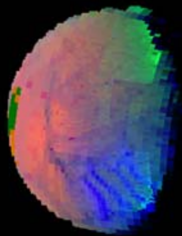
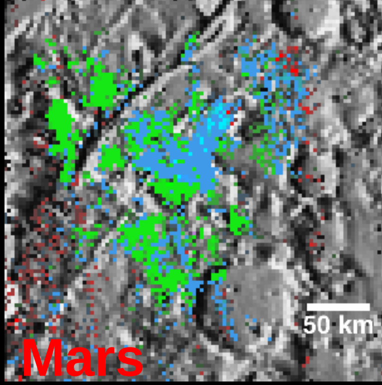
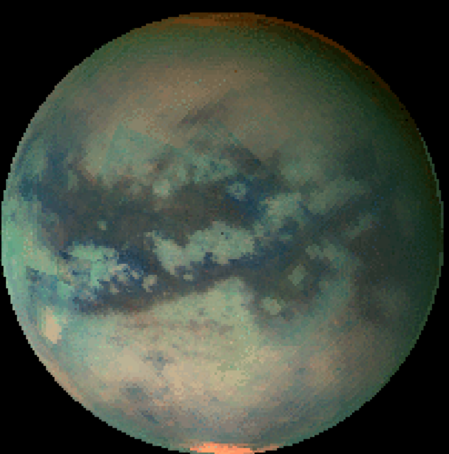
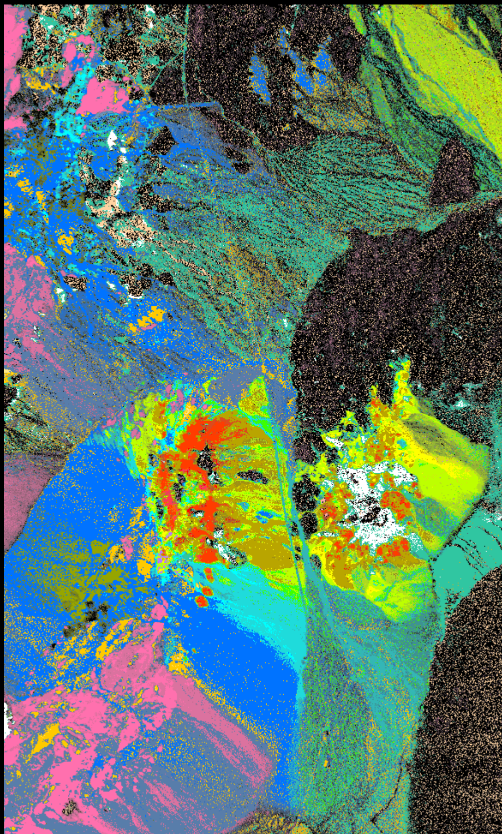




Mineral Mapping and Applications of Imaging Spectroscopy

Roger N. Clark,
Joe Boardman,
Jack Mustard, Fred Kruse,
Cindy Ong, Carle Pieters,
And Gregg Swayze



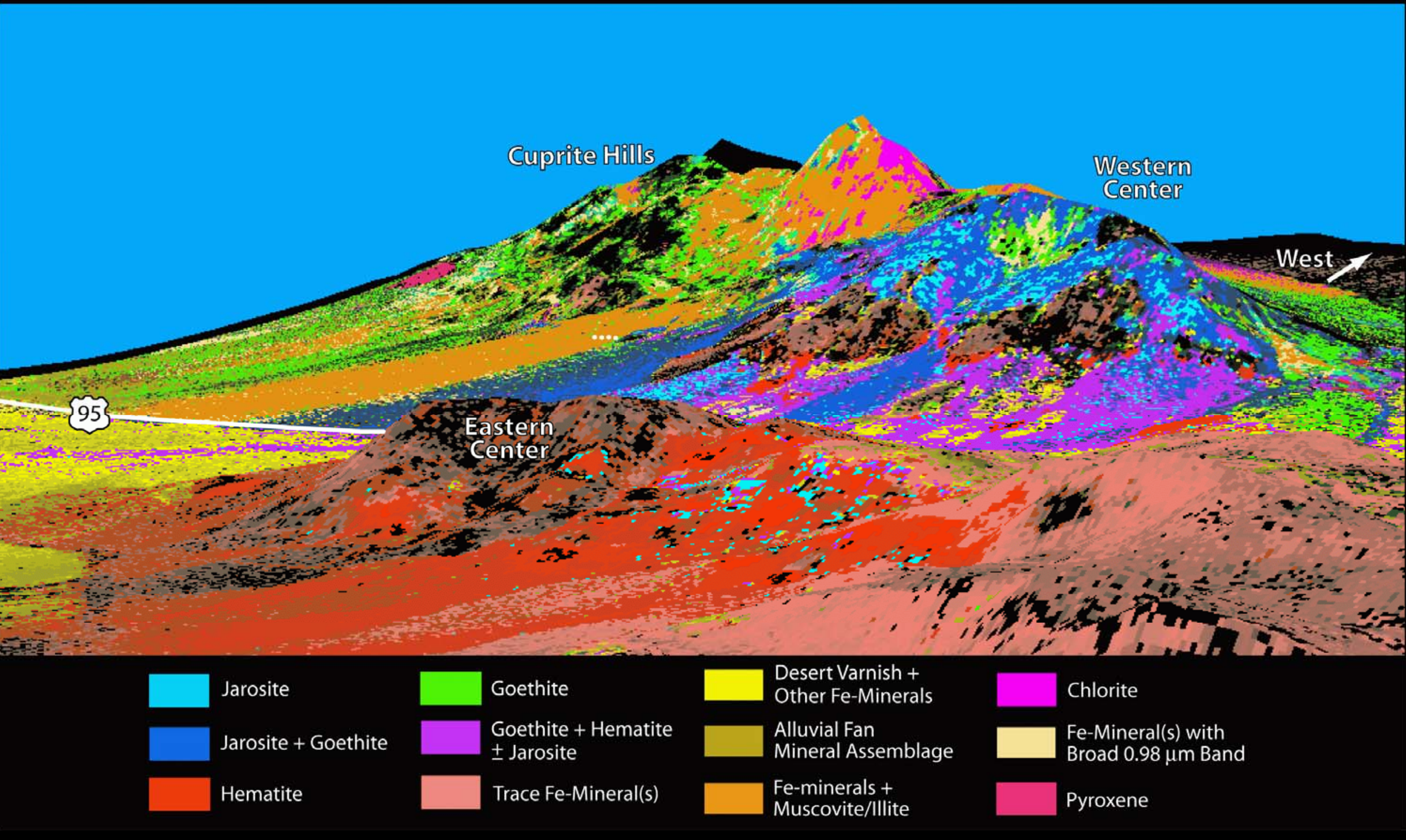


IGARSS

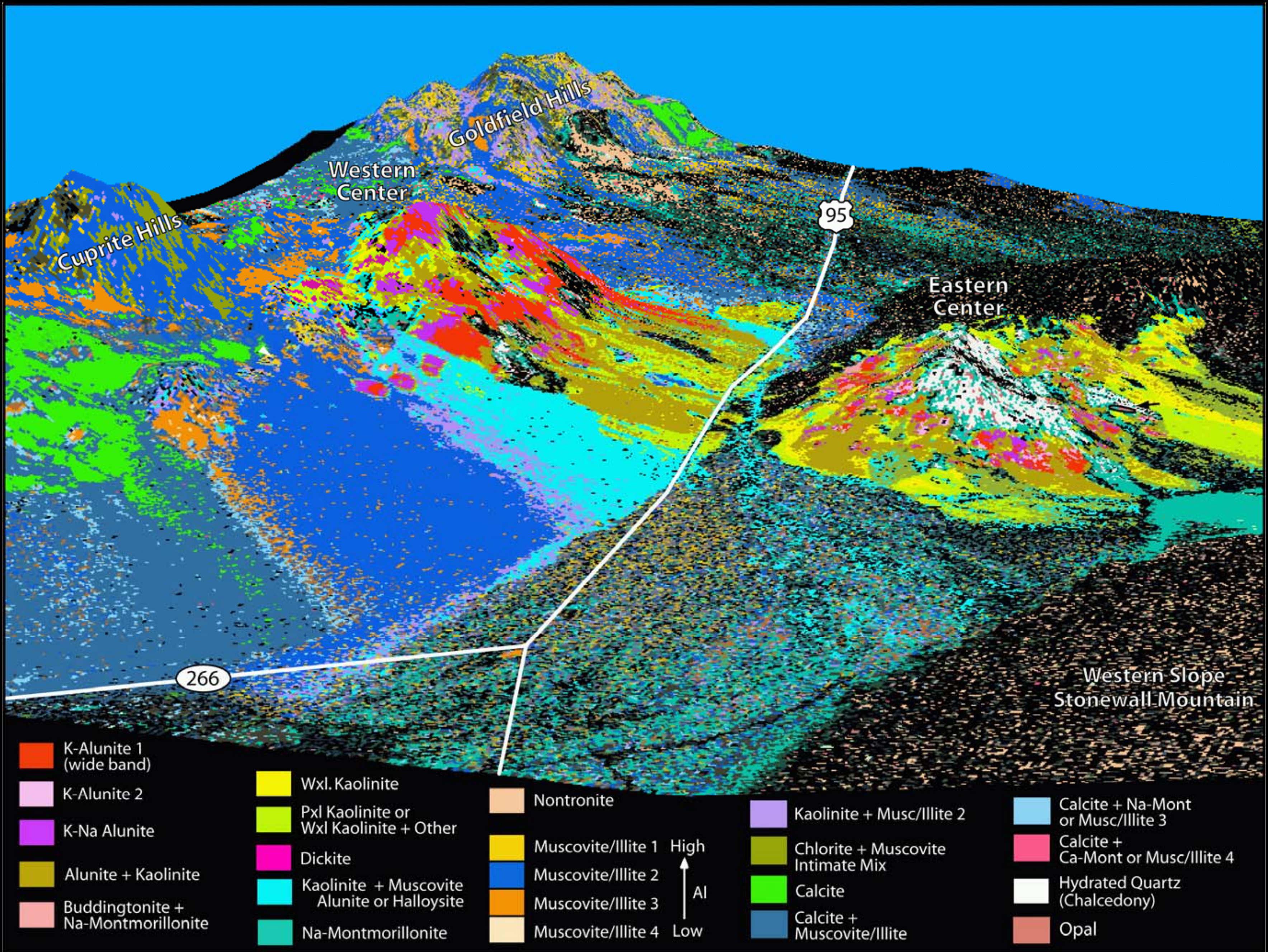
August 1, 2006

This talk is like a drink from a fire hose………

Illustrating diverse mineral mapping being done with Imaging Spectroscopy.



We honor Alex Goetz with (yet) another look at Cuprite



A real-world example

Mineral deposits.

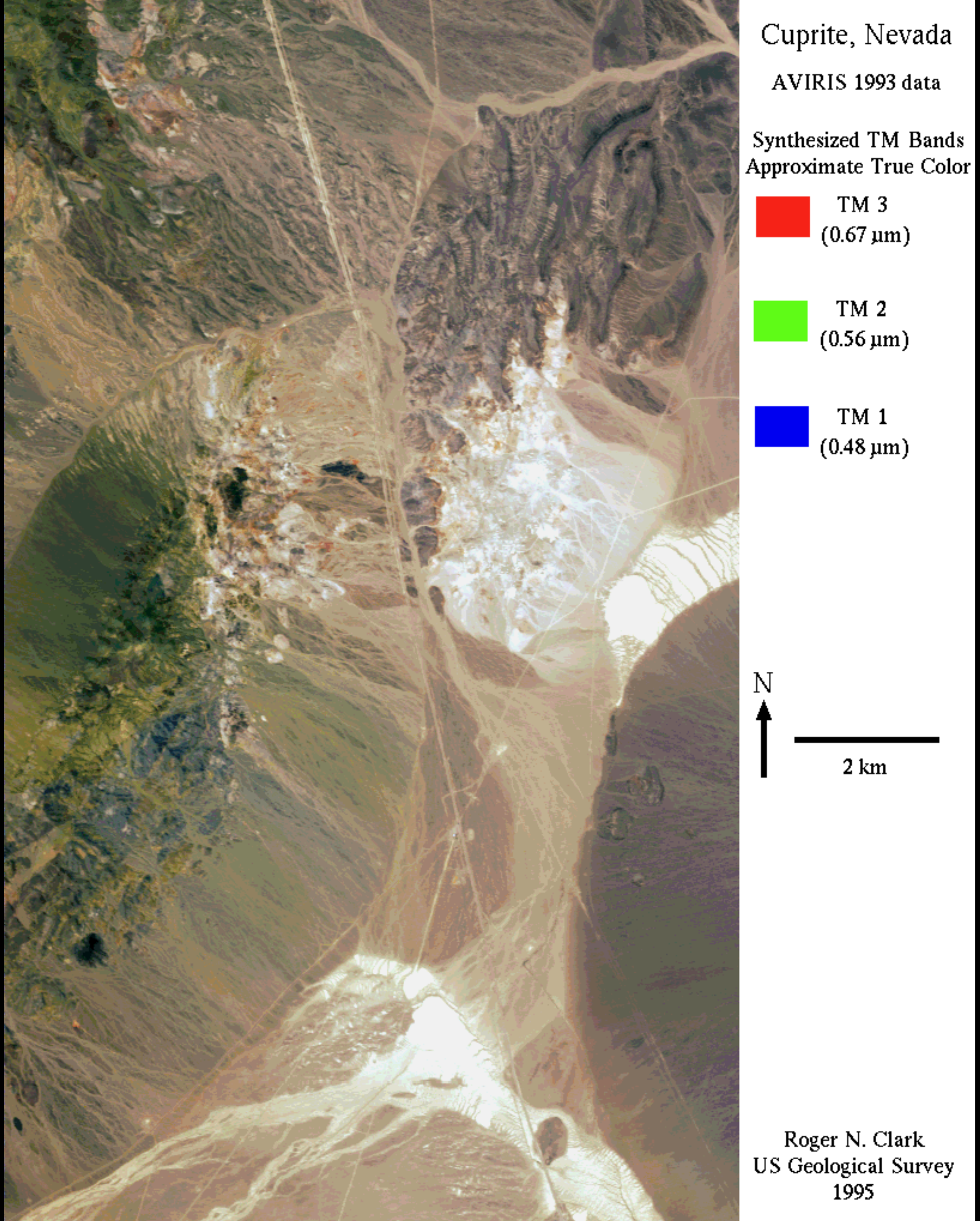
Provide resources for modern society.

