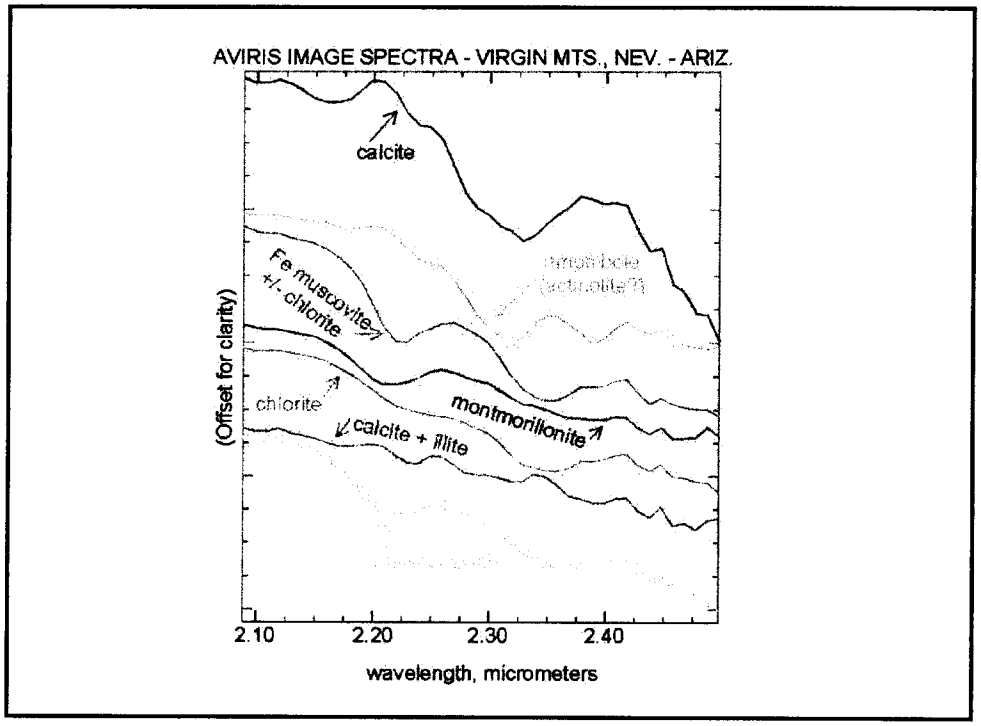
- Salt crusts in Death Valley were mapped with AVIRIS data.
- Eight saline minerals mapped included 3 previously unreported borates: hydroboracite, rivadite and pinnoite.
- Mineral maps indicated elevated magnesium and boron levels in the ground waters, and to the action of chemical divides causing subsurface fractionation of calcium.

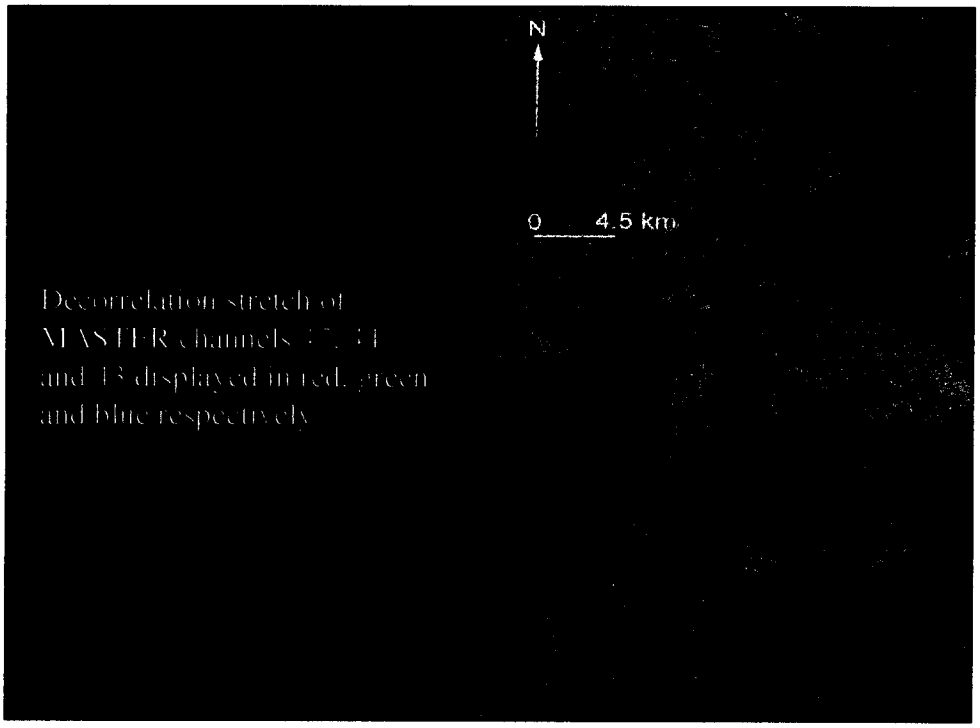
Gold Butte, Nevada

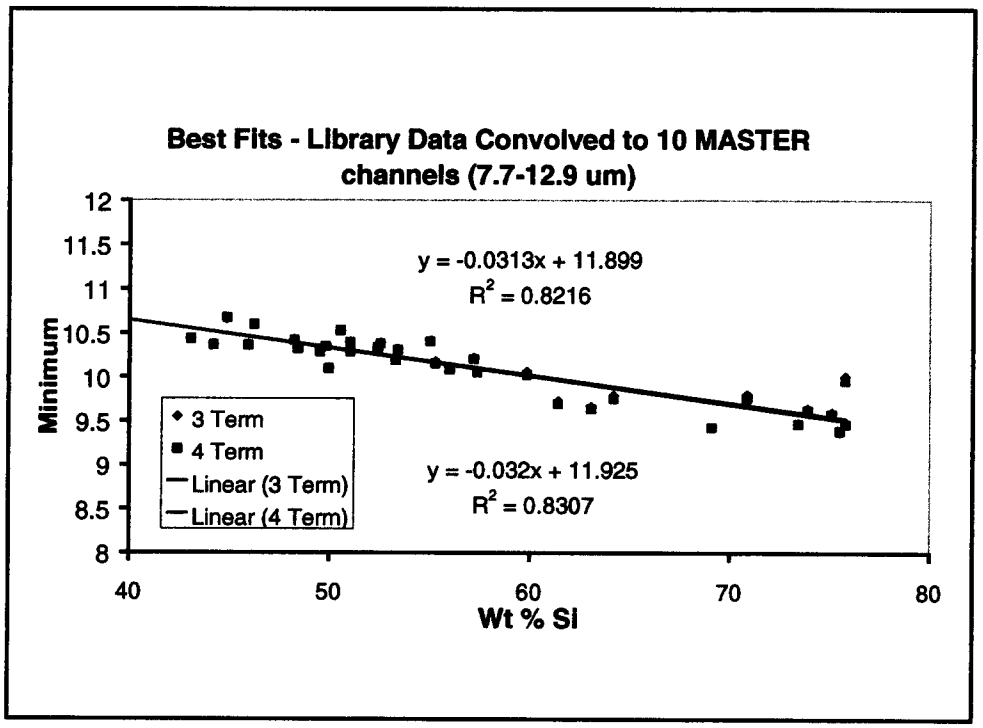
- Location and Geology
- Visible Shortwave Infrared Data
- Thermal Infrared Data
- Data Analysis
- Data Interpretation




