Potential for Regional Hyperspectral Imaging Surveys in the American Southwest

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U.S. Department of the Interior
U.S. Geological Survey

Presentation Outline

- What is hyperspectral imaging?
- Characteristics of hyperspectral data and derived information
- USGS Afghanistan project hyperspectral mapping
  - Acquisition
  - Data processing
  - Publications and map products
- Applications of hyperspectral imaging
  - Mineral resource exploration
  - Wildfire effects assessment
  - Monitoring land use changes
  - Vegetation health due to climate change
- Hypothetical survey of the American southwest
- Sources and links

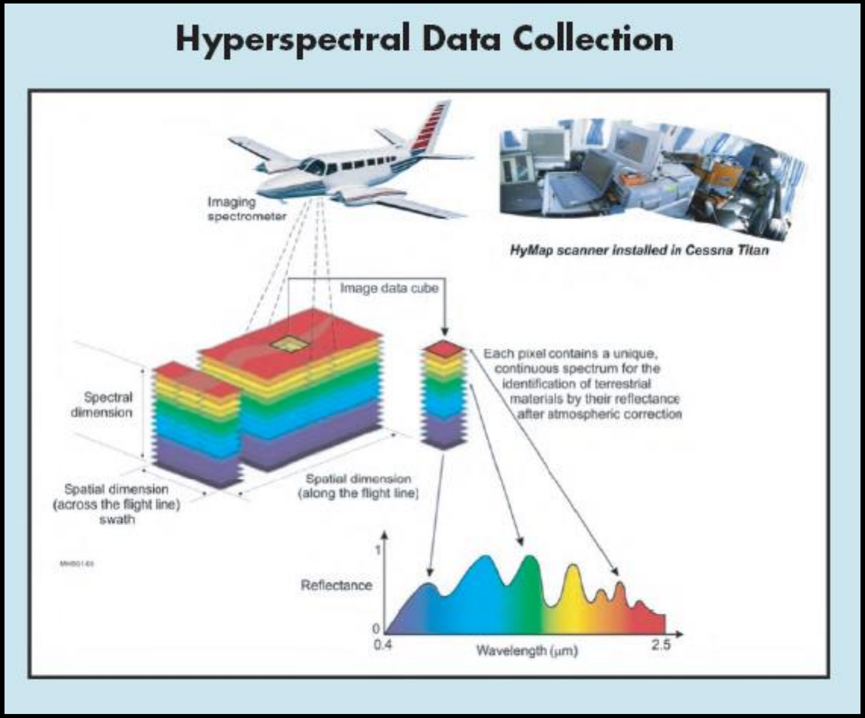
Airborne Hyperspectral Imaging, aka Imaging Spectroscopy

- Hyperspectral: Measures narrow spectral bands over a continuous spectral range, producing spectra for each pixel.
- Solar reflected spectrum (approx. 400-2500 nm)
  - Eye sensitive to approx. 390-700 nm
- Measure upwelling radiance spectrum arriving at the sensor for each pixel
- Compare against libraries of calibrated spectra
- Identify surface materials through molecular absorptions and scattering characteristics
  - Changes in electron state, and vibrations in chemical and molecular bonds

USGS

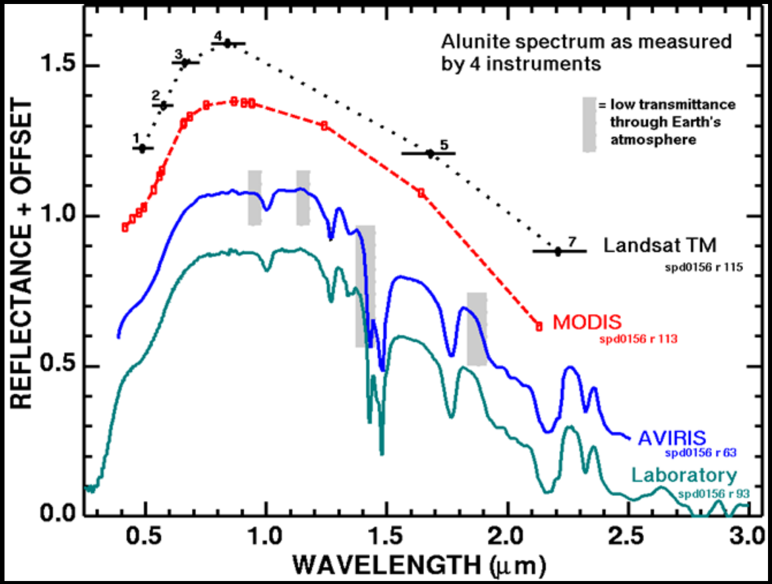
Imaging Spectroscopy Sensors

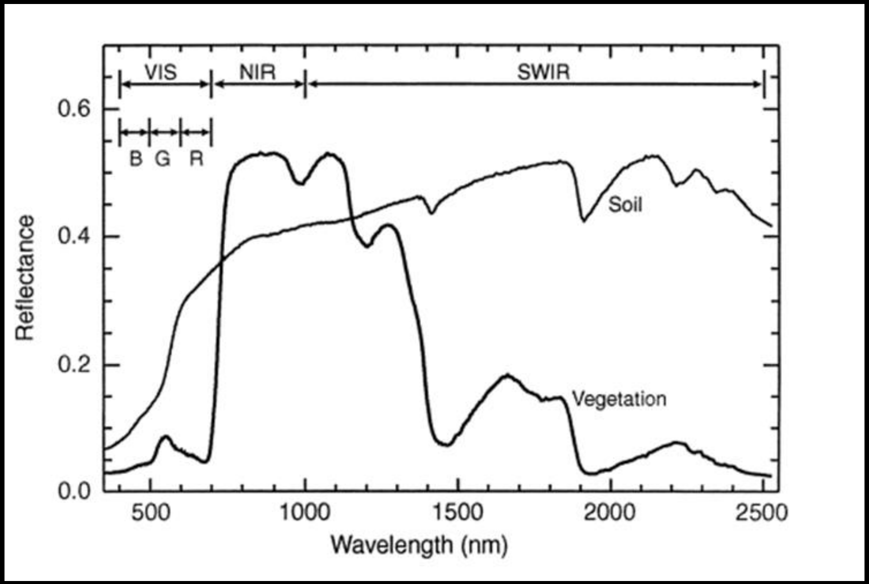
- **AVIRIS (NASA/JPL)**
  - **Airborne Visible/Infrared Imaging Spectrometer**
  - **224 bands, 677 pixel width**
    - **ER2 @ 20 km = 20 m res/11km**
    - **Twin Otter @ 4 km = 4m res/2 km**
- **HyMap® (Hyvista Corp.)**
- **SpecTIR®**
- **HyspIRI (future)**
  - **Hyperspectral Infrared Imager satellite**
  - **Integrates thermal IR (HyTES)**
  - **256 bands, 512 pixels, 60m pixel resolution**