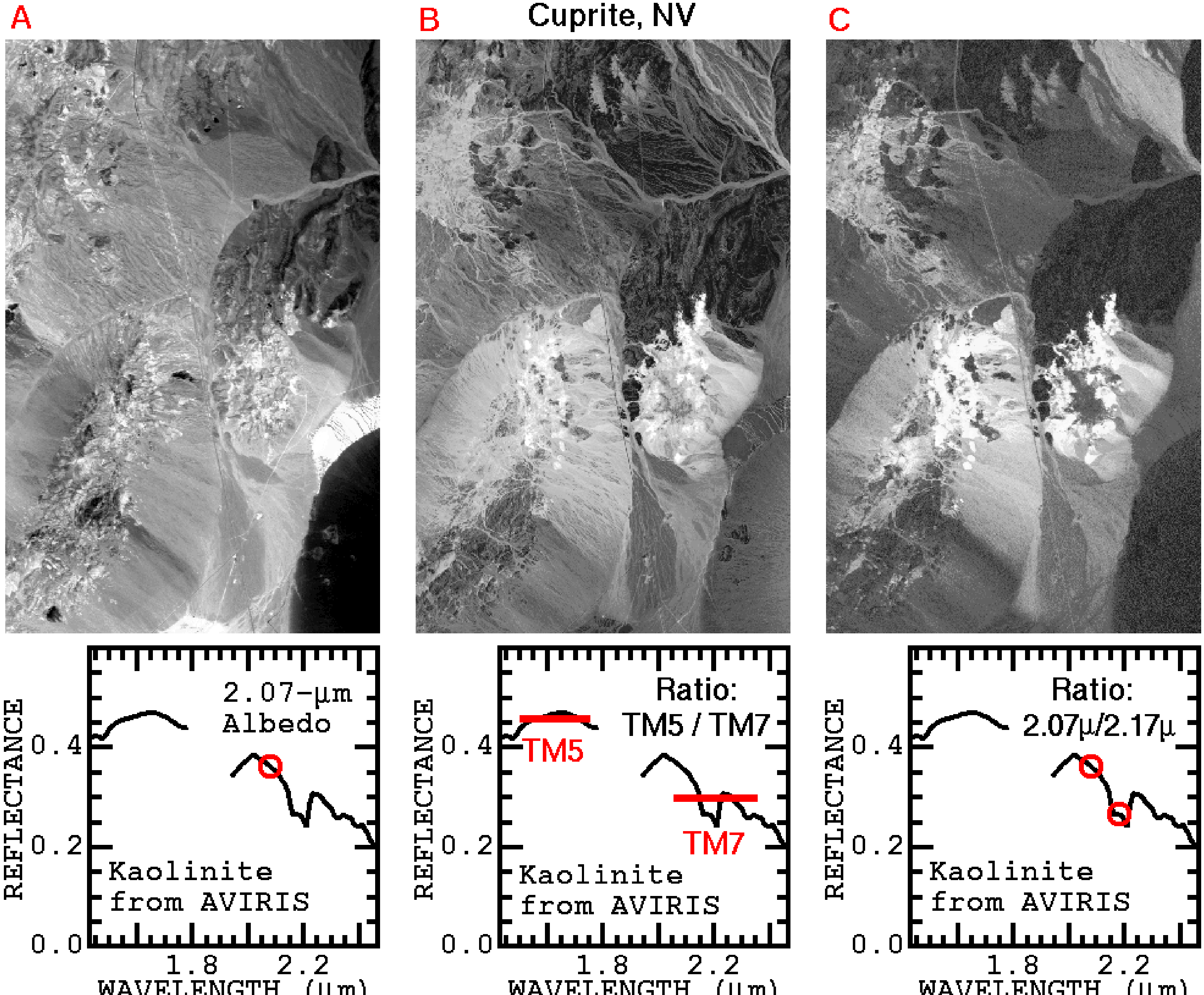
Possible sources of life.

Possible sources of acidic water.

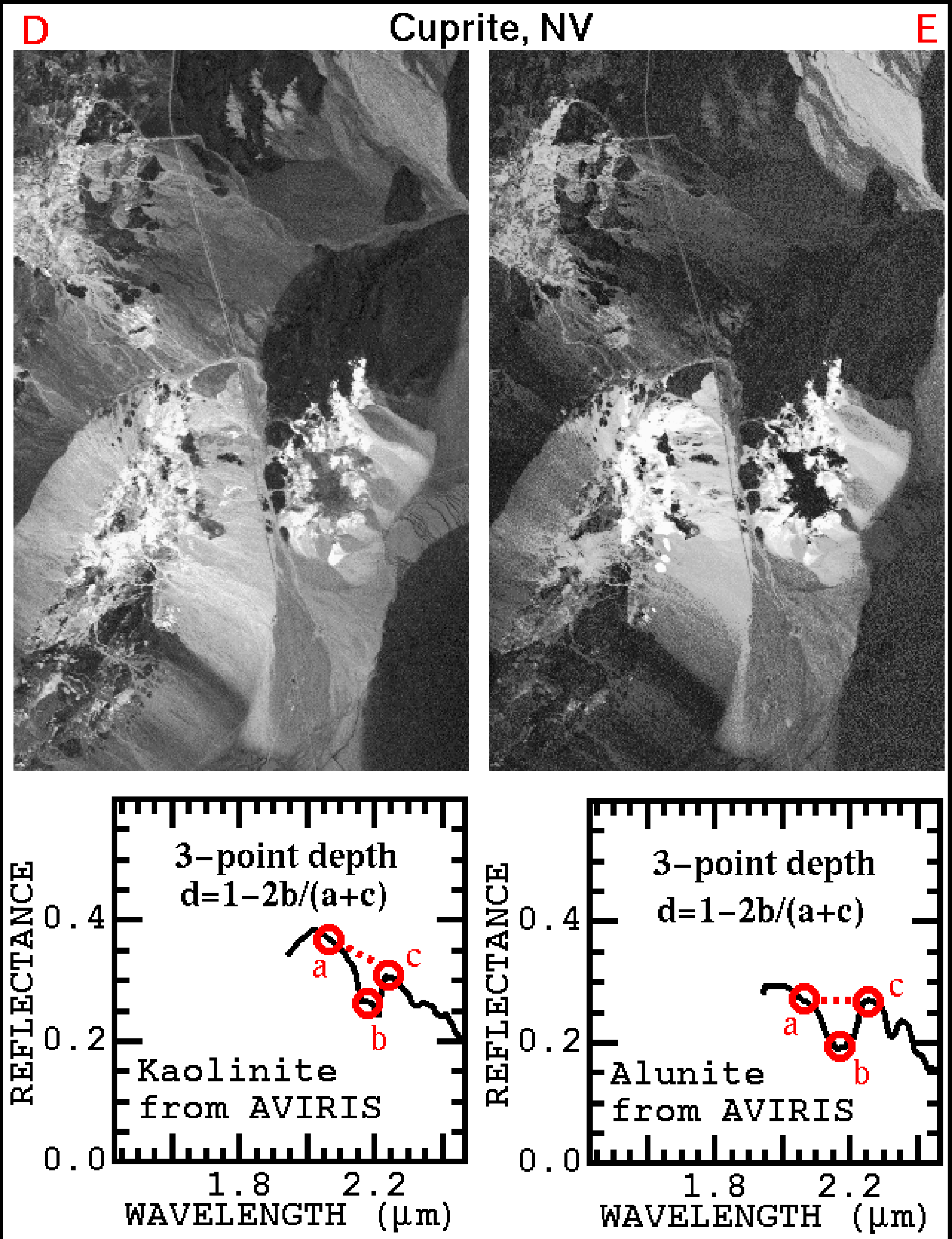
Cuprite, Nevada is an ancient hydrothermal alteration system (like yellowstone.)

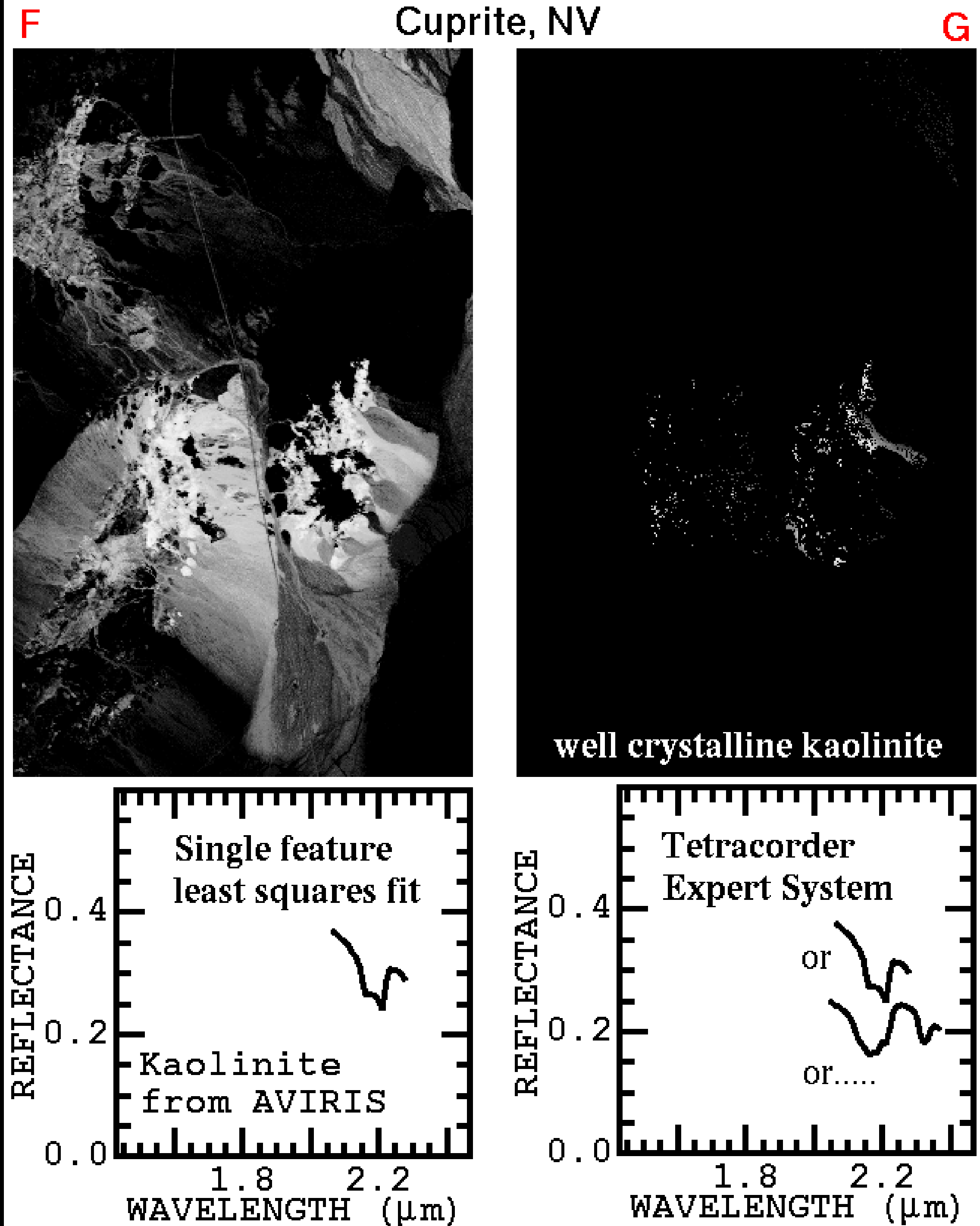
Let's look for well-crystallized kaolinite at Cuprite.





Cuprite, NV
A
B
C
2.07-µm
Albedo
Ratio:
TM5 / TM7
TM5
TM7
Ratio:
2.07µ/2.17µ
Kaolinite
from AVIRIS
REFLECTANCE
0.0
0.2
0.4
1.8
2.2
WAVELENGTH (µm)

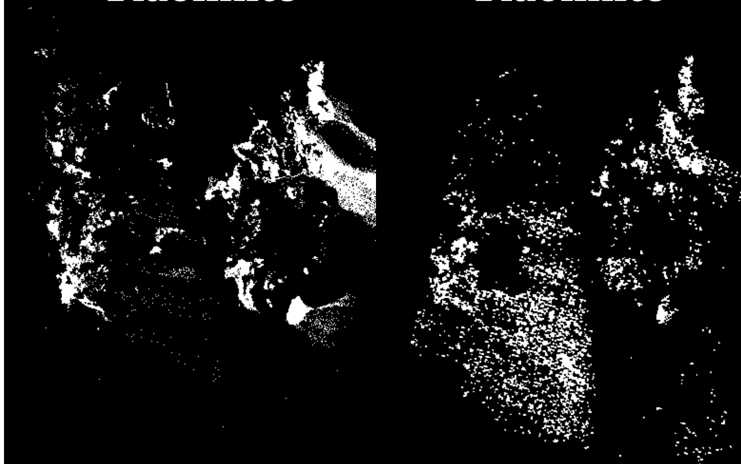

D
Cuprite, NV
E
3-point depth
d=1-2b/(a+c)
REFLECTANCE
0.4
0.2
0.0
a
b
c
Kaolinite
from AVIRIS
1.8
2.2
WAVELENGTH (μm)
3-point depth
d=1-2b/(a+c)
REFLECTANCE
0.4
0.2
0.0
a
b
c
Alunite
from AVIRIS
1.8
2.2
WAVELENGTH (μm)