AVIRIS IMAGE SPECTRA - NORTH GOLD BUTTE BLOCK
calcite
dolomite
gypsum
(Offset for clarity)
0.5
1.0
1.5
2.0
wavelength, micrometers


AVIRIS IMAGE SPECTRA - VIRGIN MTS., NEV. - ARIZ.
calcite
Fe muscovite
+/- chlorite
chlorite
calcite + illite
montmorillonite
(Offset for clarity)
2.10
2.20
2.30
2.40
wavelength, micrometers


N
0 4.5 km
Decorrelation stretch of
MASTER channels 12, 14
and 13 displayed in red, green
and blue respectively


Best Fits - Library Data Convolved to 10 MASTER channels (7.7-12.9 um)
y = -0.0313x + 11.899
R² = 0.8216
y = -0.032x + 11.925
R² = 0.8307
3 Term
4 Term
Linear (3 Term)
Linear (4 Term)
Minimum
Wt % Si
12
11.5
11
10.5
10
9.5
9
8.5
8
40
50
60
70
80

Gold Butte - VSWIR

- Map the distribution of the minerals: calcite, dolomite, chlorite/biotite, kaolinite, gypsum, muscovite and an amphibole.
- Distribution of minerals relates to age of the units, e.g. Paleozoic versus Tertiary limestones.

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  - Death Valley
  - Gold Butte
- **New Instruments: ASTER**
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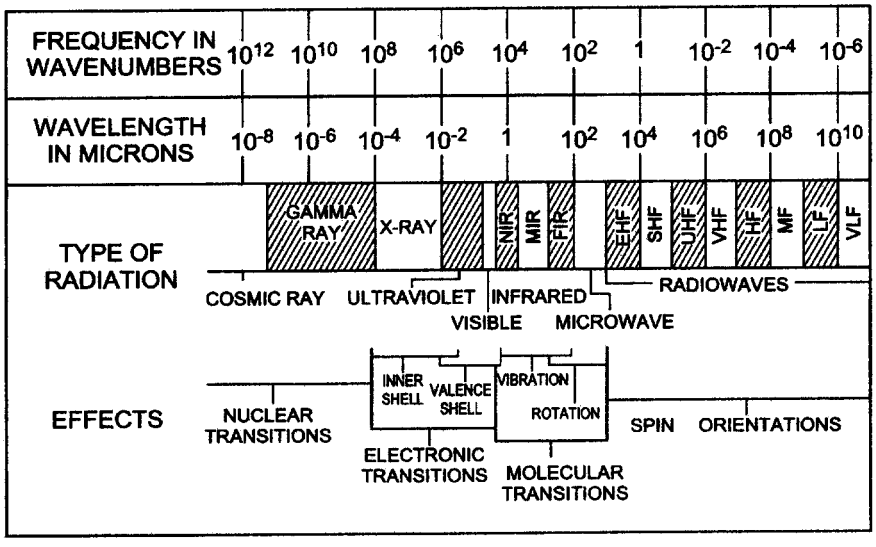


Physical Basis

The different processes require different amounts of energy to proceed, and therefore are manifest in different wavelength regions. Electronic processes require the most energy and results in spectral features at visible to near infrared wavelengths. Fundamental vibrational processes require less energy, and occur beyond 2.5 um. Between 0.5 and 2.5 um there is an overlap of features due to both processes.

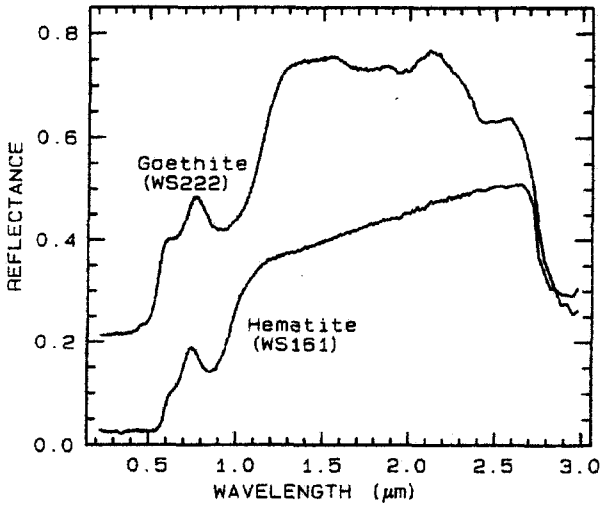
Crystal Field Effects

- Most common electronic process, seen in spectra of transition elements.
- Electron moves from lower to higher energy state by photon absorption.
- Crystal field varies with crystal structure allowing mineral identification.

Reflectance spectra of two olivines, showing change in band shape and position with composition. 1 um band due to crystal field absorption of Fe^{2+}.

Fo - forsterite (Mg_2SiO_4) in the forsterite-fayalite ($Fe_2^{2+}SiO_4$) solid solution series. Fo29 has an FeO content of 54% while Fo91 has an FeO content of 8%. The 1 um band position varies from 1.08 um at Fo 10 to 1.05 um at Fo 90.