Hoefen and others, 2012

High Information Content: Imaging Spectroscopy Data



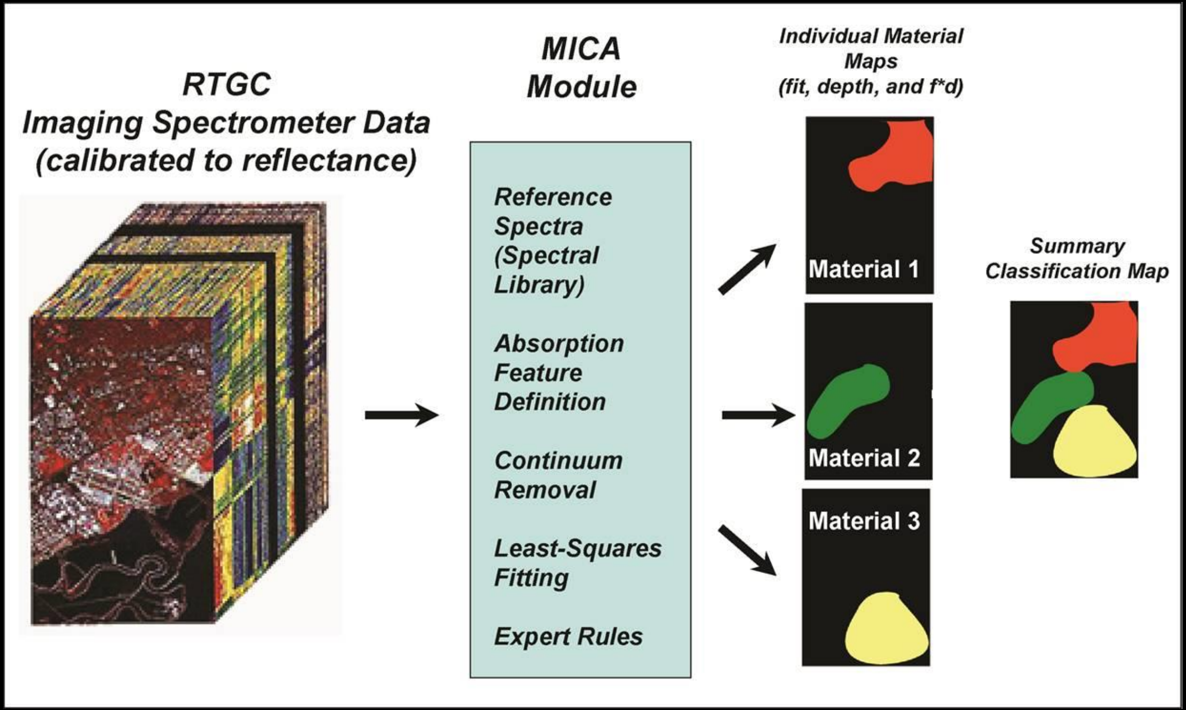


These spectra are used for direct identification of soils/minerals/vegetation and provide information on physical and chemical properties based on wavelength position and shape of absorption features

Hoefen and others, 2012

USGS

Mapping Surface Materials



The spectra of the unknown materials are compared with standard library materials as part of the data analysis. The USGS maintains and updates the premier geoscience spectral library. It contains the spectra of hundreds of well-characterized natural and anthropogenic materials. http://speclab.cr.usgs.gov/spectral.lib06/

Hoefen and others, 2012

USGS

USGS Afghanistan Projects

- Agro-Meteorology
- Airborne Geophysical Surveys
- Capacity and Institution Building
- Coal
- Earthquake Hazards
- *Geospatial Infrastructure Development*
- *Hyperspectral Data*
- *Minerals and Information Packages*
- Oil and Natural Gas
- Water

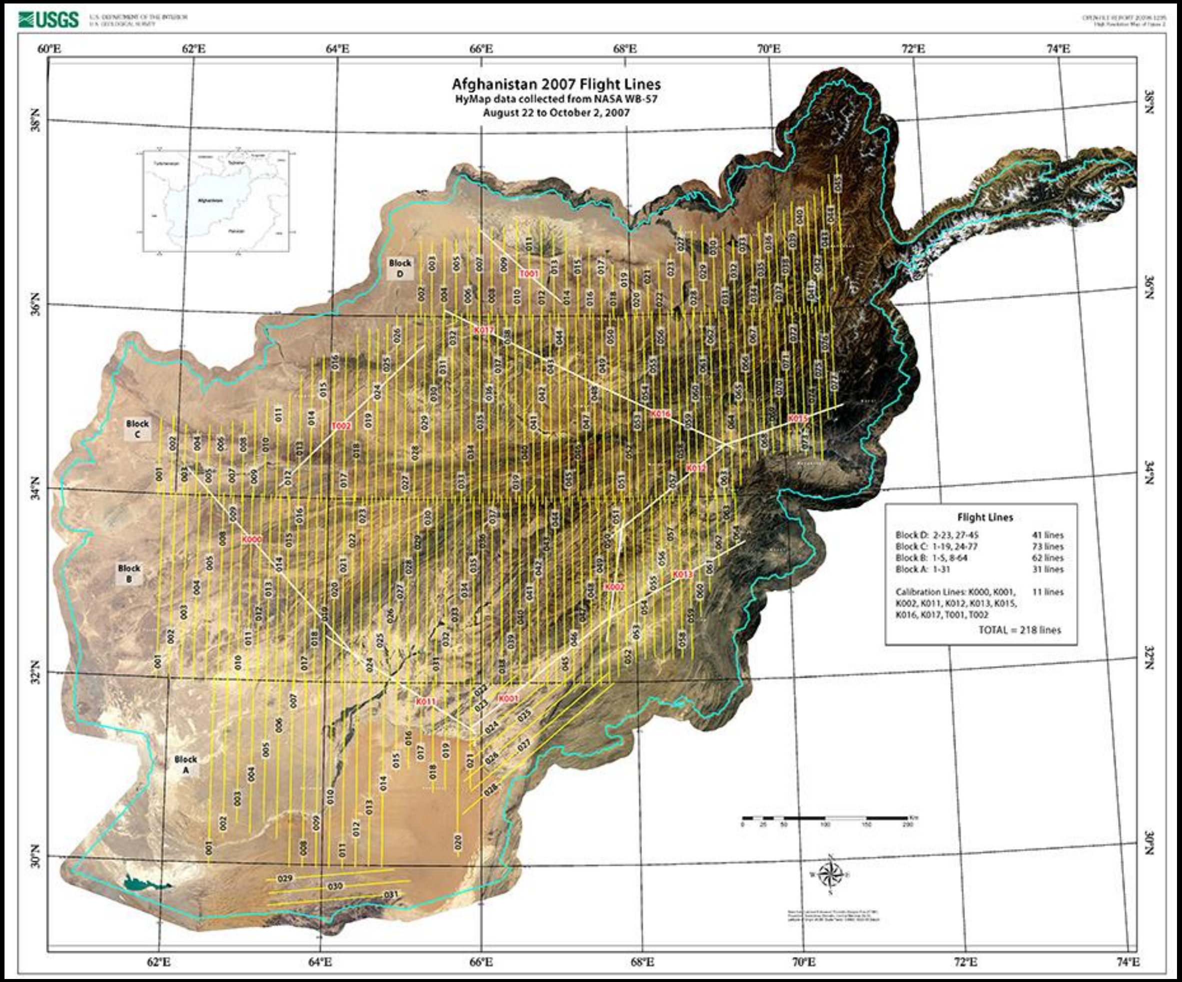
USGS

Hyperspectral Acquisition

- HyMap imaging spectrometer
- WB–57 high altitude NASA aircraft
- Constraints
  - Political border buffers (approximately 33% land area)
  - Aircraft altitude average 16.06 km (52,690 ft)
  - Liquid nitrogen in dewars limits flightline length
  - Airfield location, sensor problems, aircraft problems, weather, etc.
- August 22–October 2, 2007, 43 days, 28 flights
- 218 flightlines (207 data, 11 calibration), total 39,345 km length
- Total area of Afghanistan imaged approximately 438,012 km^2 of 652,834 km^2 (67%)