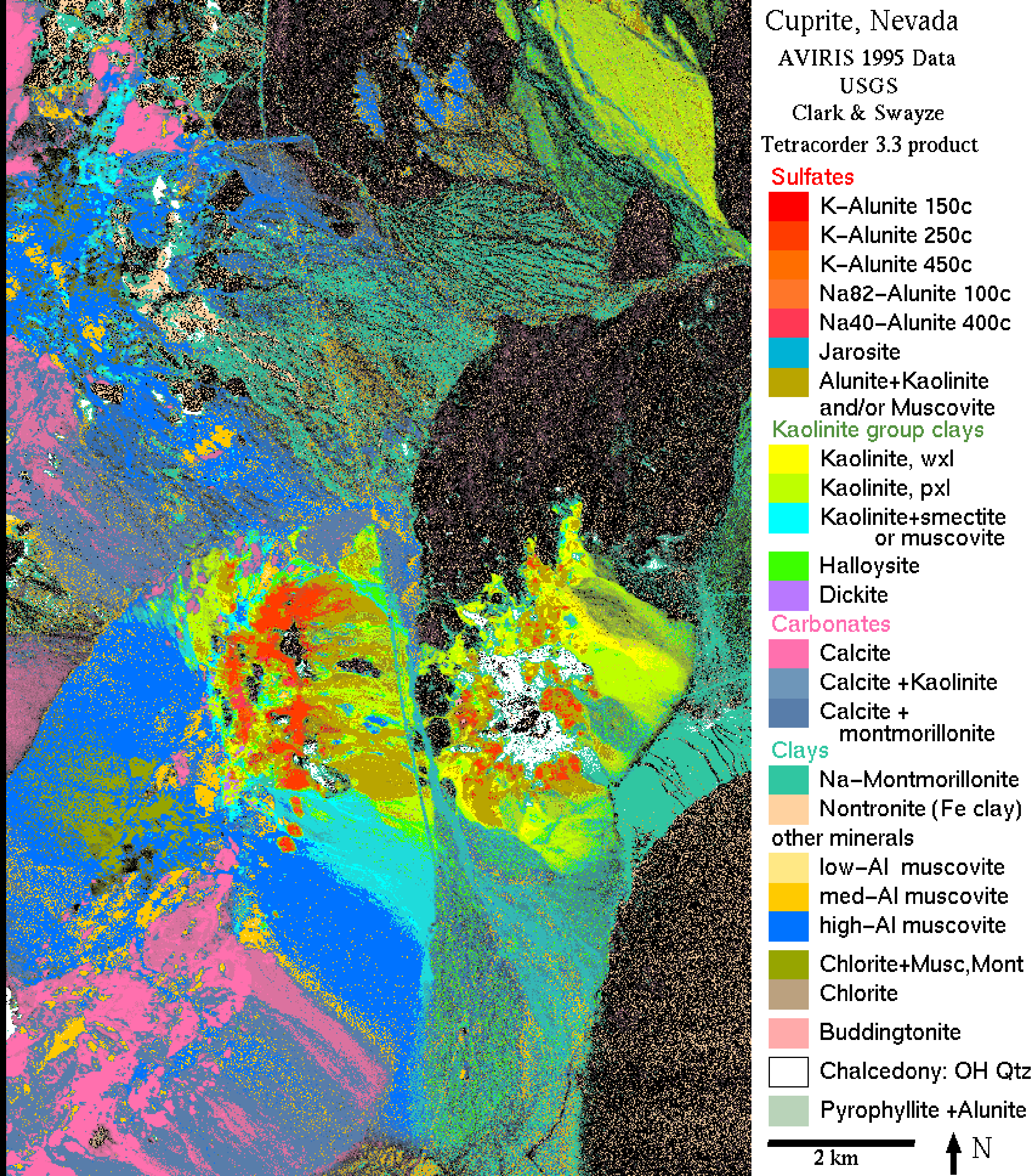
Clark *et al.* JGR 2003
Tetracorder analysis (left)

Very similar results despite
Very different methods

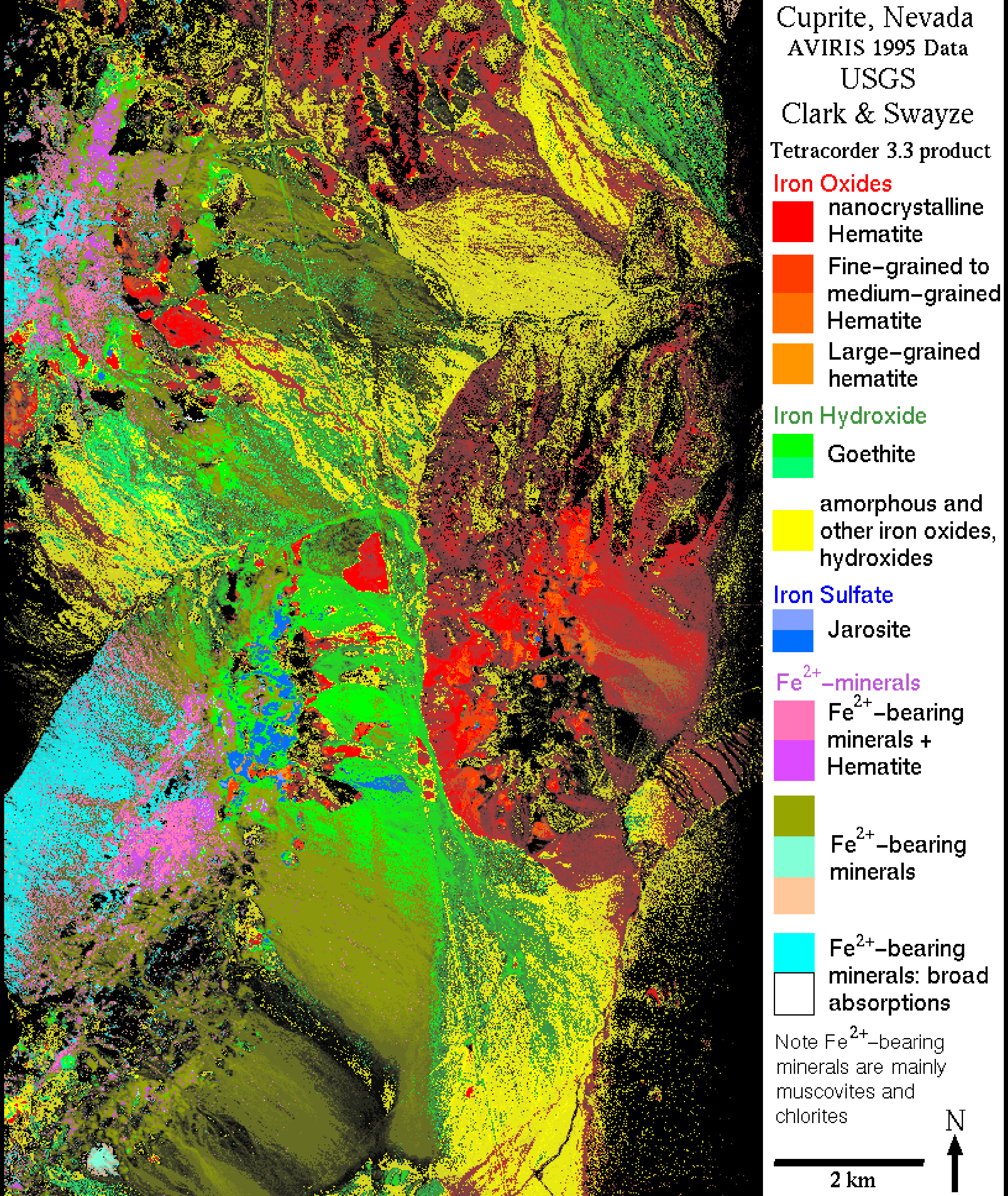
AVIRIS Kaolinite **Hyperion Kaolinite**



Kruse analysis for Kaolinite Group minerals (above): ACORN, MNF transform. Pixel Purity Index, n-D Visualizer, Spectral Analyst, Classification and subpixel analysis, Mixture-Tuned-Matched-Filtering (MTMF)

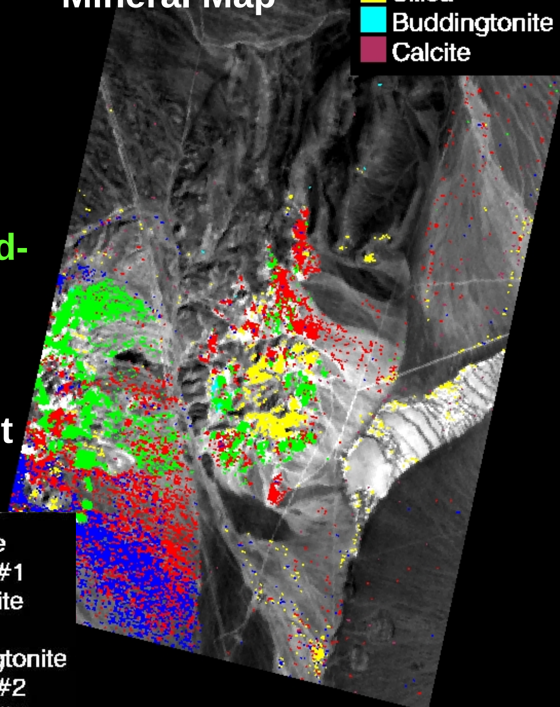


Cuprite, Nevada
AVIRIS 1995 Data
USGS
Clark & Swayze
Tetracorder 3.3 product
Sulfates
K-Alunite 150c
K-Alunite 250c
K-Alunite 450c
Na82-Alunite 100c
Na40-Alunite 400c
Jarosite
Alunite+Kaolinite and/or Muscovite
Kaolinite group clays
Kaolinite, wxl
Kaolinite, pxl
Kaolinite+smectite or muscovite
Halloysite
Dickite
Carbonates
Calcite
Calcite +Kaolinite
Calcite + montmorillonite
Clays
Na-Montmorillonite
Nontronite (Fe clay)
other minerals
low-Al muscovite
med-Al muscovite
high-Al muscovite
Chlorite+Musc,Mont
Chlorite
Buddingtonite
Chalcedony: OH Qtz
Pyrophyllite +Alunite
2 km
N

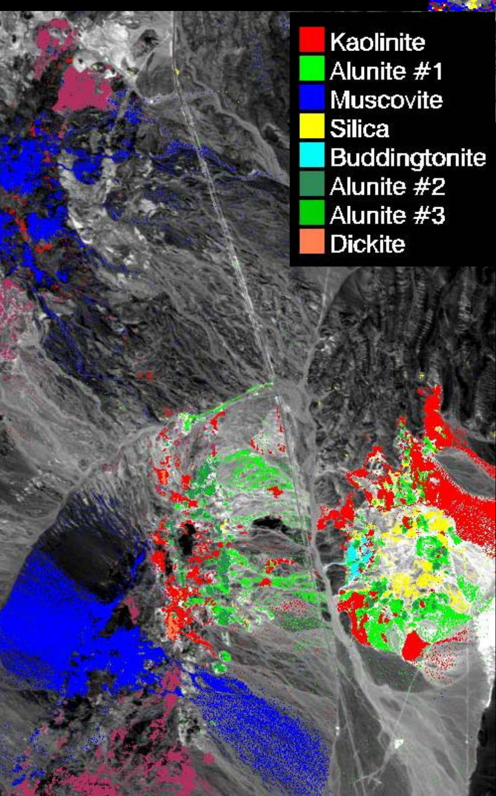

Cuprite, Nevada
AVIRIS 1995 Data
USGS
Clark & Swayze
Tetracorder 3.3 product
Iron Oxides
nanocrystalline Hematite
Fine-grained to medium-grained Hematite
Large-grained hematite
Iron Hydroxide
Goethite
amorphous and other iron oxides, hydroxides
Iron Sulfate
Jarosite
Fe^{2+}-minerals
Fe^{2+}-bearing minerals + Hematite
Fe^{2+}-bearing minerals
Fe^{2+}-bearing minerals: broad absorptions
Note Fe^{2+}-bearing minerals are mainly muscovites and chlorites
N
2 km

Kruse analysis:
ACORN, MNF transform.
Pixel Purity Index,
n-D Visualizer,
Spectral Analyst,
Classification and
subpixel analysis,
Mixture-Tuned-Matched-Filtering (MTMF)

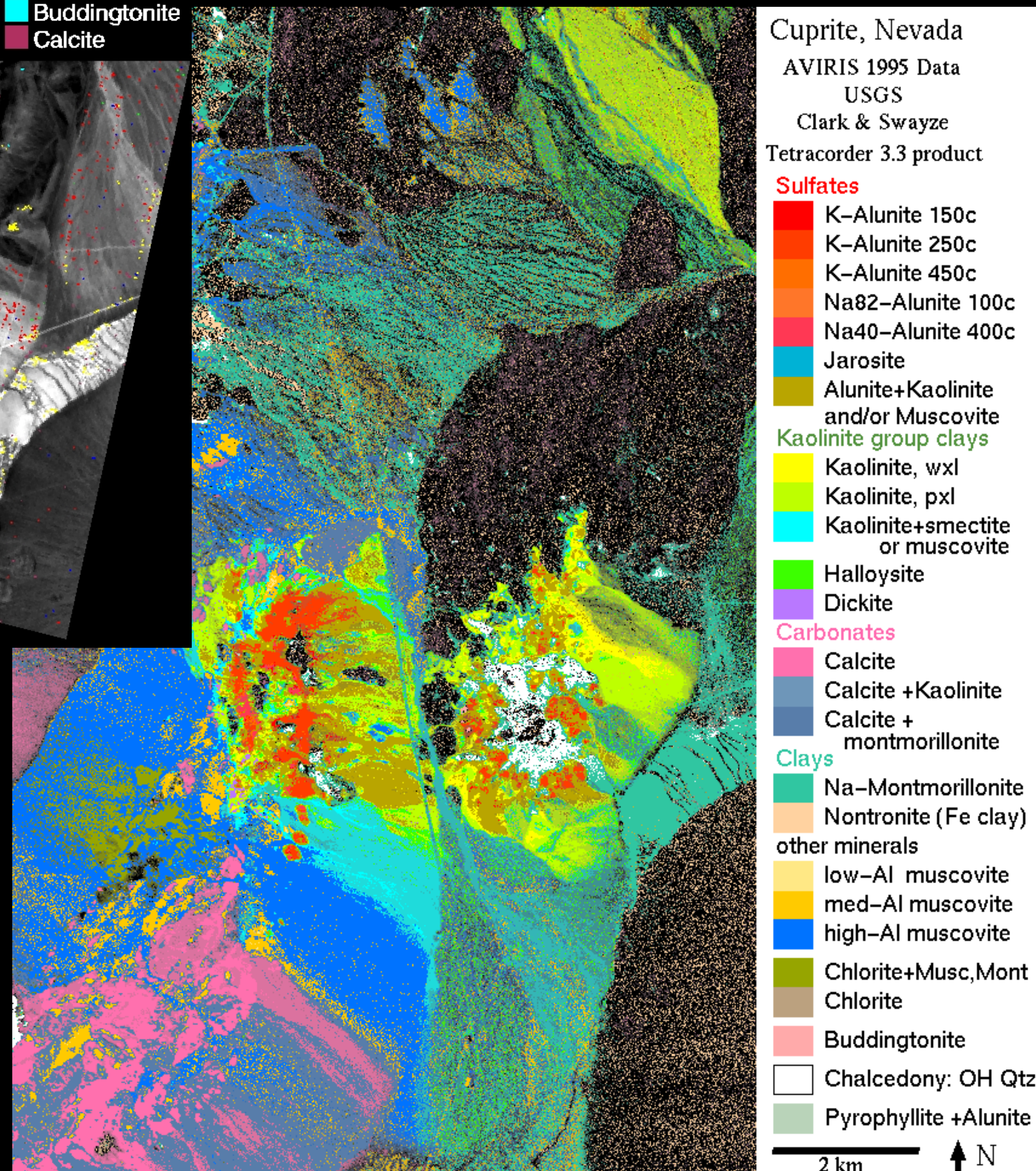
March 1, 2001
EO-1 Hyperion
Mineral Map



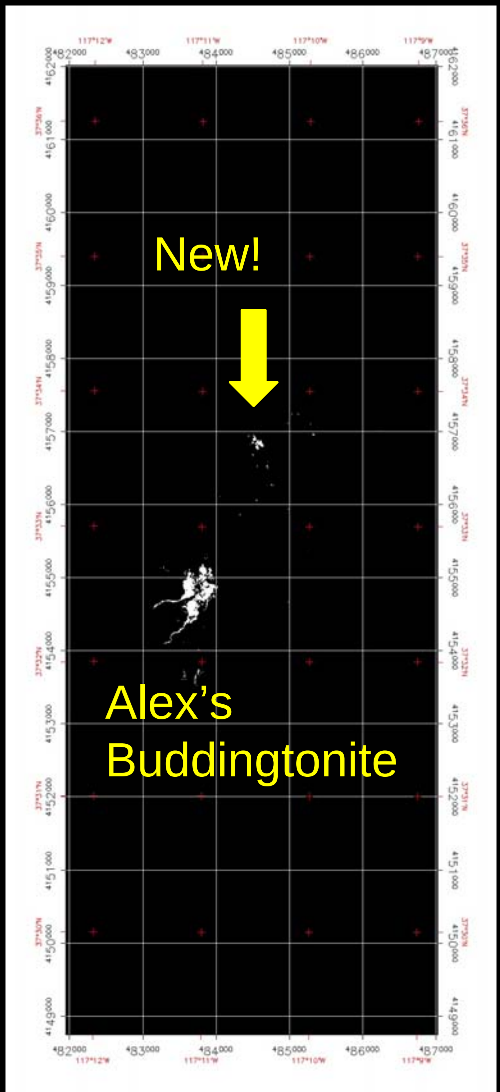
19 June 1997 AVIRIS
Spectrally Predominant
Mineral Map