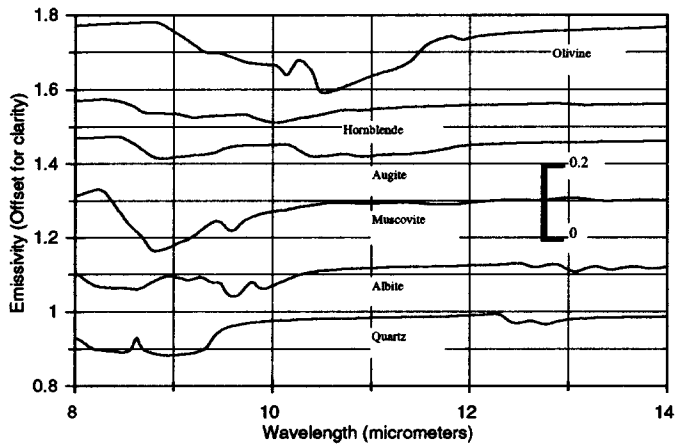
From Clark 1999.

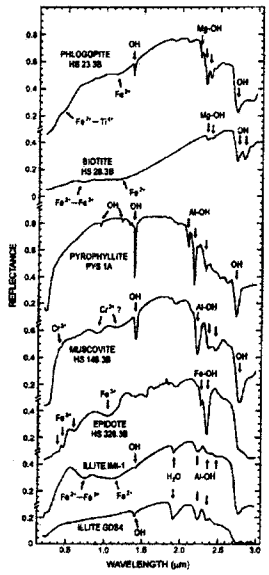


Reflectance spectra of iron oxides: hematite (Fe_2O_3) and goethite (FeOOH). The intense absorption around 0.4 um is due to charge transfer. The 0.9 and 0.86 um absorption features are due to transitions.

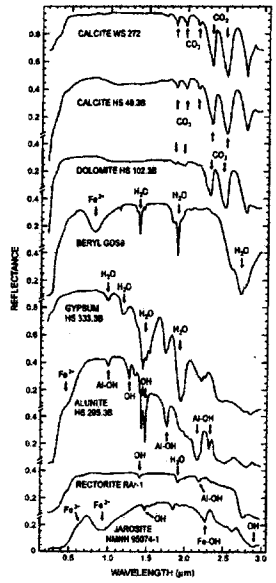
From Clark (1999).

Silicate Minerals



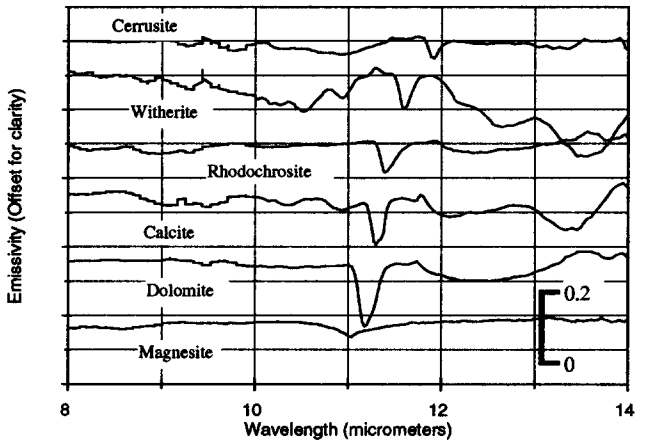


Reflectance spectra showing vibrational bands due to OH, and H_2O (from Clark 1999).

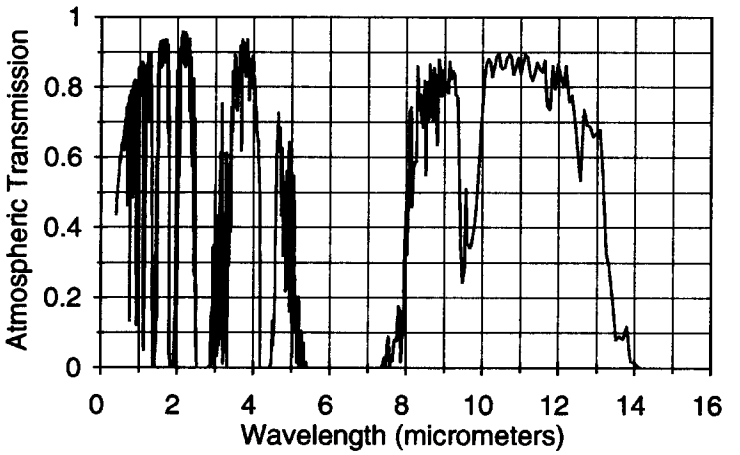


Reflectance spectra showing vibrational bands due to OH, CO_3 and H_2O (from Clark 1999).