USGS

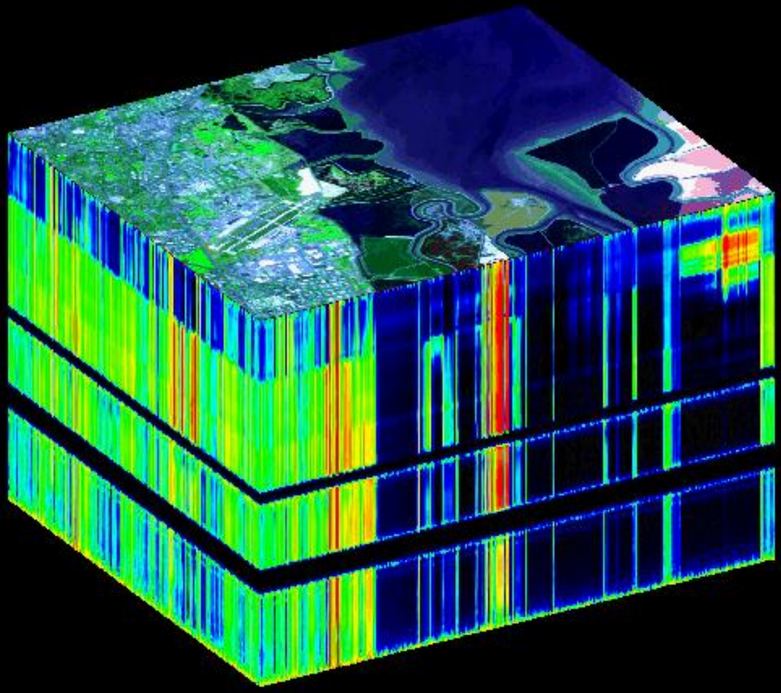
Afghanistan Flightlines



Kokaly and others, 2008

Data Management

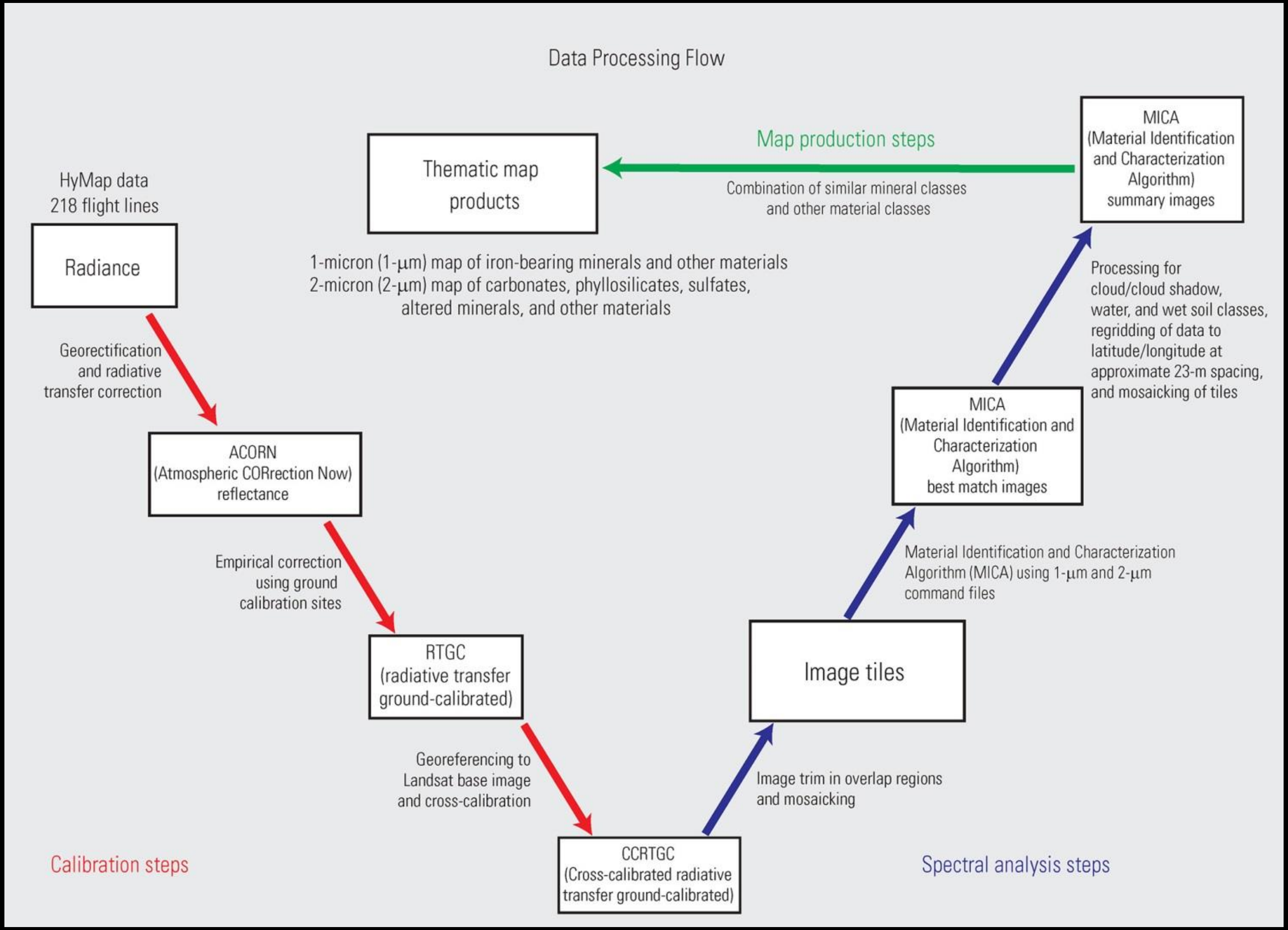
- Hypercubes
- MICA analysis
  - Material Identification and Classification Algorithm
- Rasters
- Geodatabases