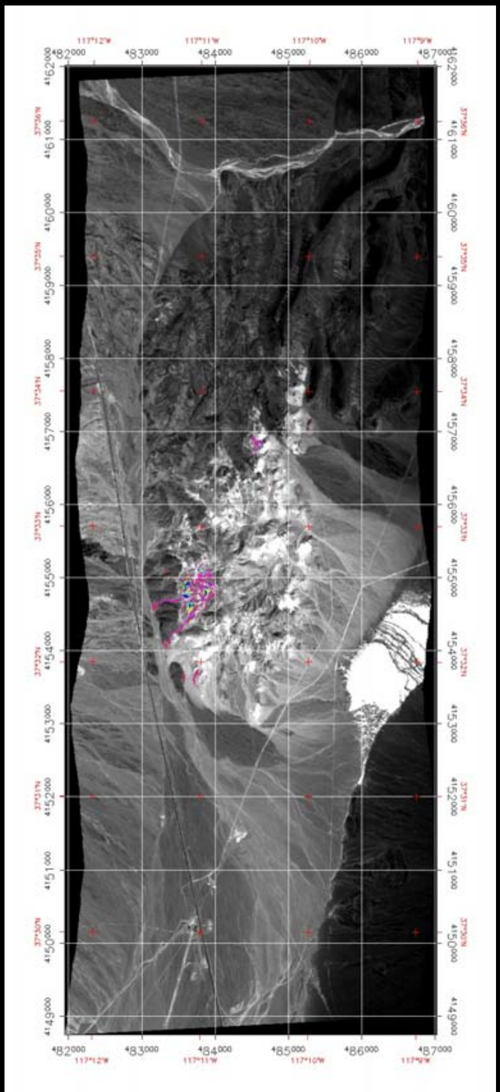


Clark *et al.* JGR 2003 Tetracorder analysis



But How Better to Honor Alex Than to Find Something New at Good Old Cuprite? Buddingtonite, Even!

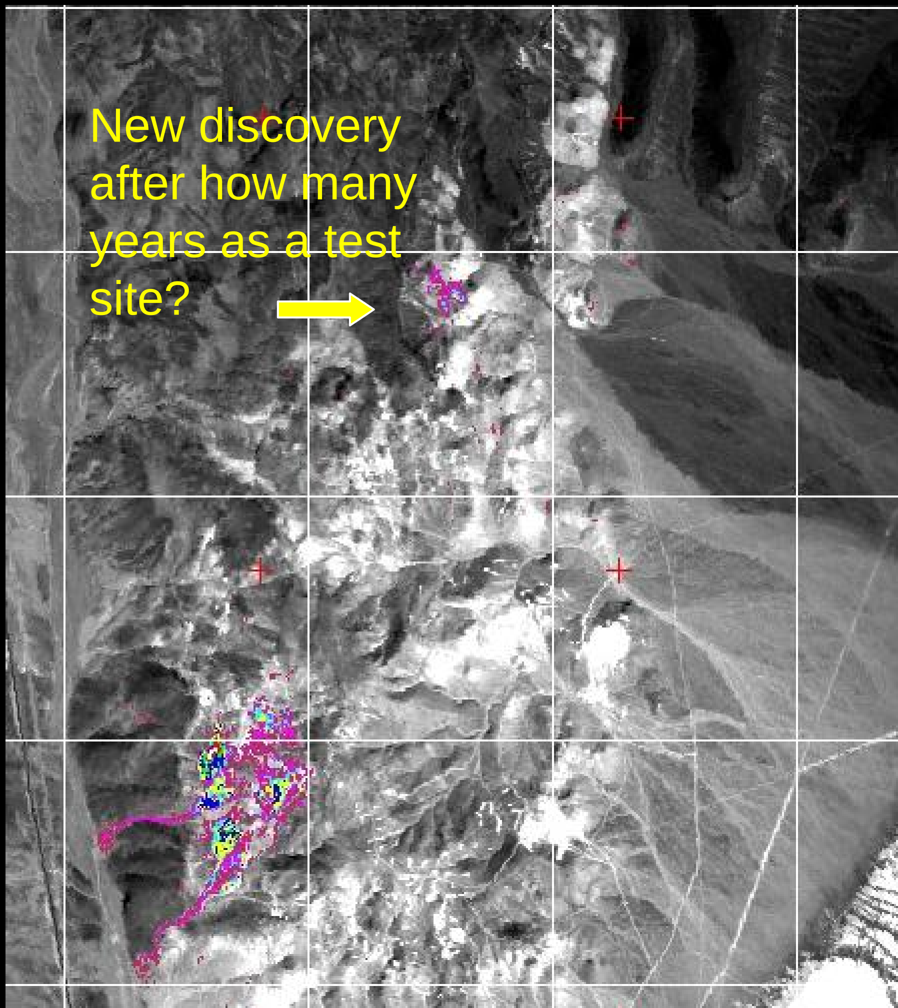


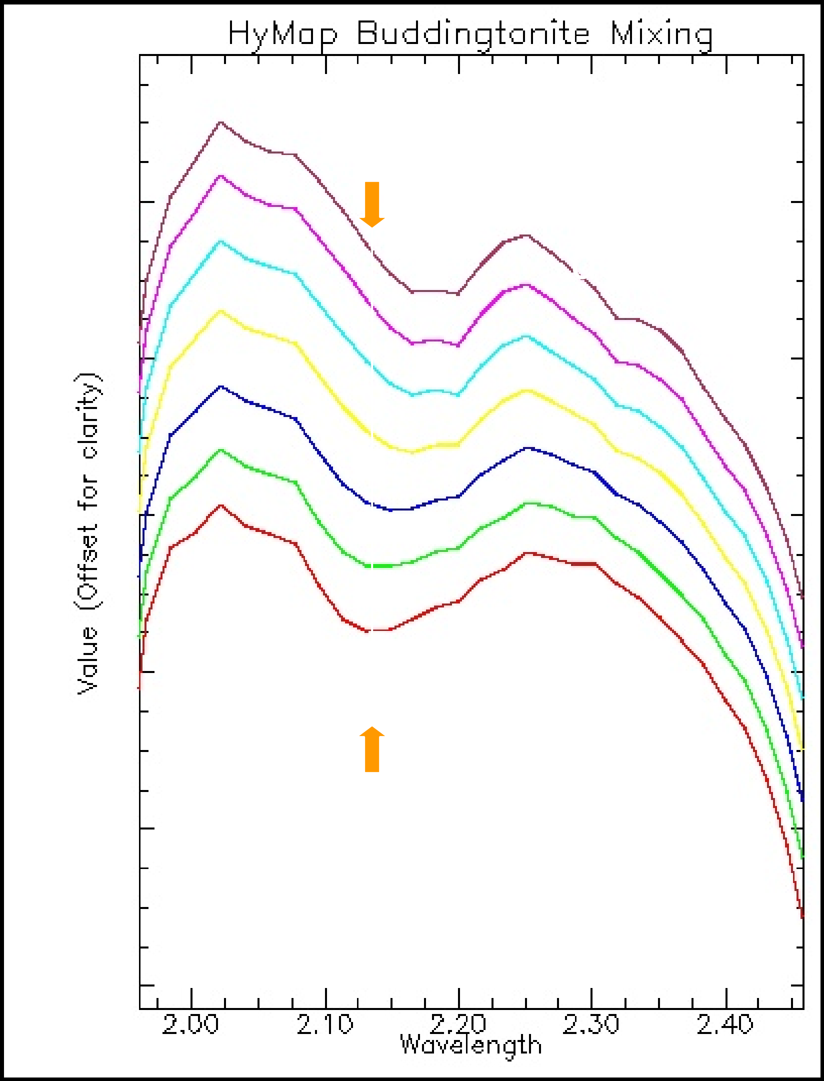


- MTMF applied to 1999 HyMap AIG Cuprite data
- Finds NEW Buddingtonite!
- Better algorithms + better data = better geologic results

From Joe Boardman

MTMF Finds Buddingtonite at ~1% Abundance (New location verified by Gregg Swayze)



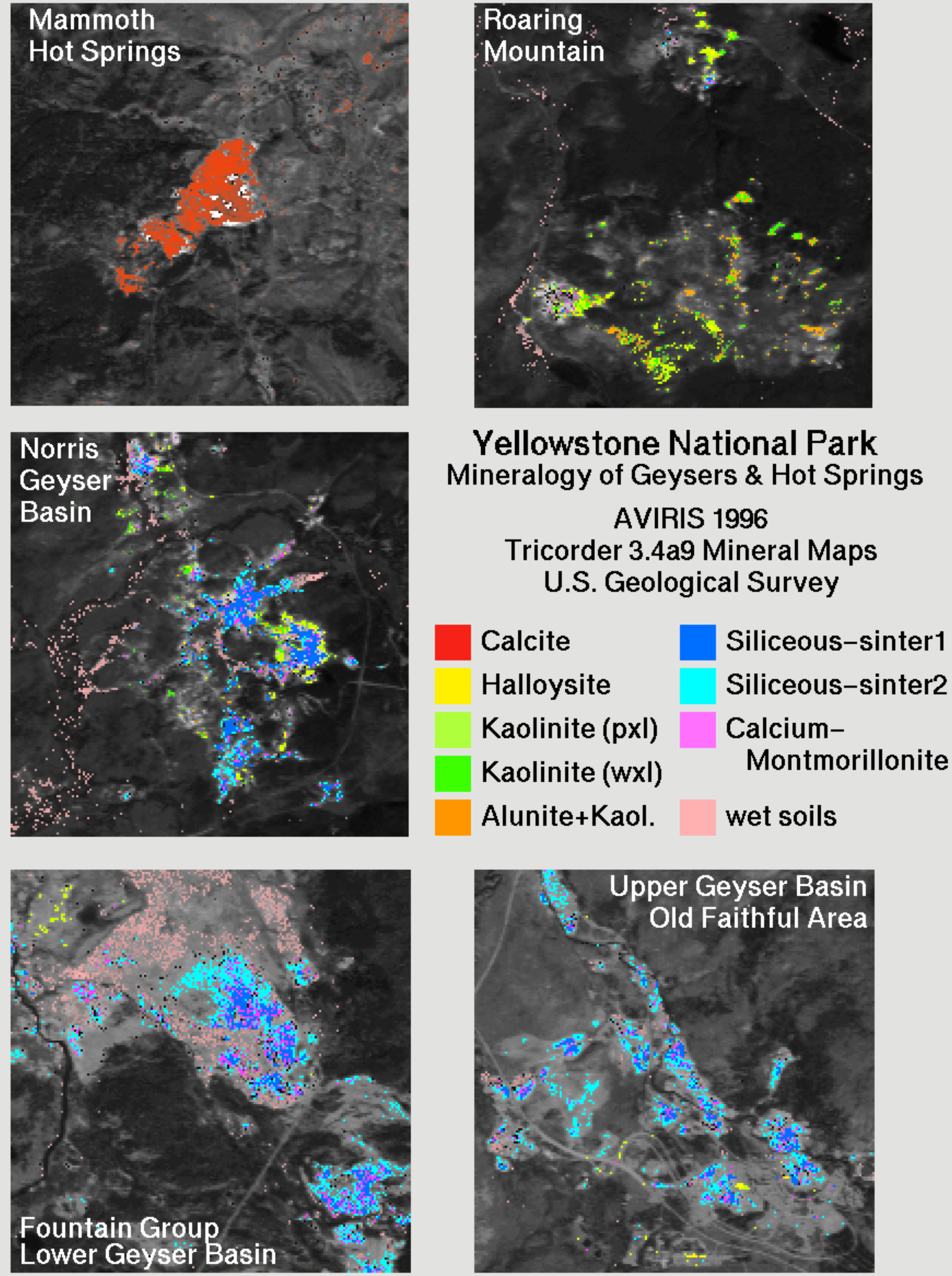


If Cuprite still has secrets, we have only just begun!