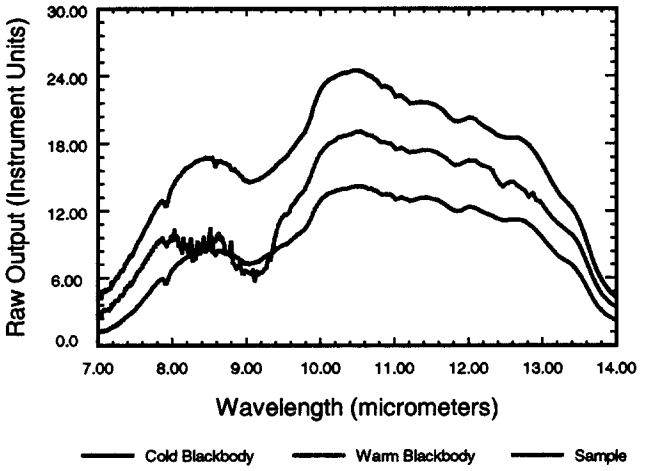
Carbonate Minerals



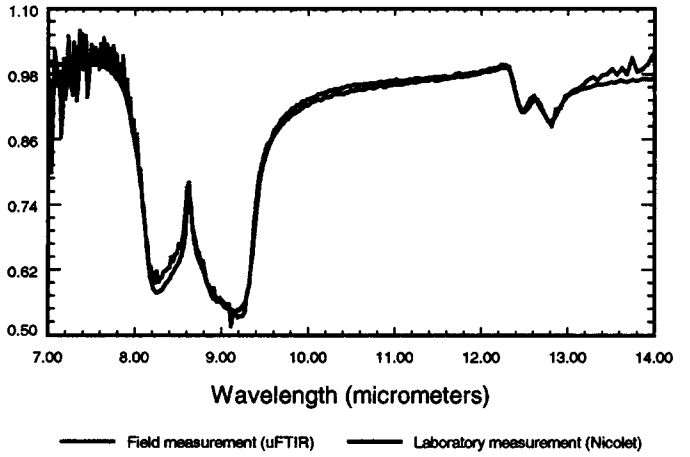
Atmospheric Windows

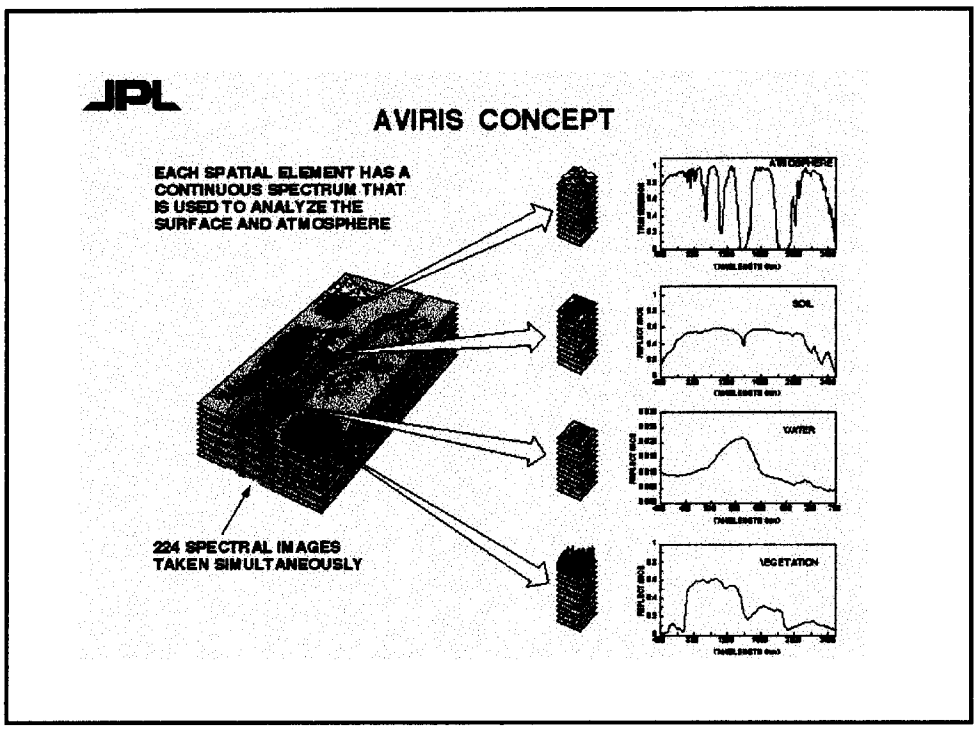


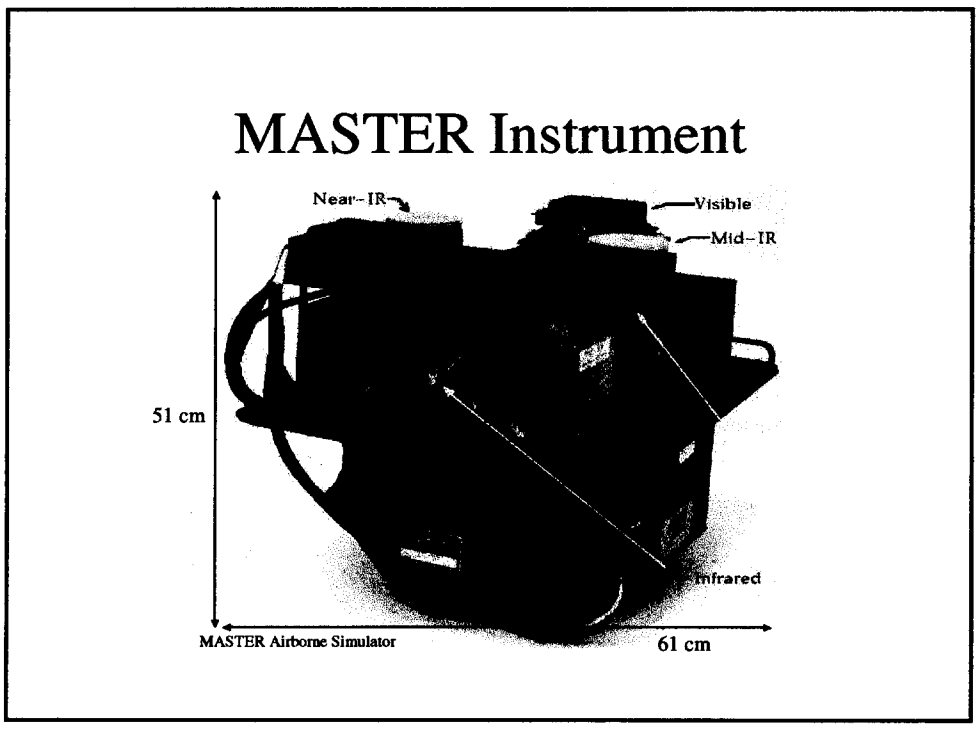
Raw Data



Field vs Lab.