NASA/JPL-Caltech

USGS

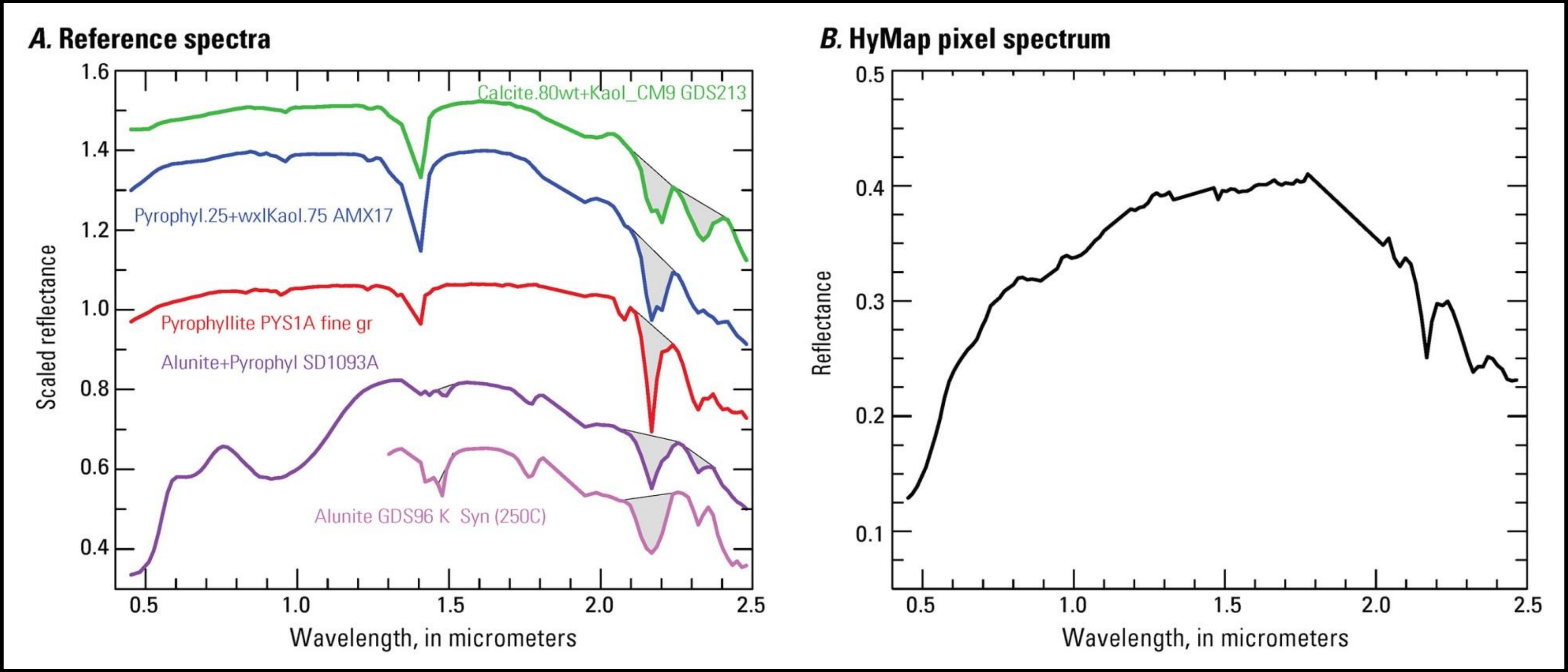
Data Processing Flow



Kokaly and others, 2013a

USGS

Spectra Comparison

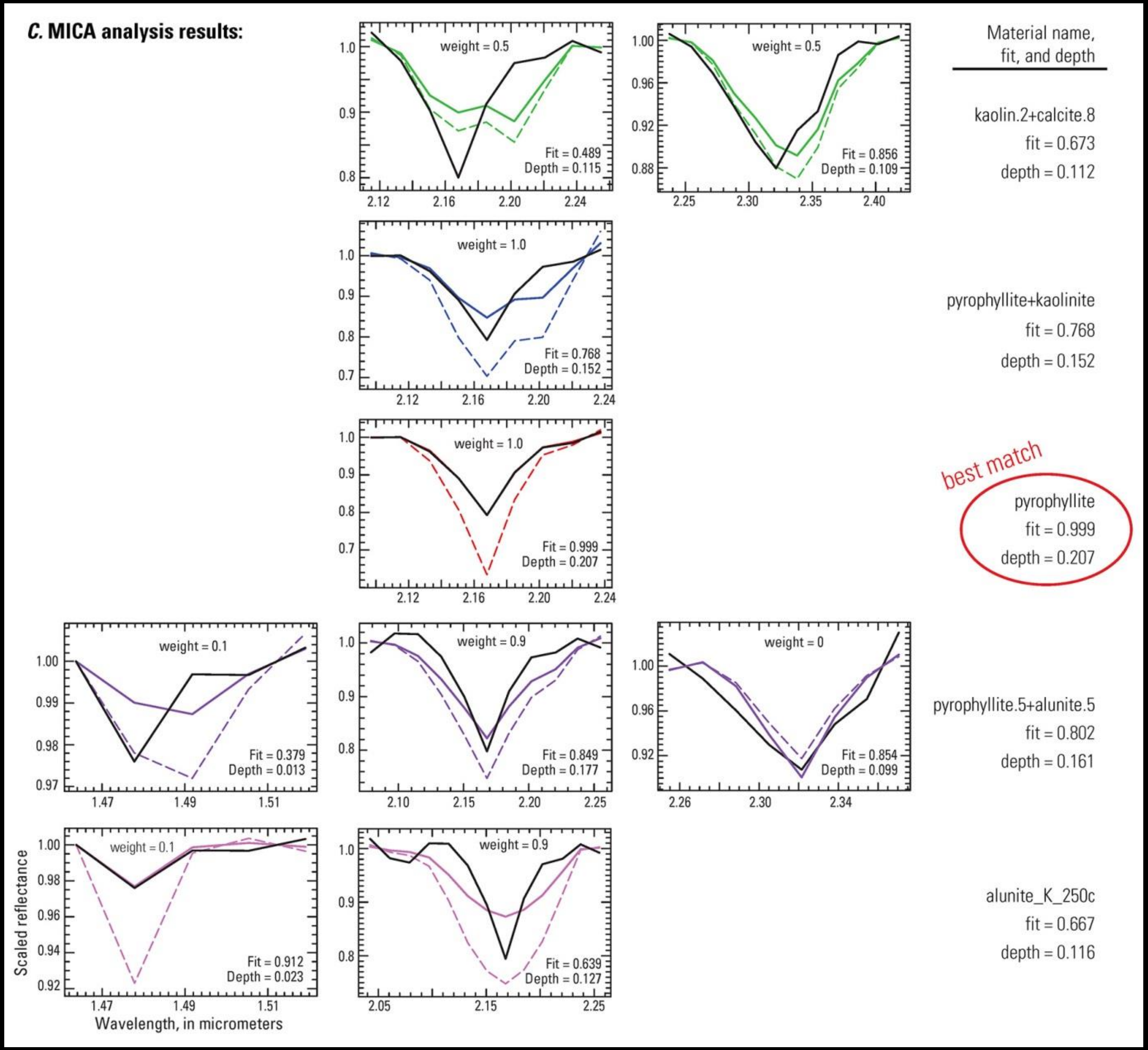


Kokaly and others, 2013a

USGS

MICA Analysis

Spectral feature comparison of HyMap pixel with reference spectra. All unlabeled axes are scaled reflectance for the y-axis and wavelength, in micrometers, for the x-axis.