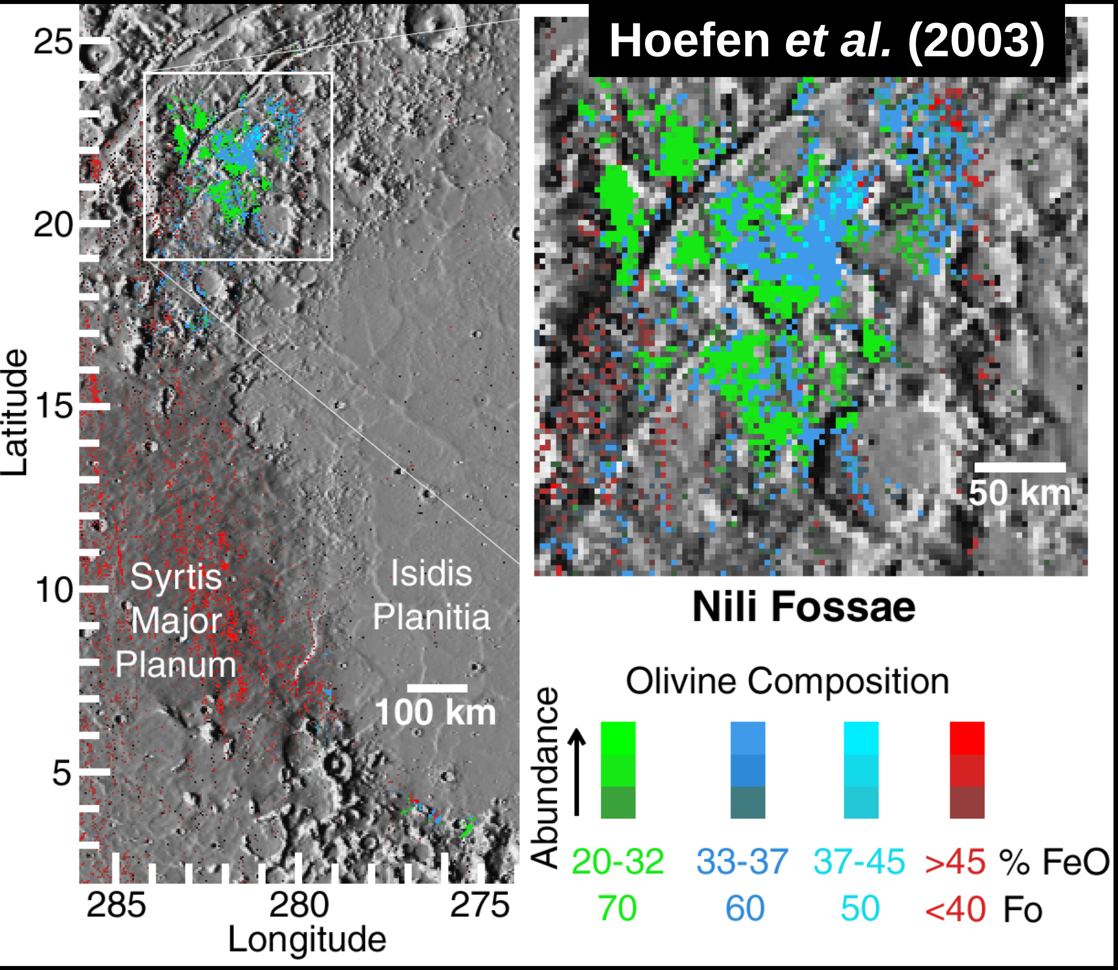
From Joe Boardman

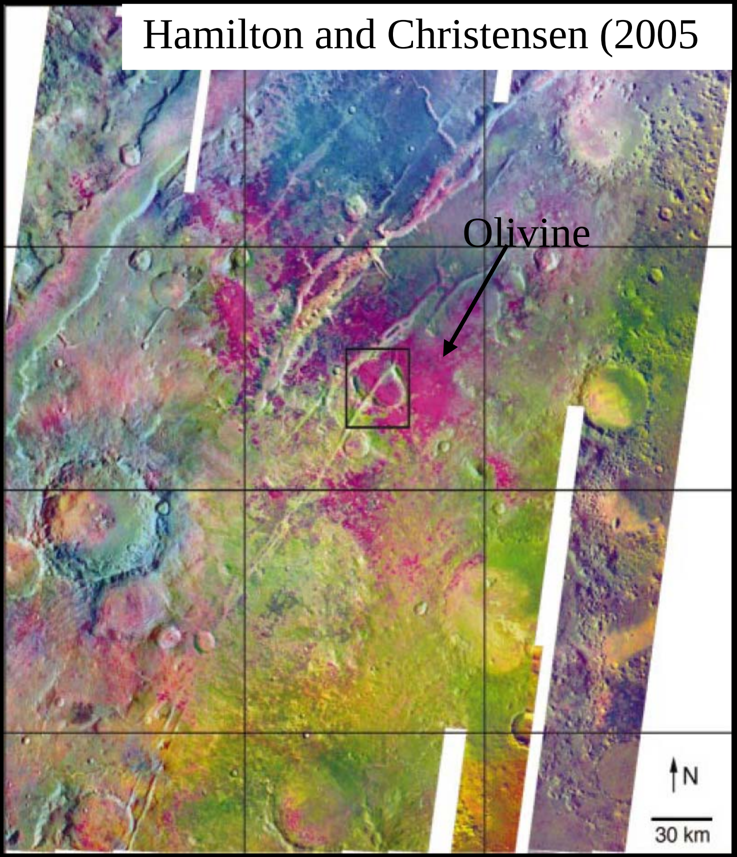
Yellowstone

Yellowstone thermal pool.
Colors indicate life living at different temperatures.



Mineral Mapping on Mars

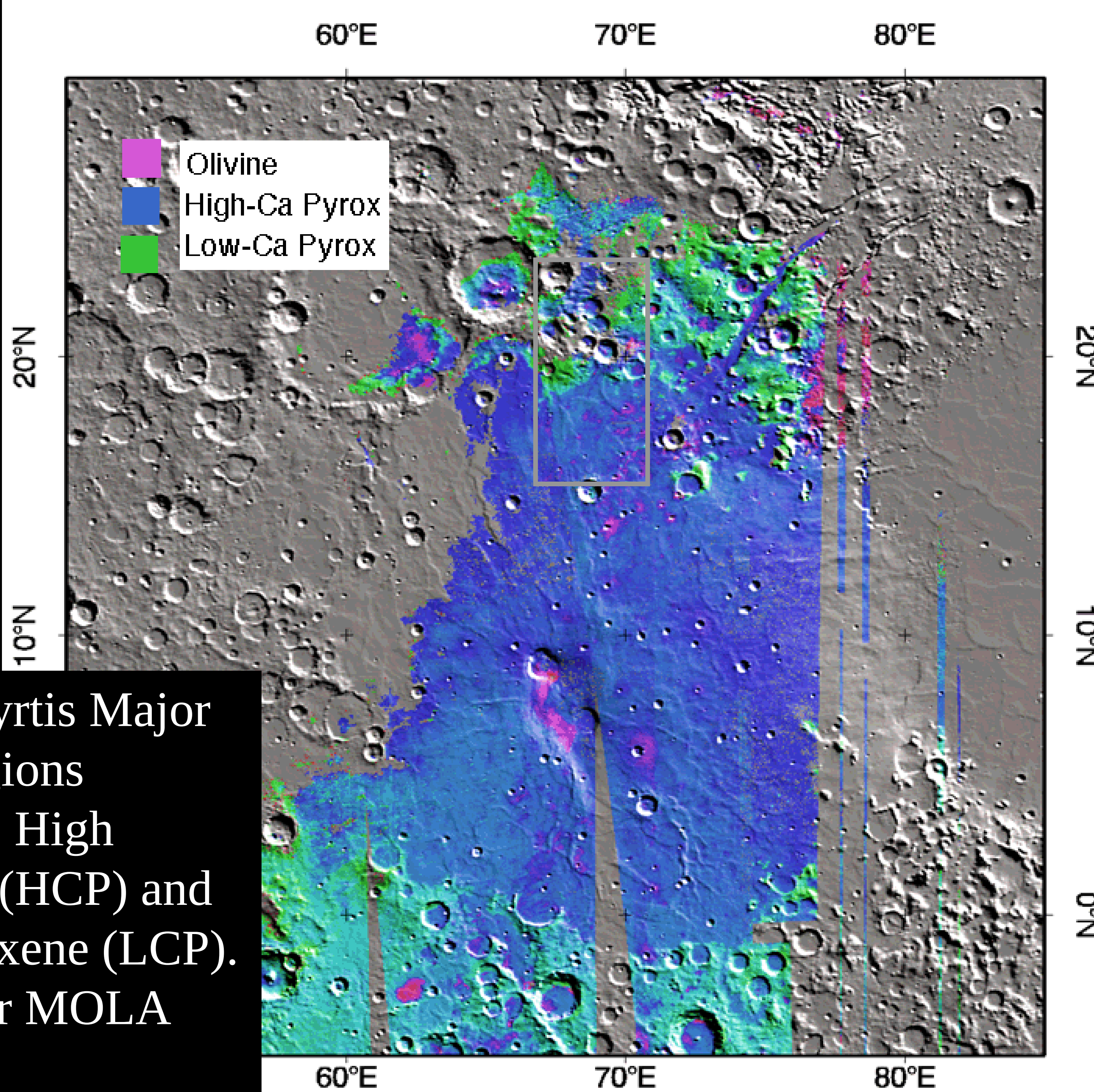




Major distinctive mineralogy from TES/THEMIS: Olivine (Hoefen et al. (2003); Hamilton and Christensen (2005)

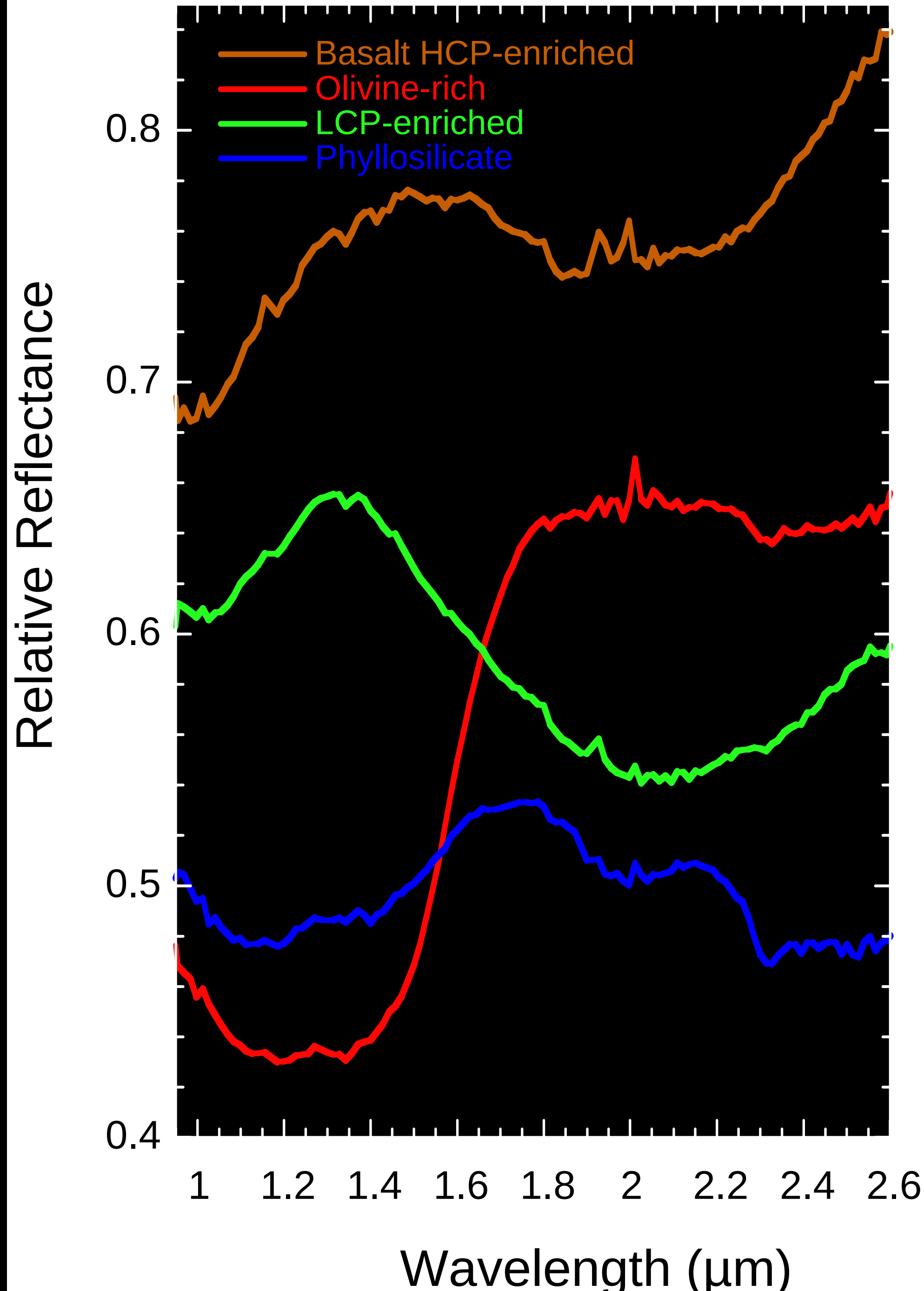
Mars: Mineral Mapping with OMEGA

Mustard *et al.*, *Science*, 2005



Regional map of Syrtis Major region showing regions enriched in olivine, High Calcium Pyroxene (HCP) and Low Calcium Pyroxene (LCP). Results draped over MOLA shaded relief

Local map of Nili Fossae region showing regions enriched in olivine (red), LCP (green) and Phyllosilcate (blue). Results draped over HRSC imaging



Moon Mineralogy Mapper (M3)

Chandrayaan-1 launches in early 2008 from India

- 100 km circular polar Orbit
- Two year mission duration
- PI: C. Pieters, Brown U.; Built by JPL

M3 is a pushbroom imaging spectrometer

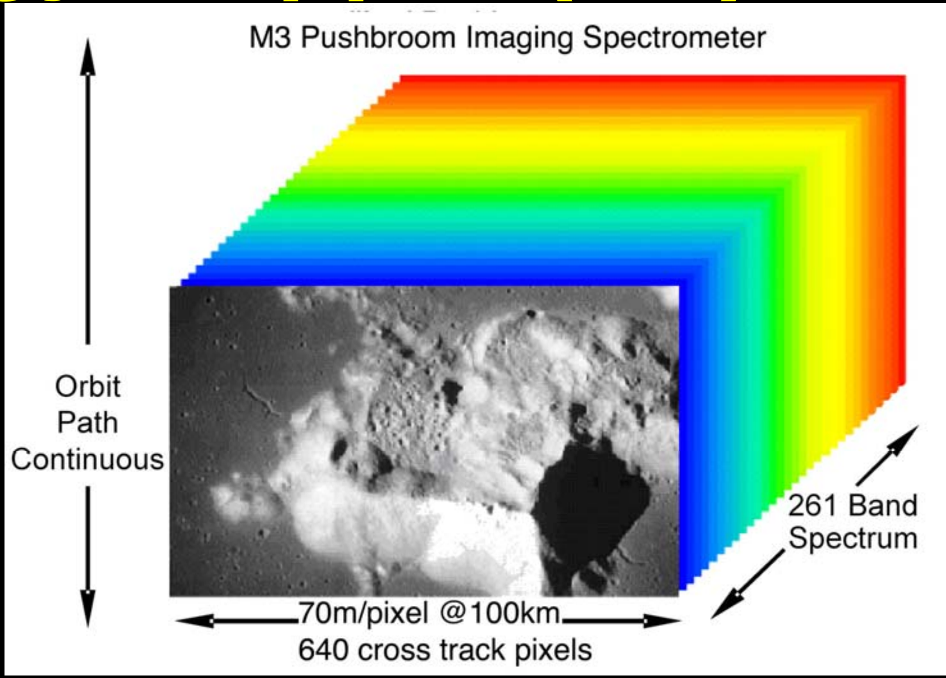
- 40 km FOV, contiguous orbits
- 0.43 to 3.0 µm, high SNR
- 1 Gbyte/orbit