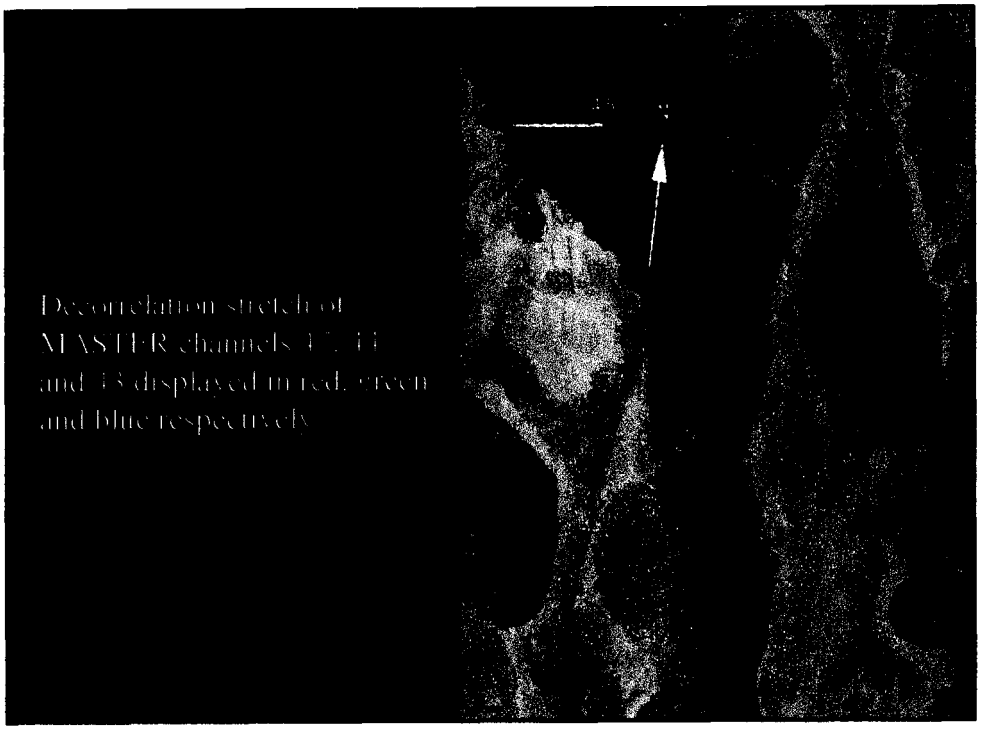


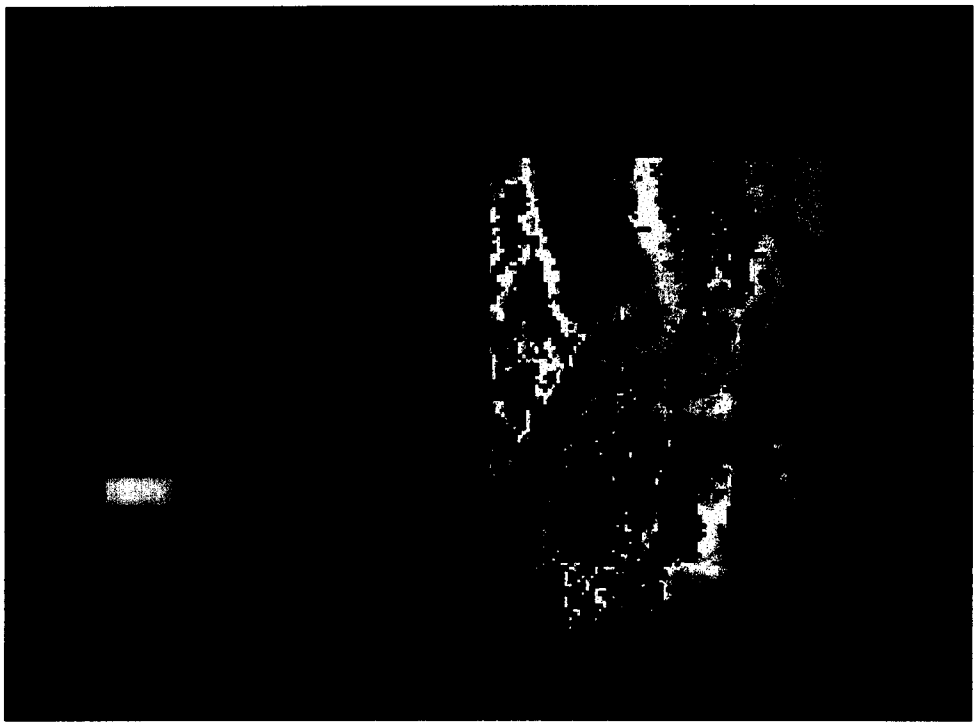

JPL
AVIRIS CONCEPT
EACH SPATIAL ELEMENT HAS A CONTINUOUS SPECTRUM THAT IS USED TO ANALYZE THE SURFACE AND ATMOSPHERE
224 SPECTRAL IMAGES TAKEN SIMULTANEOUSLY
SOIL
WATER
VEGETATION

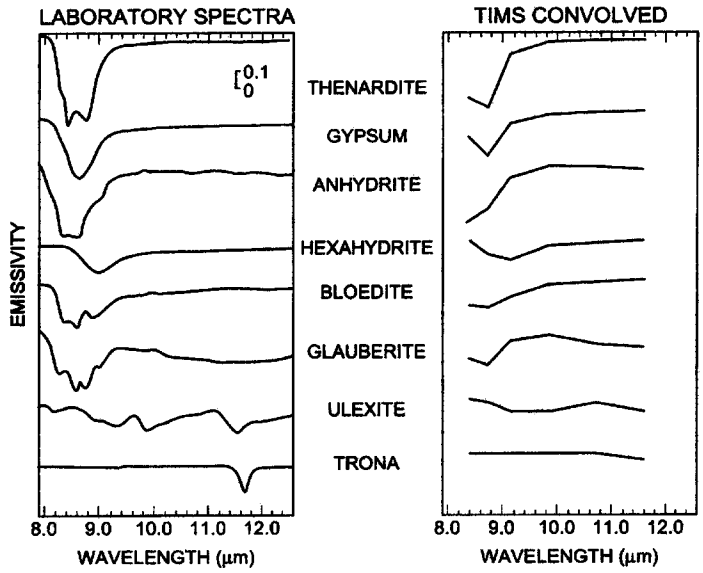

MASTER Instrument
Near-IR
Visible
Mid-IR
51 cm
Infrared
MASTER Airborne Simulator
61 cm

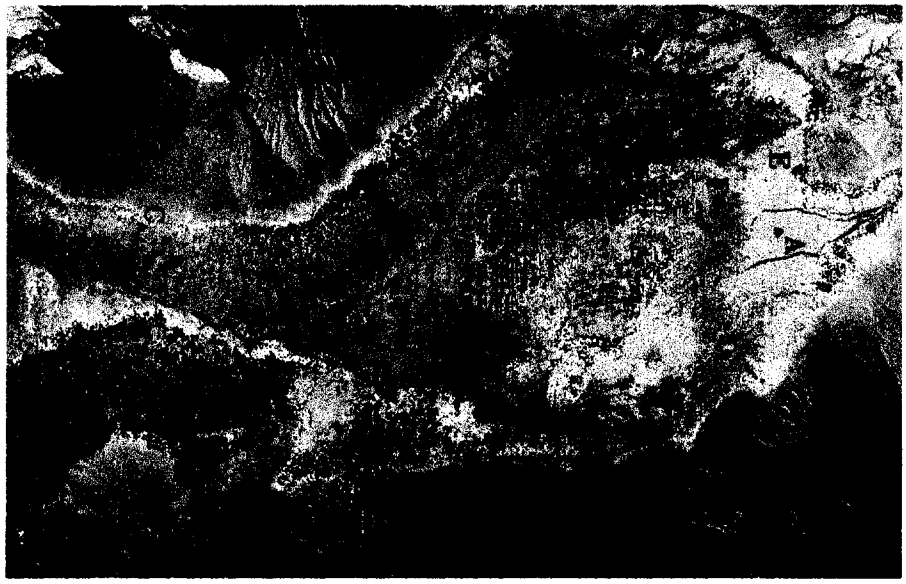
Death Valley, California

- Location and Geology
- Visible Shortwave Infrared Data
- Thermal Infrared Data
- Data Analysis
- Data Interpretation