Kokaly and others, 2013a

USGS

GIS Data Products

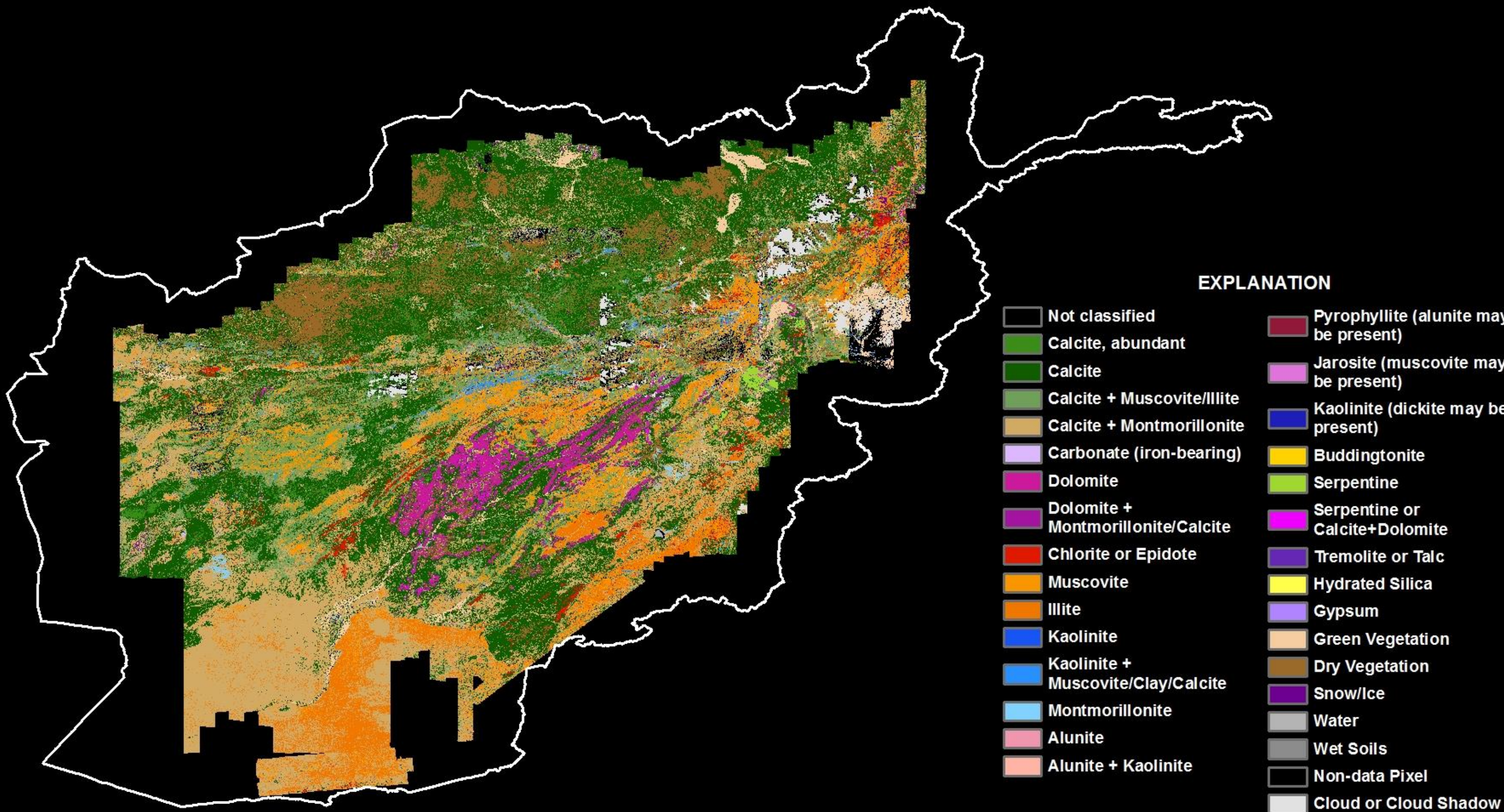
- Hyperspectral data
  - MICA summary/fit images
  - Thematic rasters
    - Iron-bearing minerals and other materials
      - Absorption features in the visible to near-infrared (1-μm)
    - Carbonates, phyllosilicates, sulfates, altered minerals, and other materials
      - Absorption features in the shortwave infrared (2-μm)
  - Data Series 787

- AOI information packages
  - 24 initial Areas of Interest
  - Geodatabases
  - Commodity reports
  - Open-file Report 2011–1204

- Resource anomalies
  - Open-file Report 2011–1229

USGS

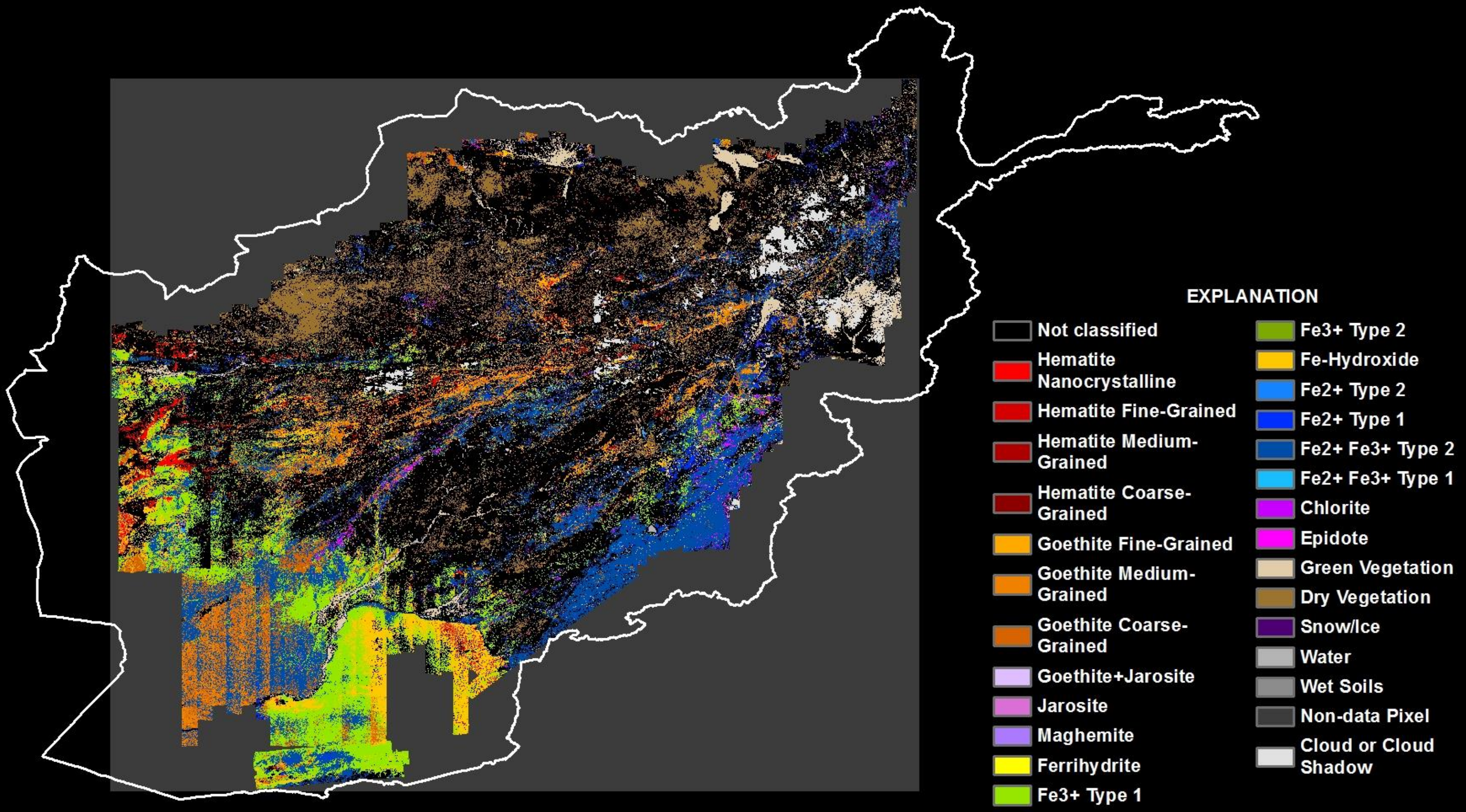
Afghanistan 2-µm Surface Materials Data: Carbonates, Phyllosilicates, Sulfates, Altered minerals