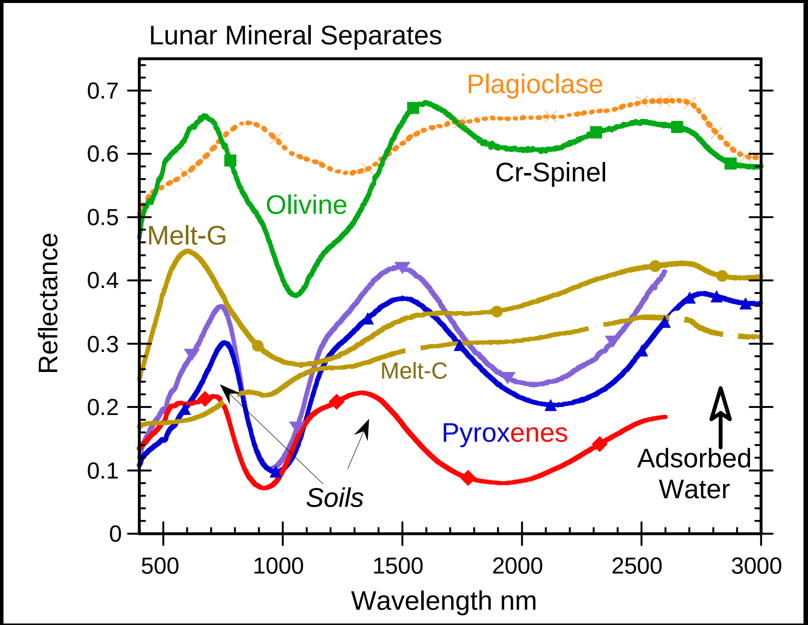
Targeted Mode: Optimum

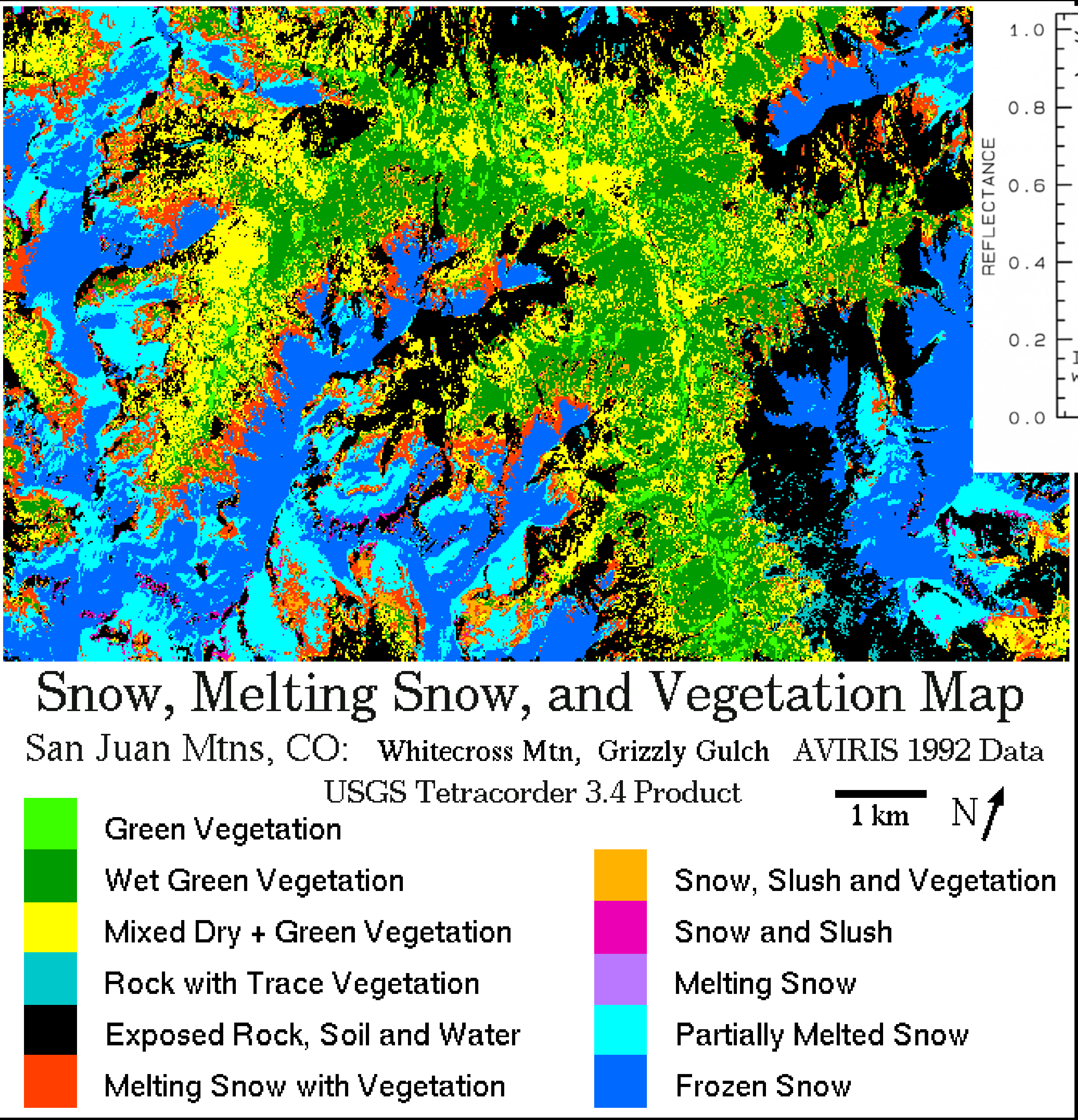
- Resolution (100 km orbit):
  - 70 m/pixel spatial
  - 10 nm spectral [261 bands]
- 3 optical periods [10 - 30% coverage]
  - 12 to 15 deg latitude/orbit

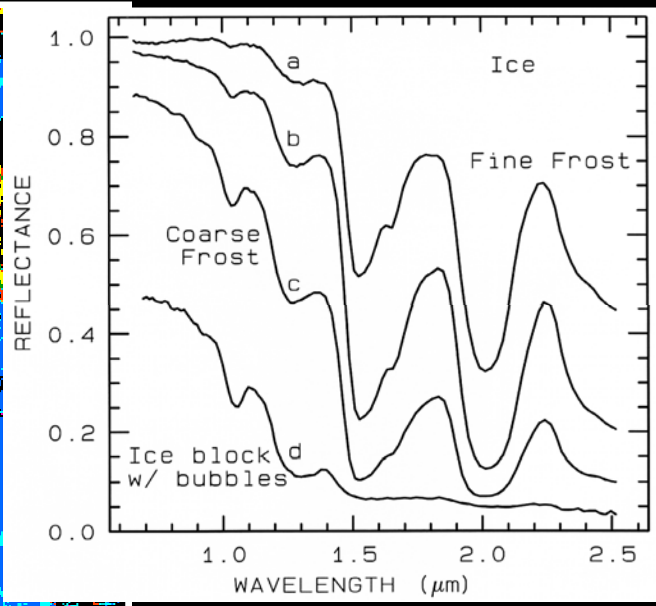
Global Mode: Full Coverage

- Resolution (100 km orbit):
  - 140 m/pixel spatial
  - 20 & 40 nm selected (87 bands, ~3x spectral averaging)
- 1 optical period [100%]









Ice shows a large range of spectral properties as a function of grain size. Phase change shifts bands. This allows ice grain size and melting snow to be mapped.

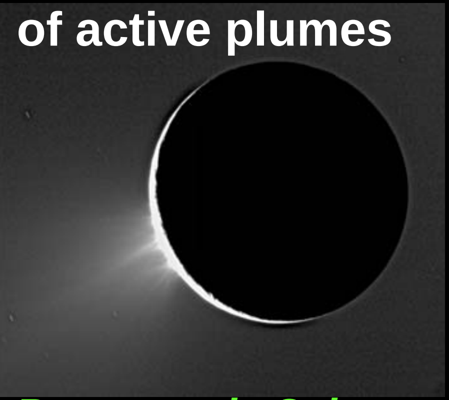
Clark *et al.*, JGR (2003)

Cassini VIMS Enceladus Ice Map

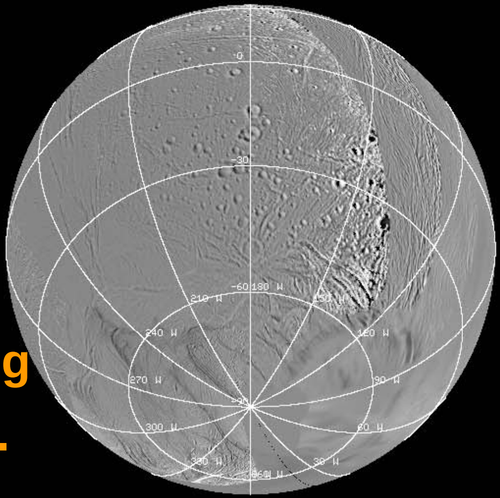
Enceladus:
260 km in radius
Orbital radius:
4 Saturn radii
Active plumes contribute to E-ring

Very bright surface.

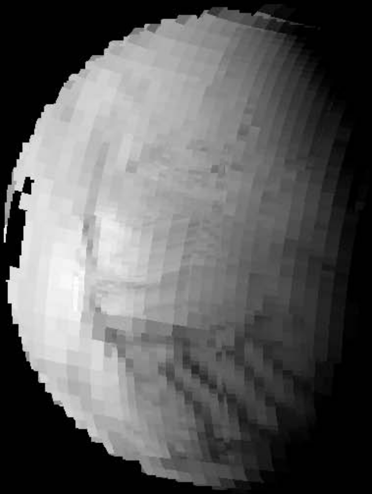
Cassini ISS Image of active plumes



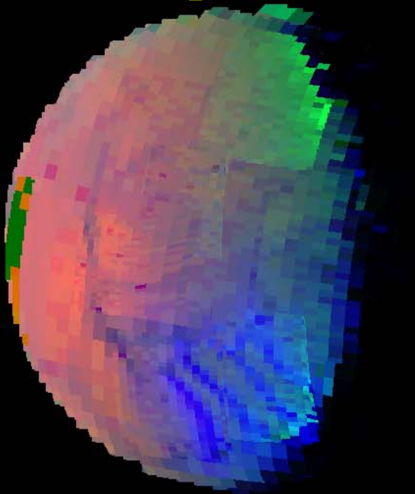
Porco *et al.*, *Science*, 2006.



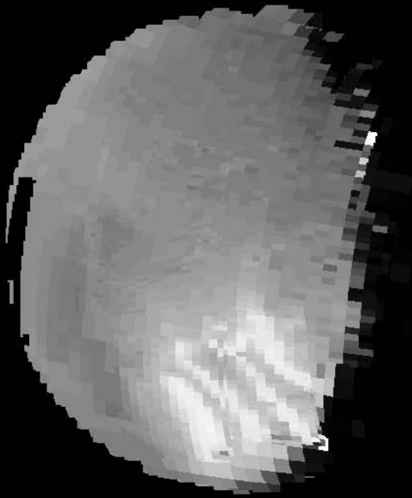
ISS Reference



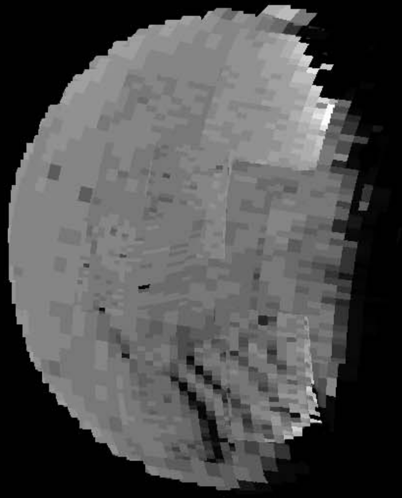
2.2-micron Reflectance



Color composite:
Red = 2.2-micron Reflectance
Green=3-micron Ice
Blue = 2-micron Ice