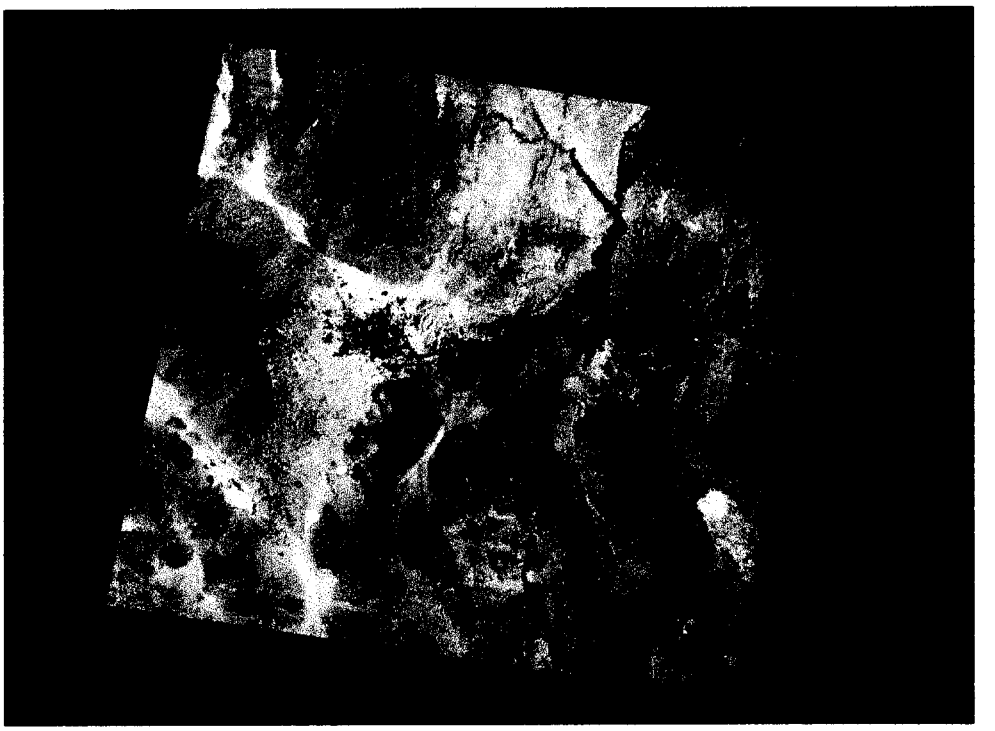


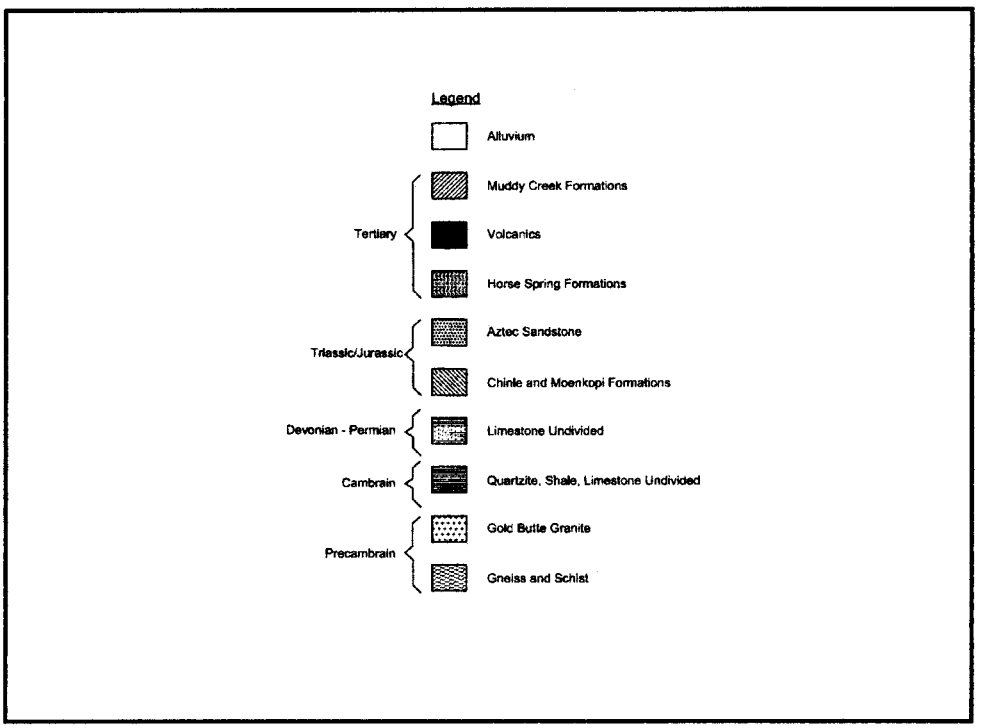

LABORATORY SPECTRA
TIMS CONVOLVED
0.1
0
THENARDITE
GYPSUM
ANHYDRITE
HEXAHYDRITE
BLOEDITE
GLAUBERITE
ULEXITE
TRONA
EMISSIVITY
8.0 9.0 10.0 11.0 12.0
WAVELENGTH (µm)
8.0 9.0 10.0 11.0 12.0
WAVELENGTH (µm)