Kokaly and others, 2013a

USGS

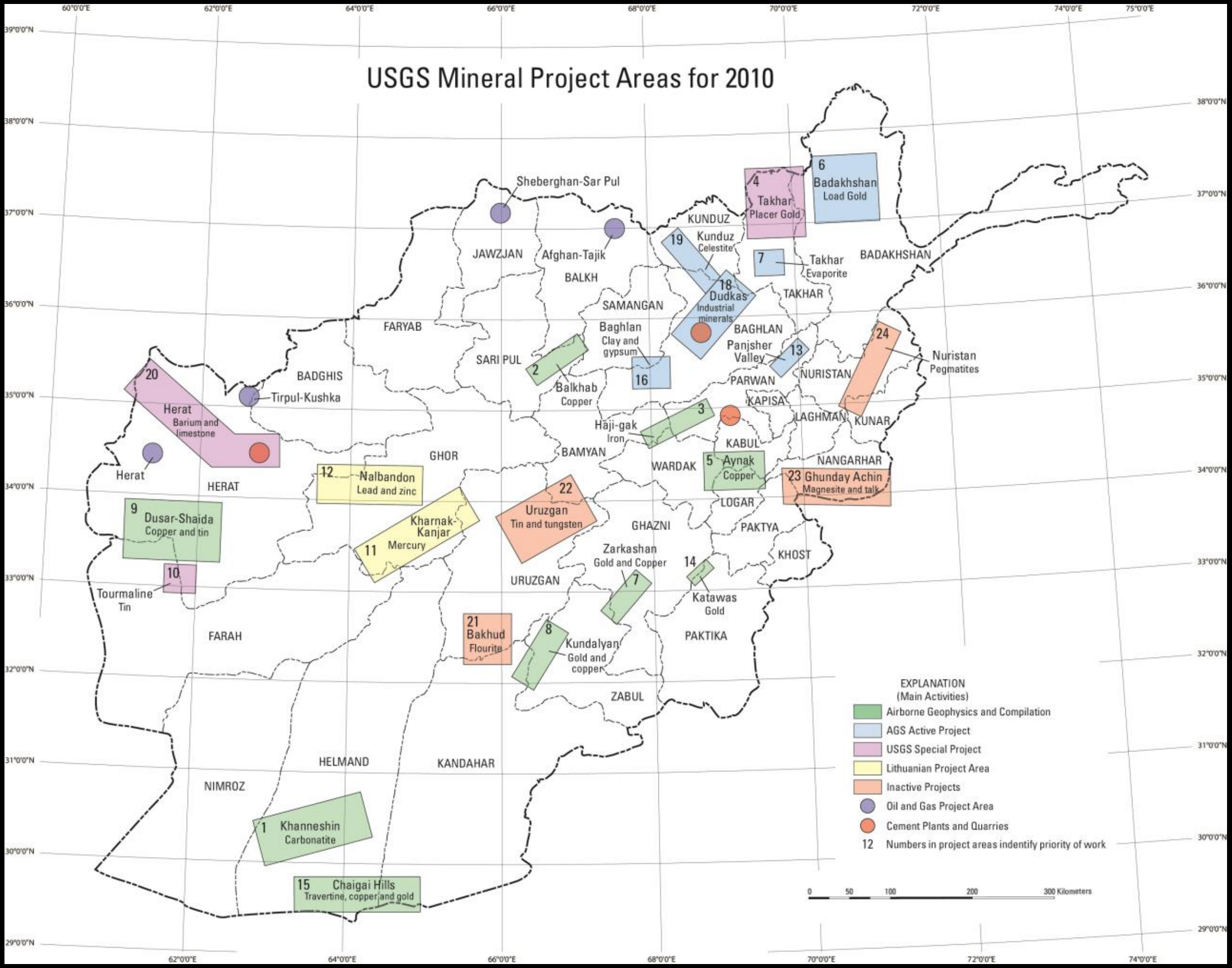
Afghanistan 1-µm Surface Materials Data: Iron-bearing Minerals



Kokaly and others, 2013a

USGS

Afghanistan Areas of Interest



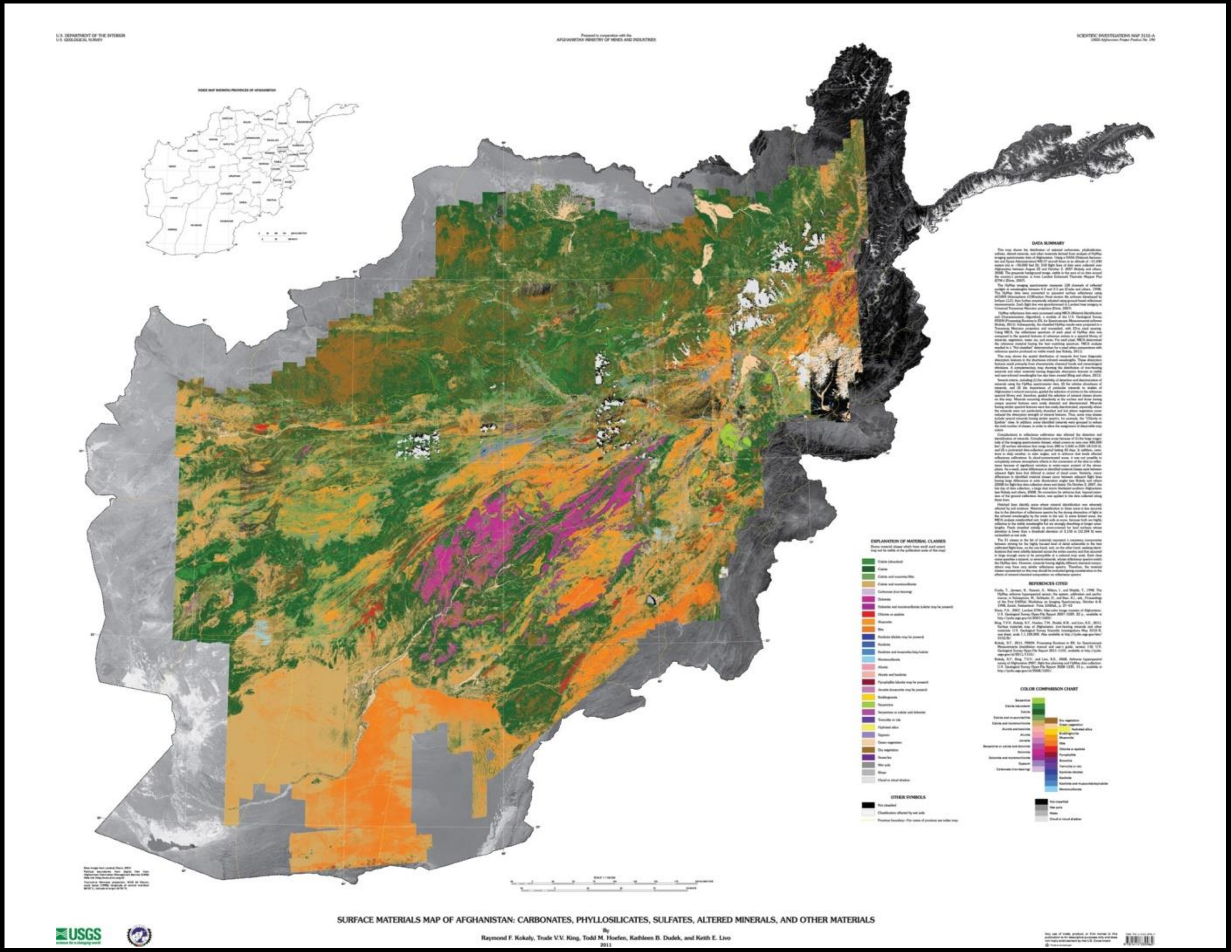
Hoefen and others, 2012

Thematic Mapping Products

- Countrywide surface materials wall maps
  - Iron-bearing minerals and other materials
    - Scientific Investigations Map 3152–A
  - Carbonates, phyllosilicates, sulfates, altered minerals, and other materials
    - Scientific Investigations Map 3152–B
- Hyperspectral quadrangle maps
  - 1-µm, 2-µm maps of each quadrangle
  - 30 quadrangles, 60 maps
    - Carbonates, Phyllosilicates, Sulfates, Altered Minerals, and Other Materials
      - Open-file Report 2013–1191–A through
      - Open-file Report 2013–1220–A
    - Iron-bearing Minerals and Other Materials
      - Open-file Report 2013–1191–B through
      - Open-file Report 2013–1220–B
- Summaries of important areas for mining investment and production opportunities
  - Open-File Report 2011–1229