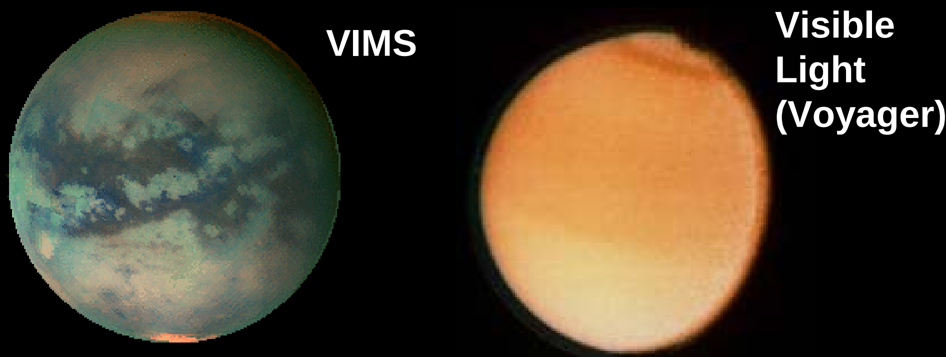
2-micron Ice Absorption Strength

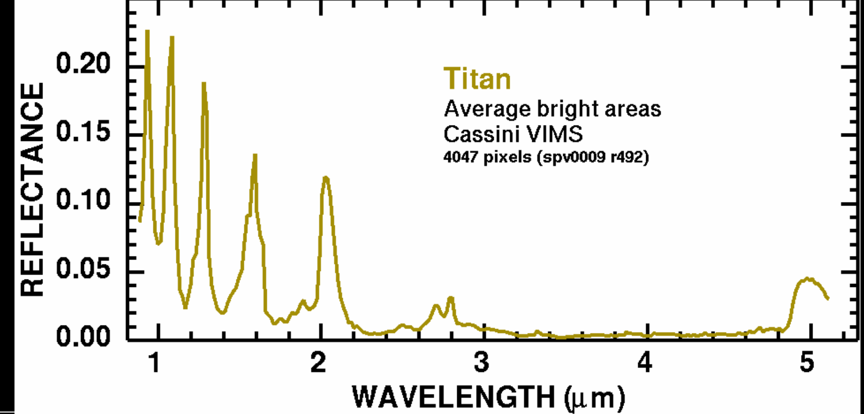


3-micron Ice Absorption Strength

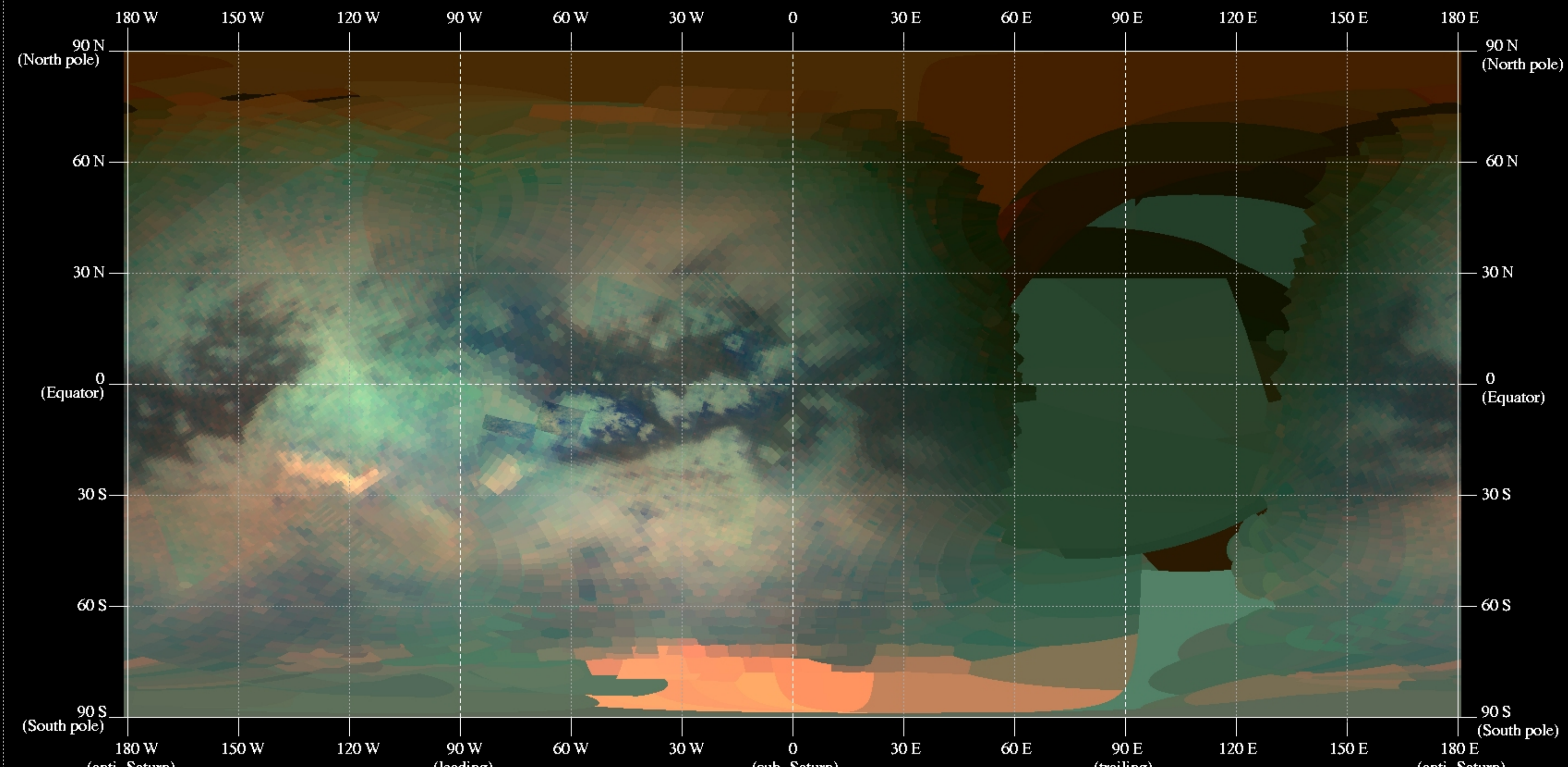
Cassini
Visual and Infrared
Mapping Spectrometer

Brown et al., *Science*, 311, p. 1425-1428, 2006.





Cassini / VIMS Map of Titan
Created from T8 and T9 Flyby Observations



Environmental Studies of the World Trade Center area after the September 11, 2001 attack.

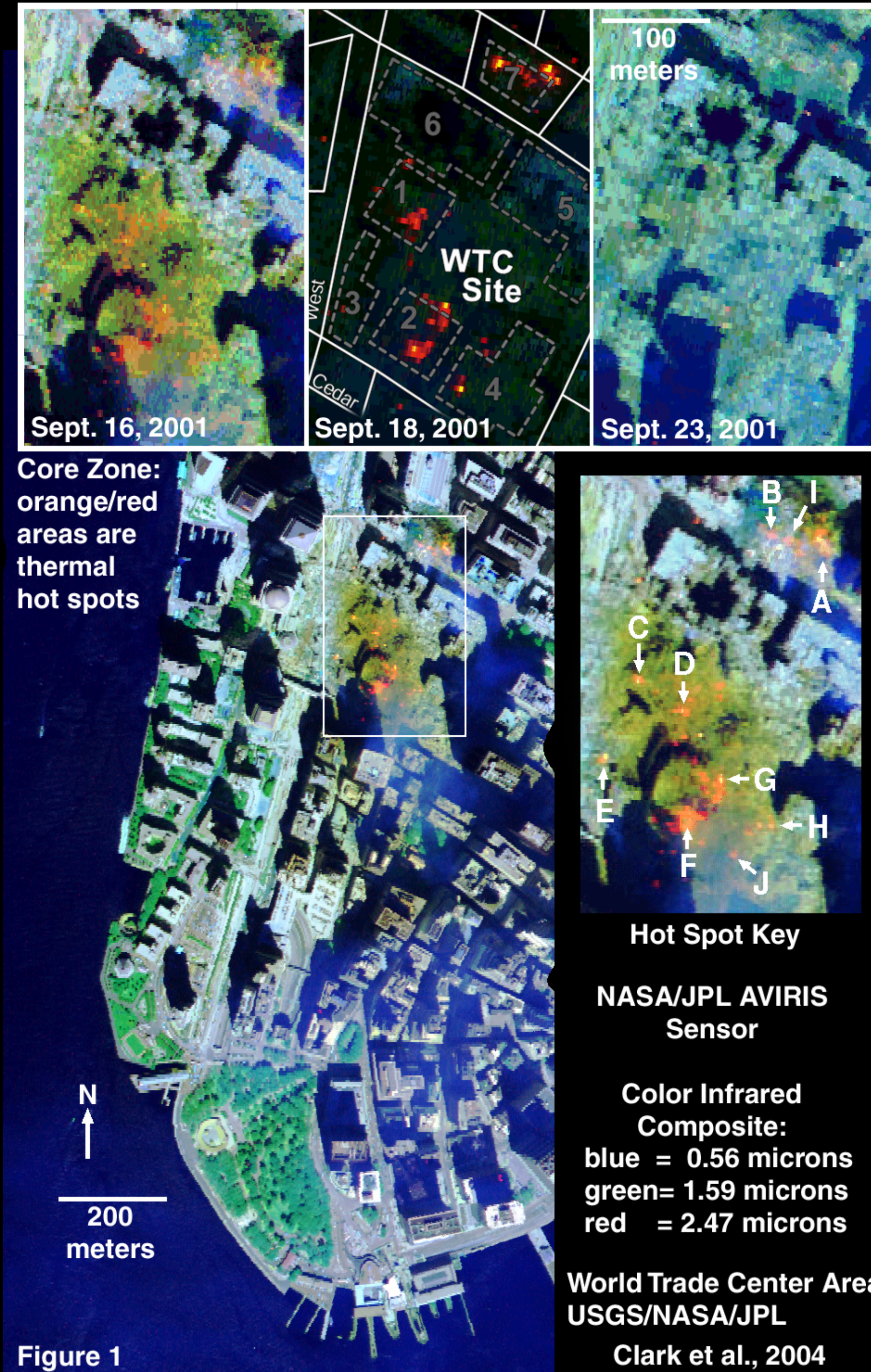
Roger N. Clark, Robert O. Green, Gregg A. Swayze, Greg Meeker, Steve Sutley, Todd M. Hoefen, K. Eric Livo, Geoff Plumlee, Betina Pavri, Chuck Sarture, Steve Wilson, Phil Hageman, Paul Lamothe, J. Sam Vance, Joe Boardman, Isabelle Brownfield, Carol Gent, Laurie C. Morath, Joseph Taggart,

Peter M. Theodorakos, and Monique Adams

USGS NASA/JPL USEPA

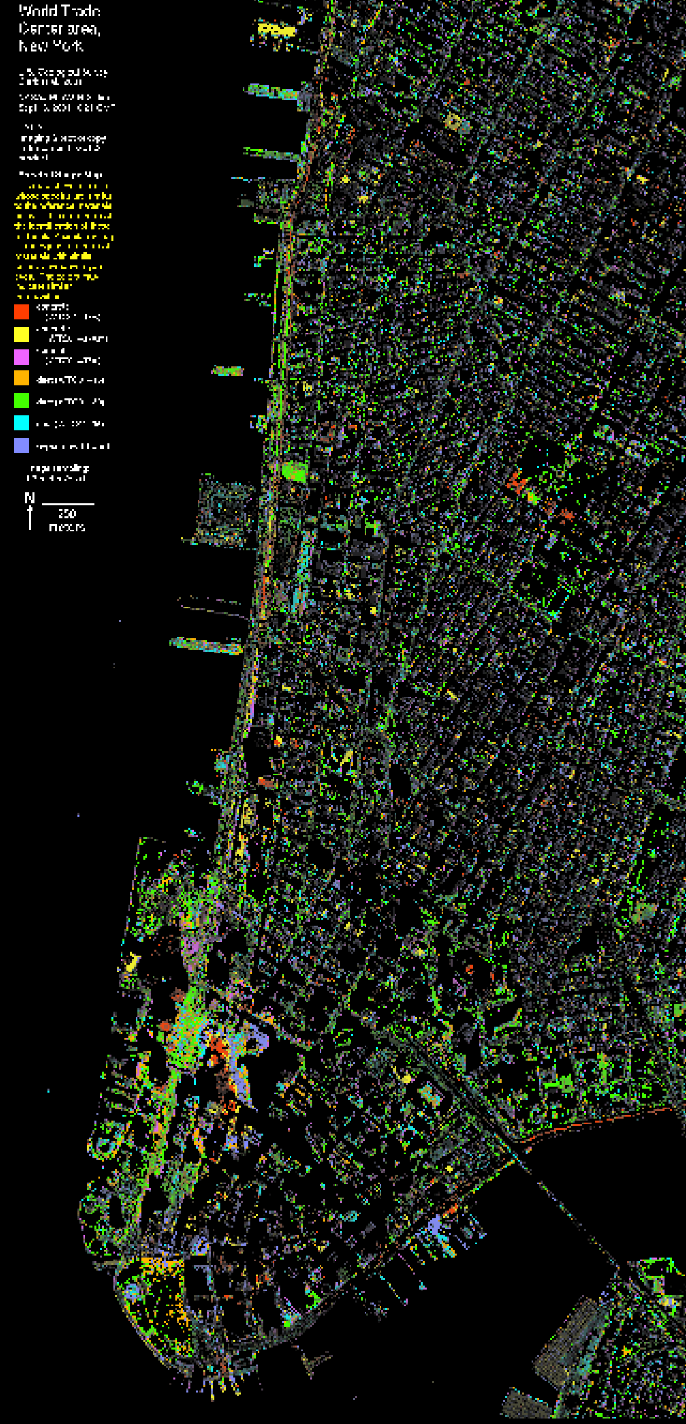
AVIRIS sees the fires through the smoke, making repeat observations

- Sept 16th fire images were delivered to the White House where agencies were briefed on the results and implications.
- Tuesday evening, Sept. 18: fire fighting methods were changed. CNN announces the firefighters are changing from a rescue operation to a recovery effort.
- Flights occur Sept 16, 18, 22, and 23, 2001.
- The fire fighting strategy helped.
- Spectral shape was used to determine fire temperatures; intensity the area of the fires.
- Analysis of fire temperatures Indicated over 800º C on 9/16, but mostly out by 9/23.



The debris has the same composition as the rest of the city

- The similarities in composition makes mapping WTC materials a challenge.
- The same materials can be seen throughout the city.
- But one can use context to see the debris cloud.



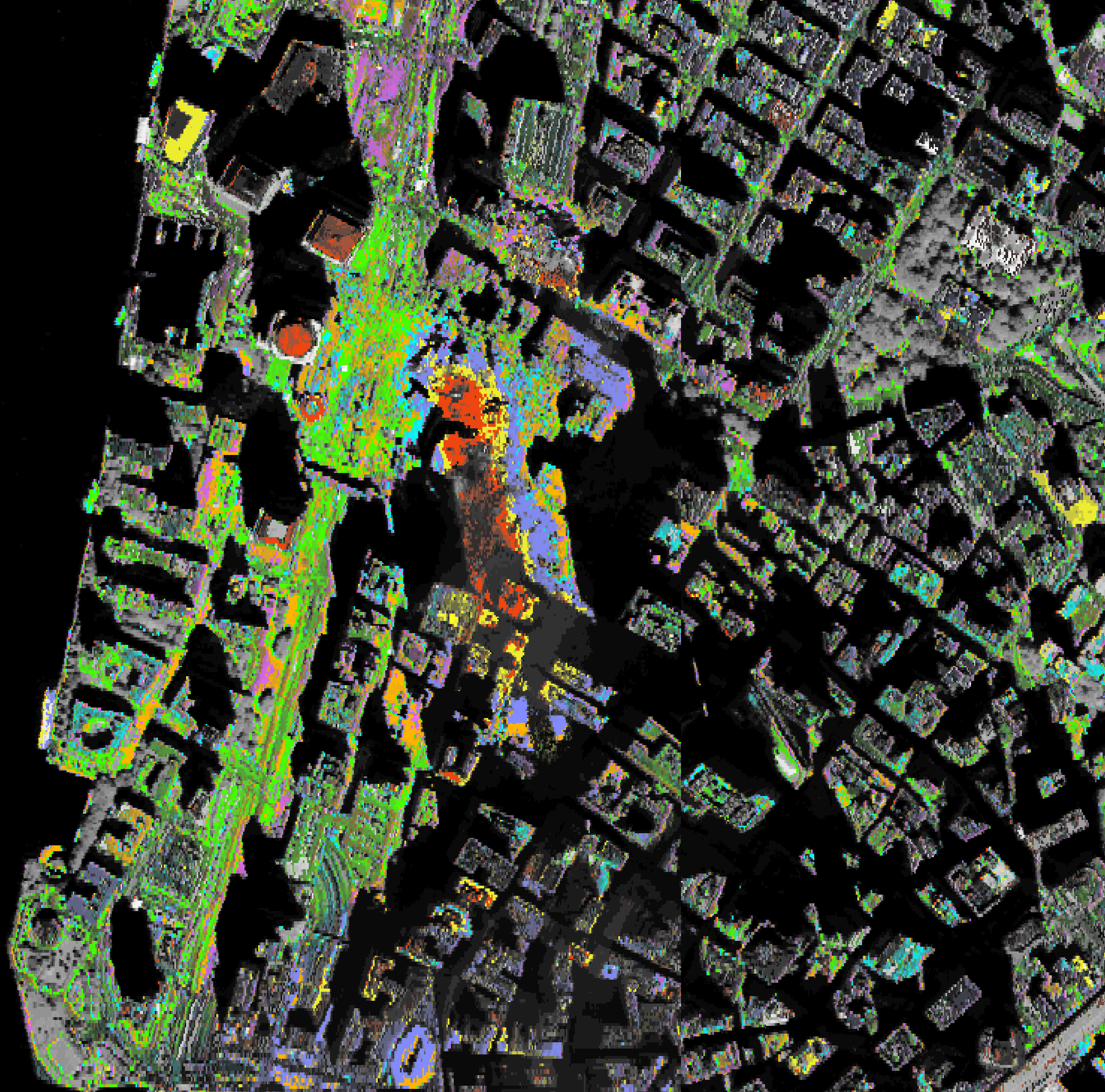
Spectral Shape Map

This map shows materials whose spectra are similar to the reference materials below. It is not a map of the identification of these materials. A similarity map is analogous to a map of materials with similar colors viewed with your eyes. The colors may indicate similar compositions.