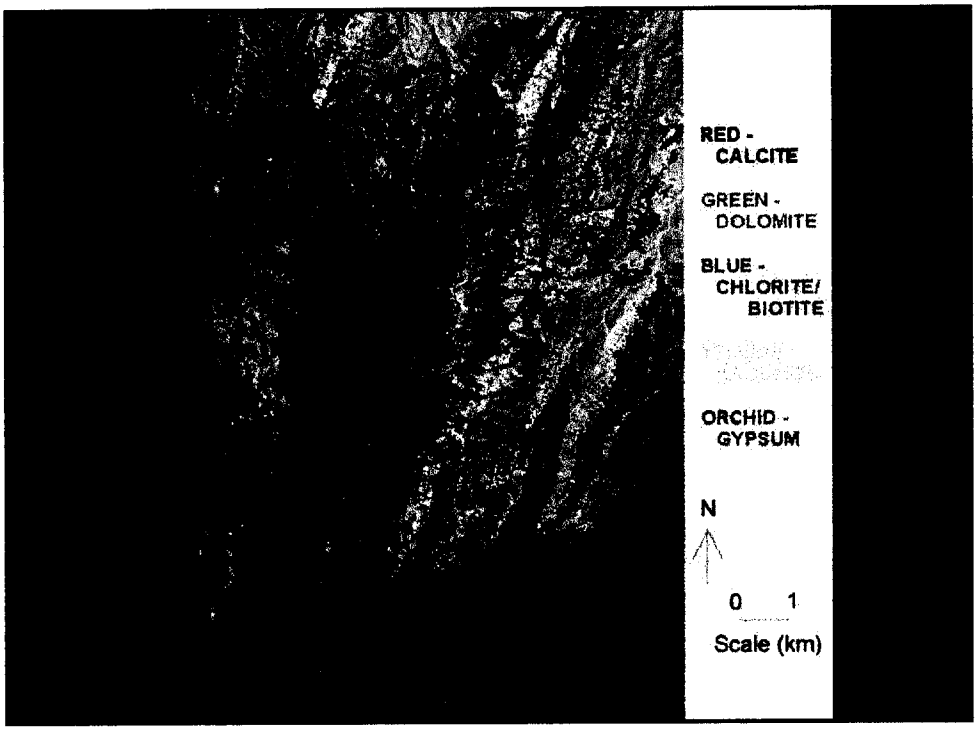


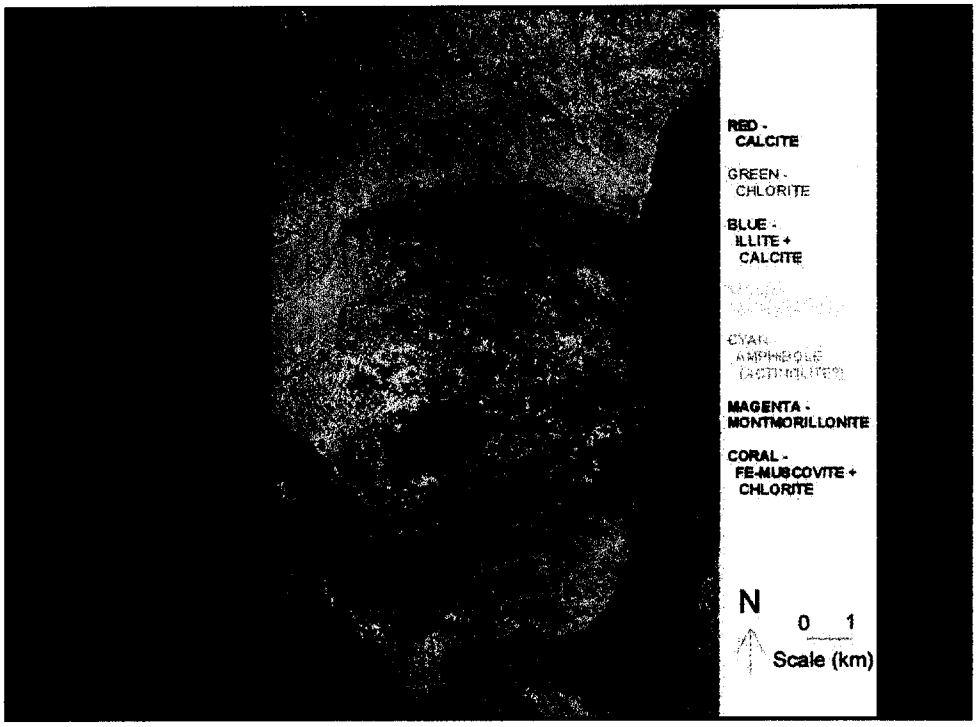
Death Valley - TIR

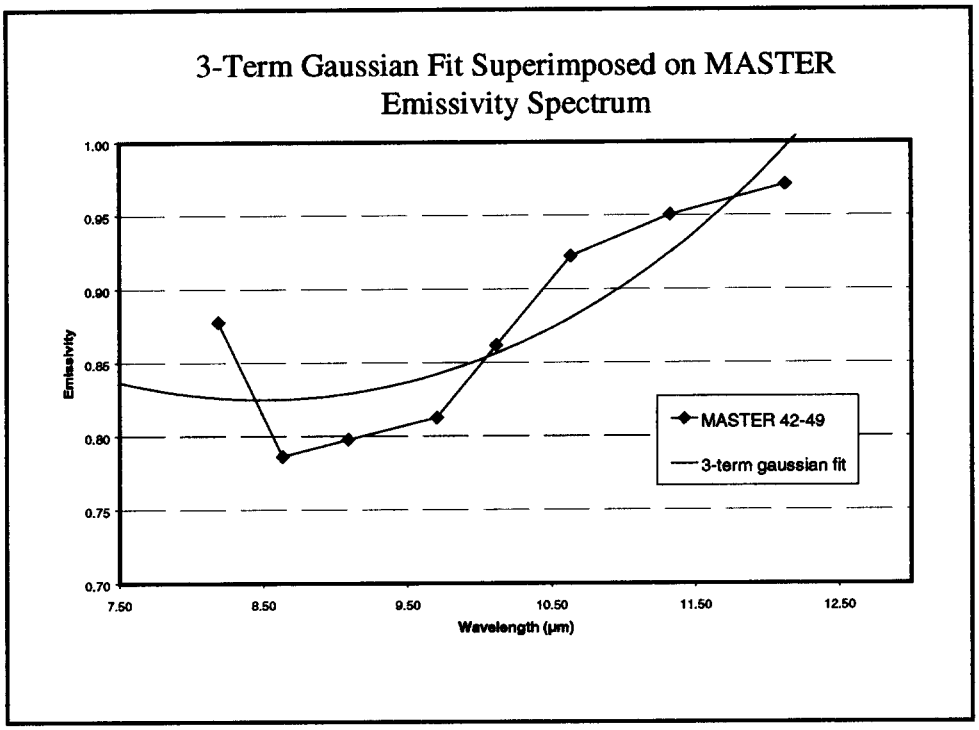
- Nine spectral classes that represent a variety of surface materials were distinguished including several classes that reflect important aspects of the groundwater chemistry and hydrology.
- The northern and eastern margins of Cottonball Basin contain abundant thenardite where the inflow waters are rich in sodium.
- The south western margin of Badwater Basin contain abundant gypsum where the inflow waters are rich in calcium.
- Abundant evaporite minerals indicated areas where groundwater is near the surface and thus able to replenish the salt crusts via capillary action.