USGS

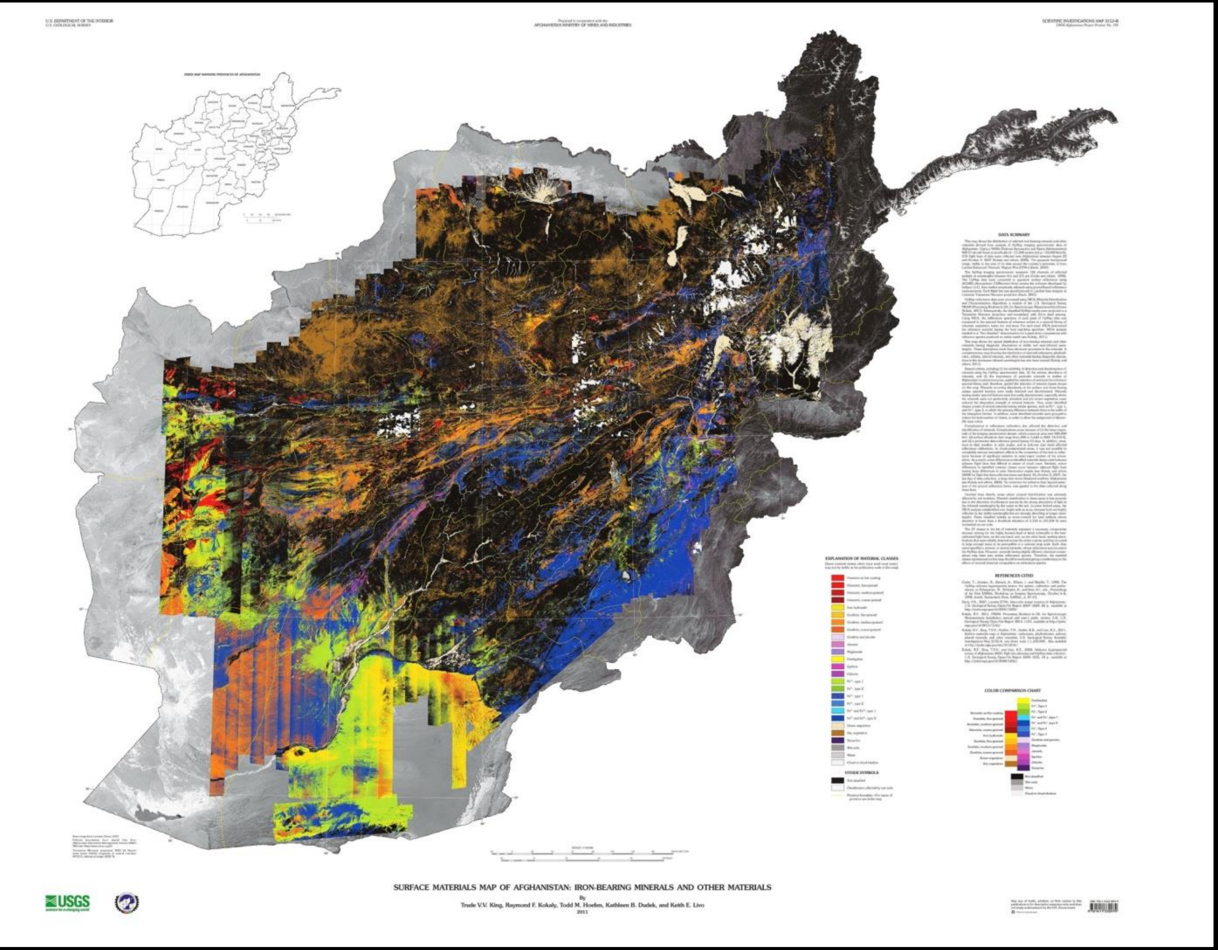
Afghanistan 2-µm Surface Materials Wall Map: Carbonates, Phyllosilicates, Sulfates, Altered Minerals