- concrete (WTC01-37B)
- concrete (WTC01-37Am)
- cement (WTC01-37A)
- dust (WTC01-15)
- dust (WTC01-28)
- dust (WTC01_36)
- gypsum wall board

Image sampling: 1.7 meters/pixel

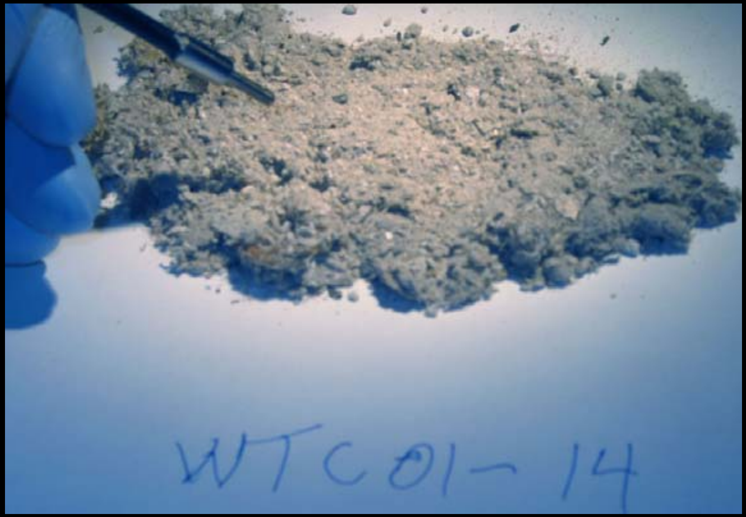
N



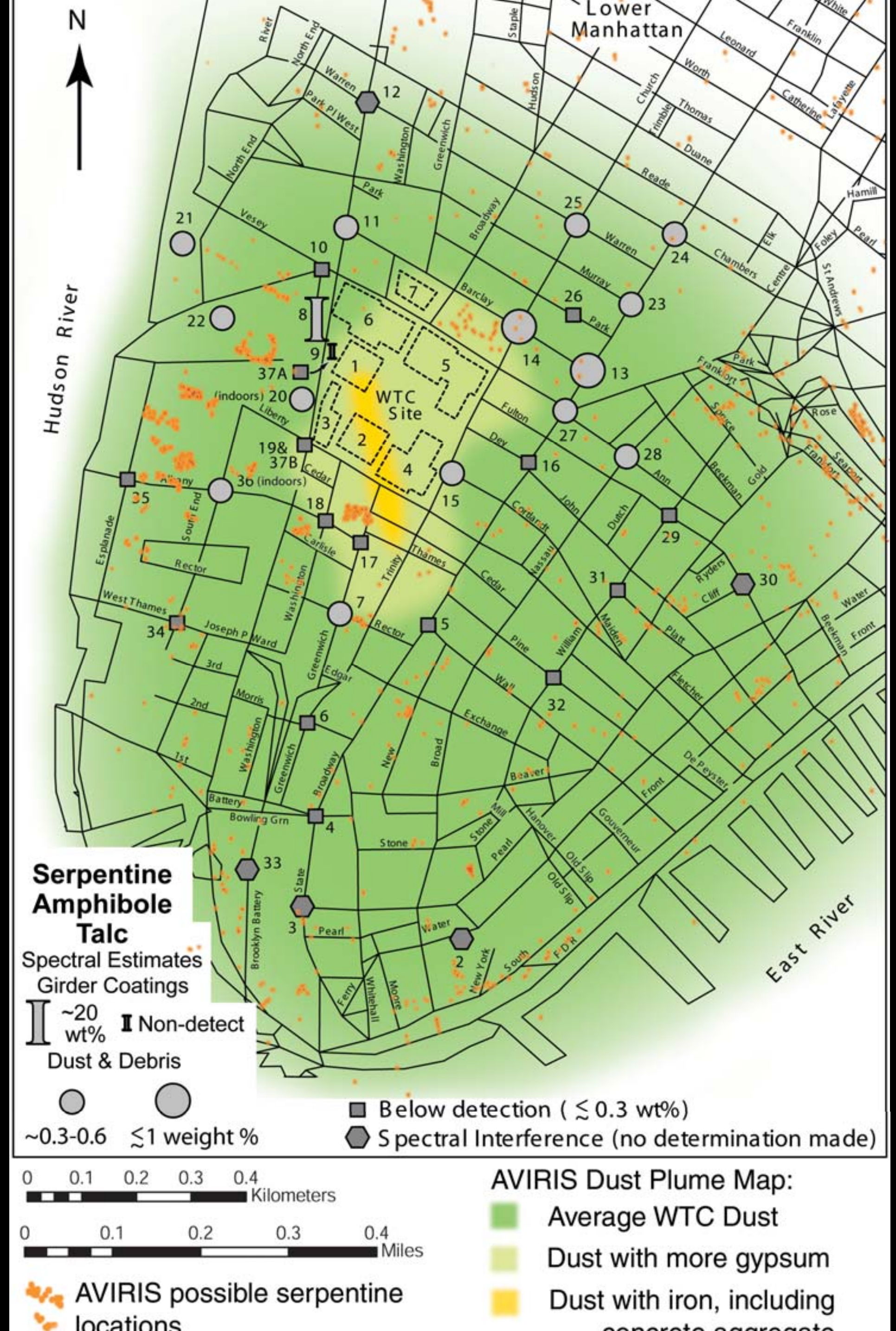
Synthesis of Results:
AVIRIS + Sample Analysis

Orange pixels indicate possible serpentines.
Clark et al., American Chemical Society, 2005.

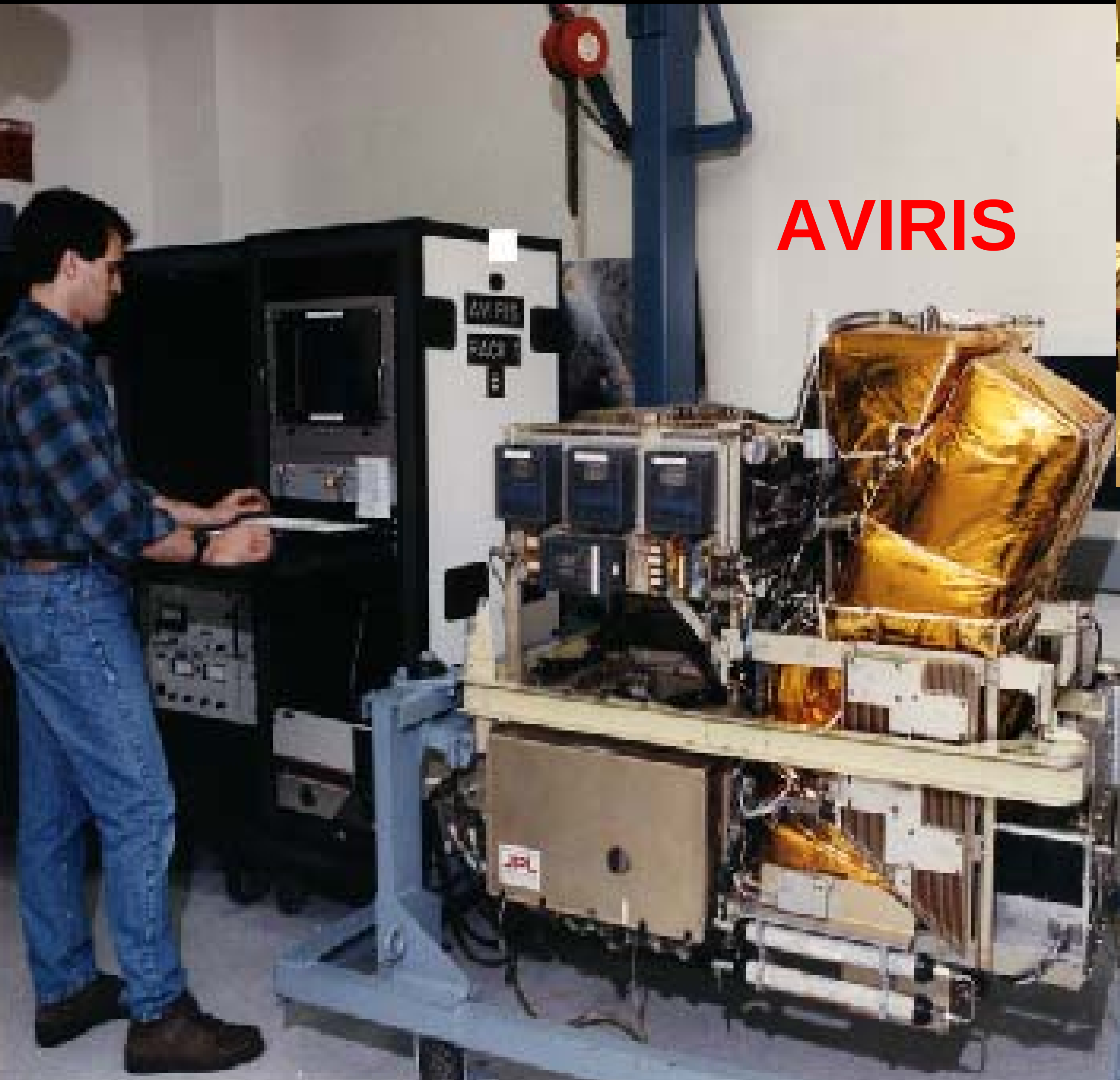
Green to yellow: WTC dust.

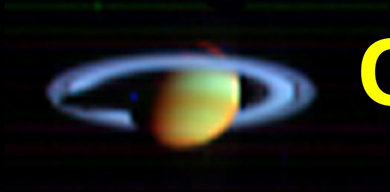


Spectroscopy was done on each WTC sample then each sample was chemically and physically analyzed (Swayze *et al.*, ACS, 2005).

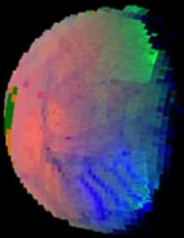


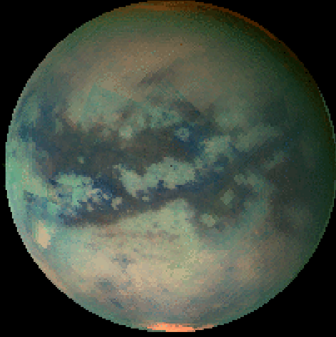
Spectrometers: evolution in size



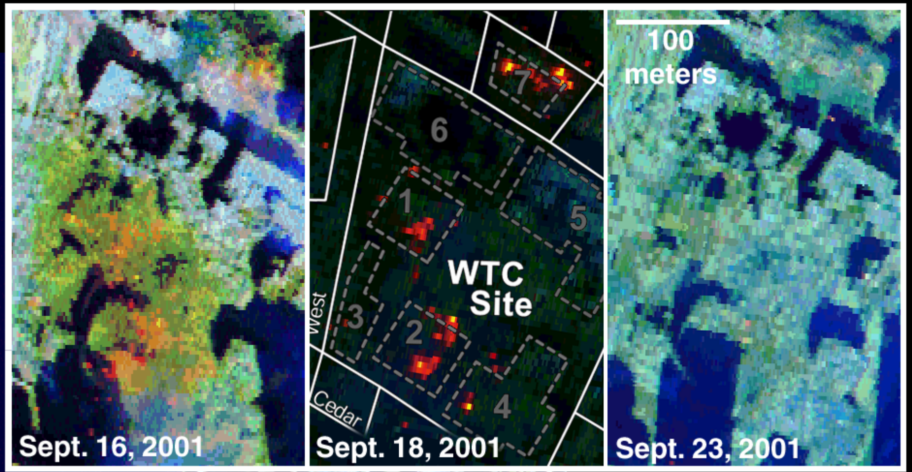


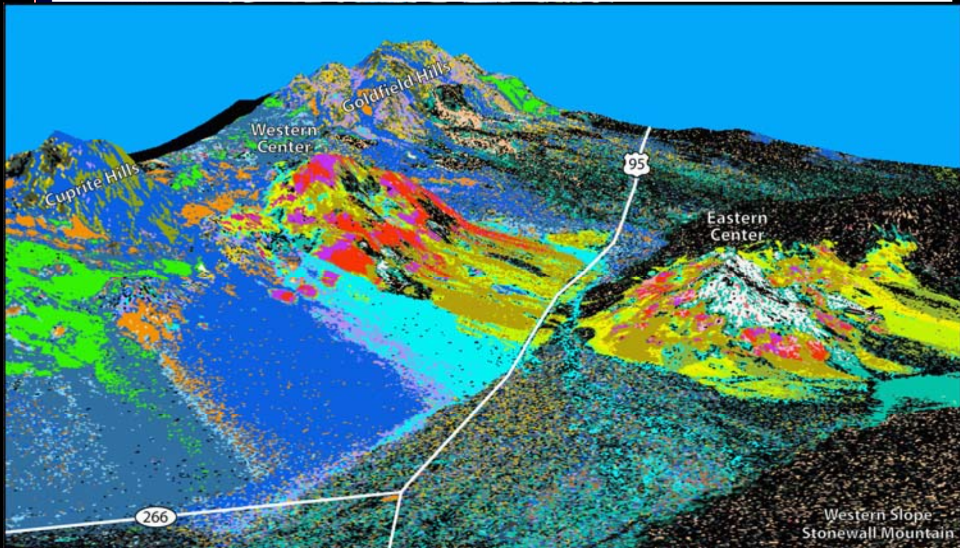
Conclusions





- Imaging Spectroscopy has matured in the last few years showing abilities to map materials in environmental and disaster situations. As well as geology and ecosystems.
- As reference reflectance spectral libraries become mature, more applications could be developed, including screening methods, real time monitoring, and post event assessment.
- Applications could include detection and mapping of minerals, organics, mineral fibers, biota, fires and their temperatures and many other materials.
- Operational imaging spectrometers are working throughout the Solar System





Imaging Spectroscopy: A powerful Tool

Thank You Alex!

A field spectrometer is used to measure the composition of a mud pit in Yellowstone National Park (it is kaolinite).