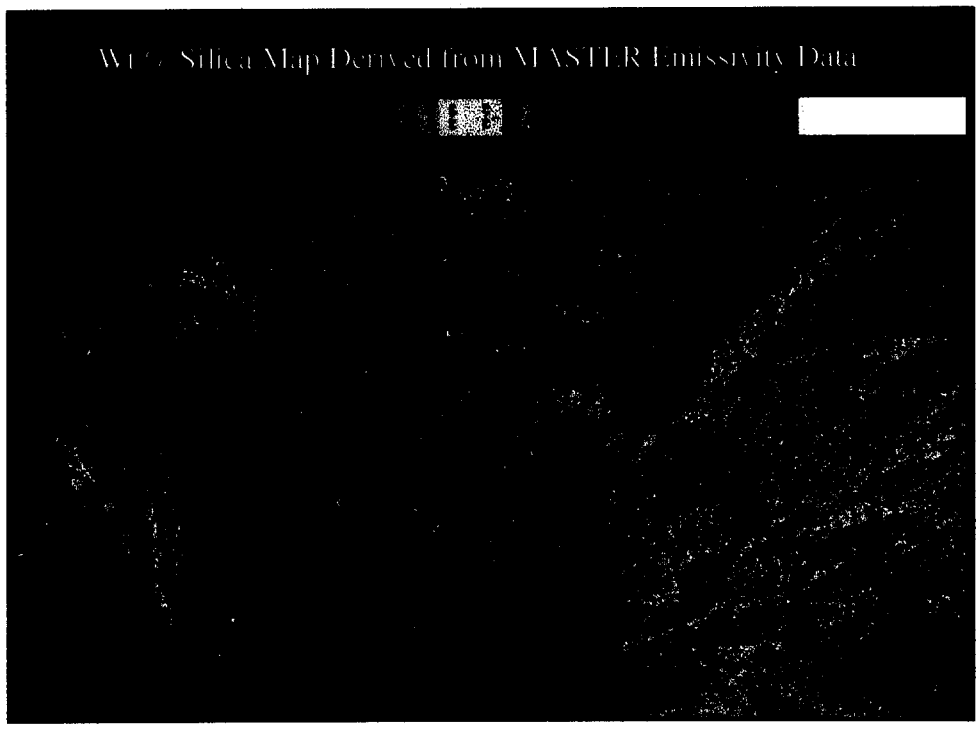


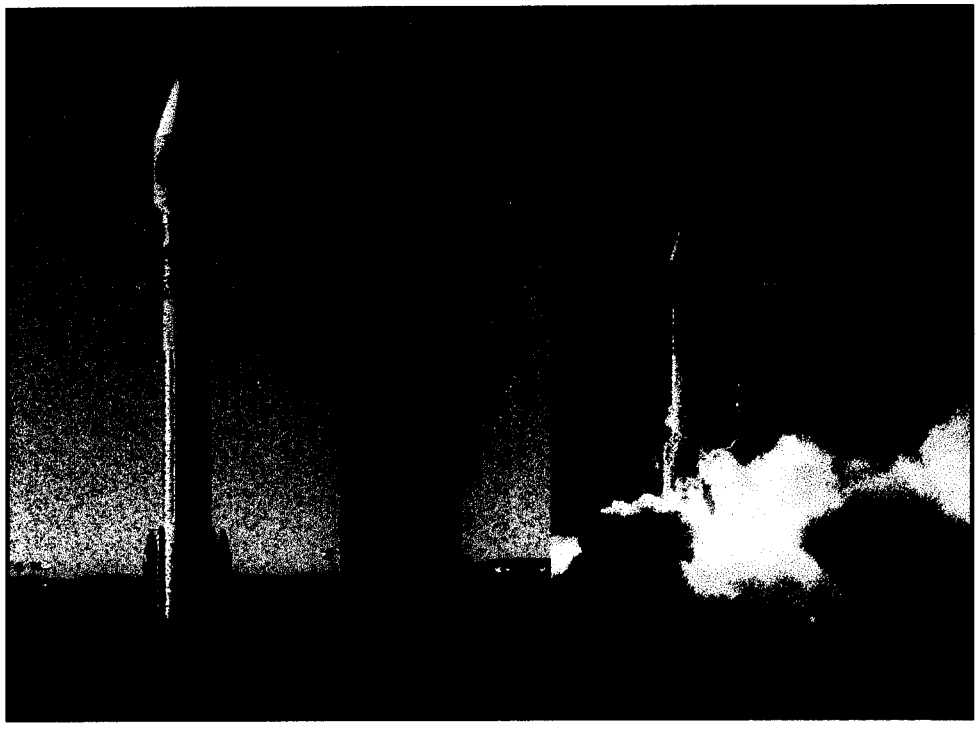

Legend
Alluvium
Tertiary
Muddy Creek Formations
Volcanics
Horse Spring Formations
Triassic/Jurassic
Aztec Sandstone
Chinle and Moenkopi Formations
Devonian - Permian
Limestone Undivided
Cambrain
Quartzite, Shale, Limestone Undivided
Precambrain
Gold Butte Granite
Gneiss and Schist


RED -
CALCITE
GREEN -
DOLOMITE
BLUE -
CHLORITE/
BIOTITE
ORCHID -
GYPSUM
N
0 1
Scale (km)


RED -
CALCITE
GREEN -
CHLORITE
BLUE -
ILLITE +
CALCITE
MAGENTA -
MONTMORILLONITE
CORAL -
FE-MUSCOVITE +
CHLORITE
N
0 1
Scale (km)


3-Term Gaussian Fit Superimposed on MASTER Emissivity Spectrum
1.00
0.95
0.90
0.85
0.80
0.75
0.70
Emissivity
7.50
8.50
9.50
10.50
11.50
12.50
Wavelength (µm)
MASTER 42-49
3-term gaussian fit


Wt % Silica Map Derived from MASTER Emissivity Data

Gold Butte - TIR

- Map contact between the Proterozoic and Cambrian (Tapeats).
- Map compositional variation within the highly variable Proterozoic at appropriate map scales.
- Identify several previously unmapped units e.g. Syenite.
- Map Wt % Silica of units.