Kokaly and others, 2011

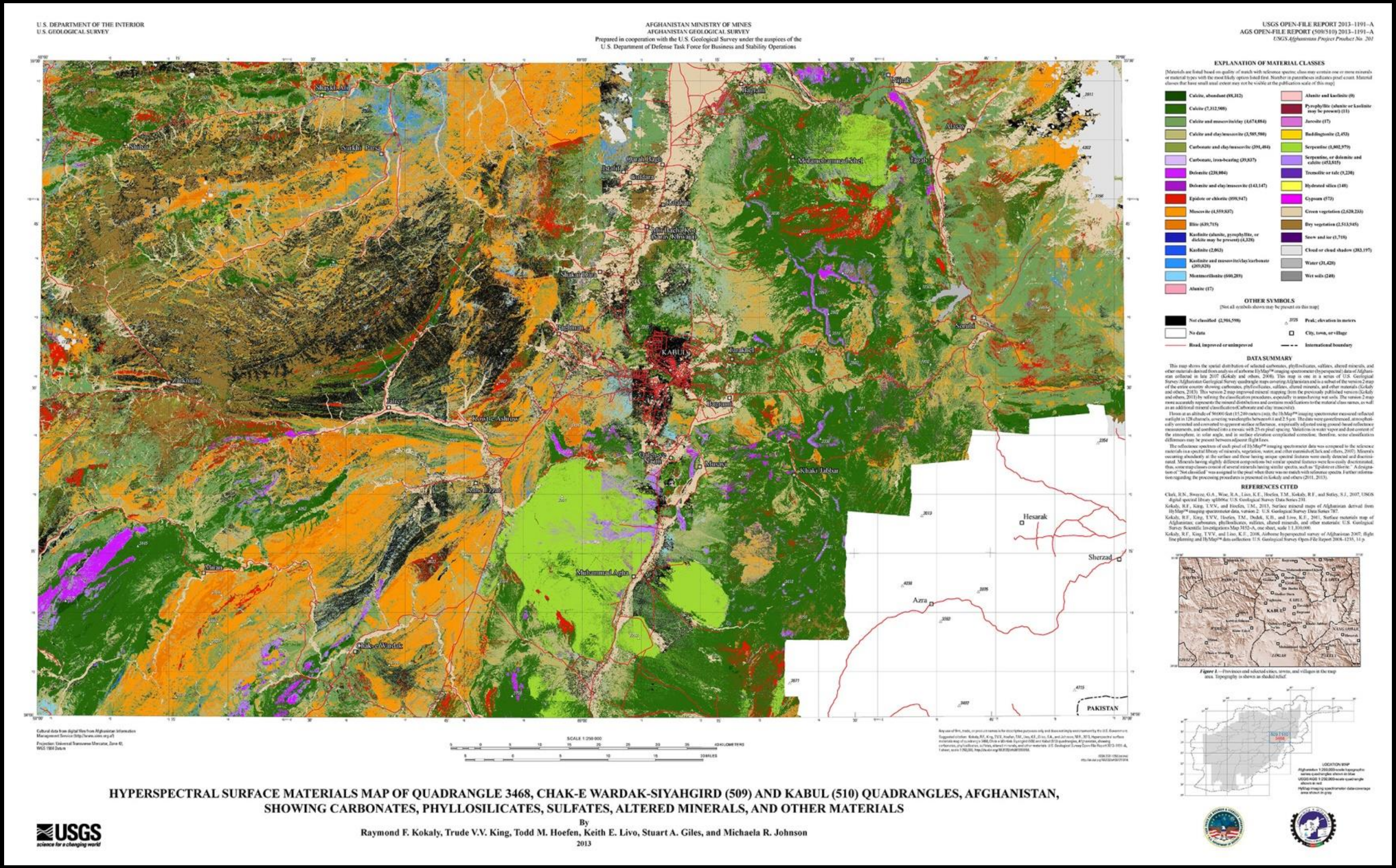
USGS

Afghanistan 1-μm Surface Materials Wall Map: Iron-bearing Minerals



King and others, 2011b

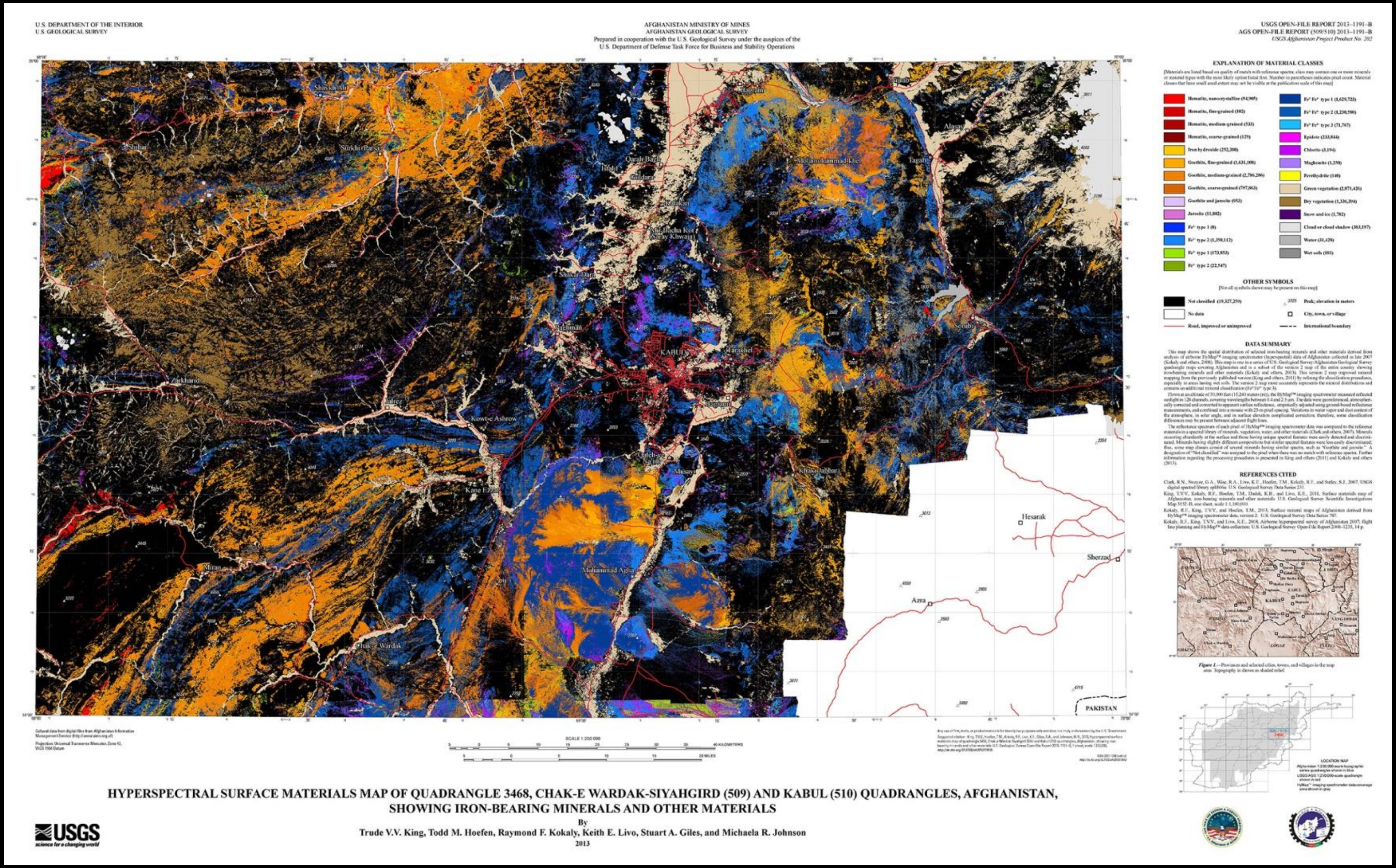
Hyperspectral Quadrangles: Carbonates, Phyllosilicates, Sulfates, Altered Minerals



Kokaly and others, 2013b

USGS

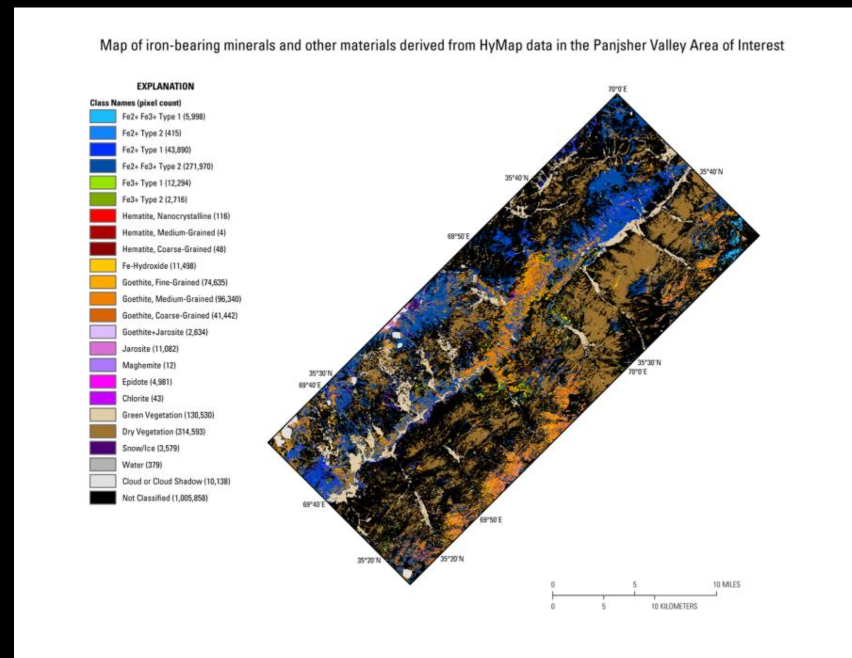
Hyperspectral Quadrangles: Iron-bearing minerals



King and others, 2013

USGS

Summaries of Important Areas



Peters and others, 2011

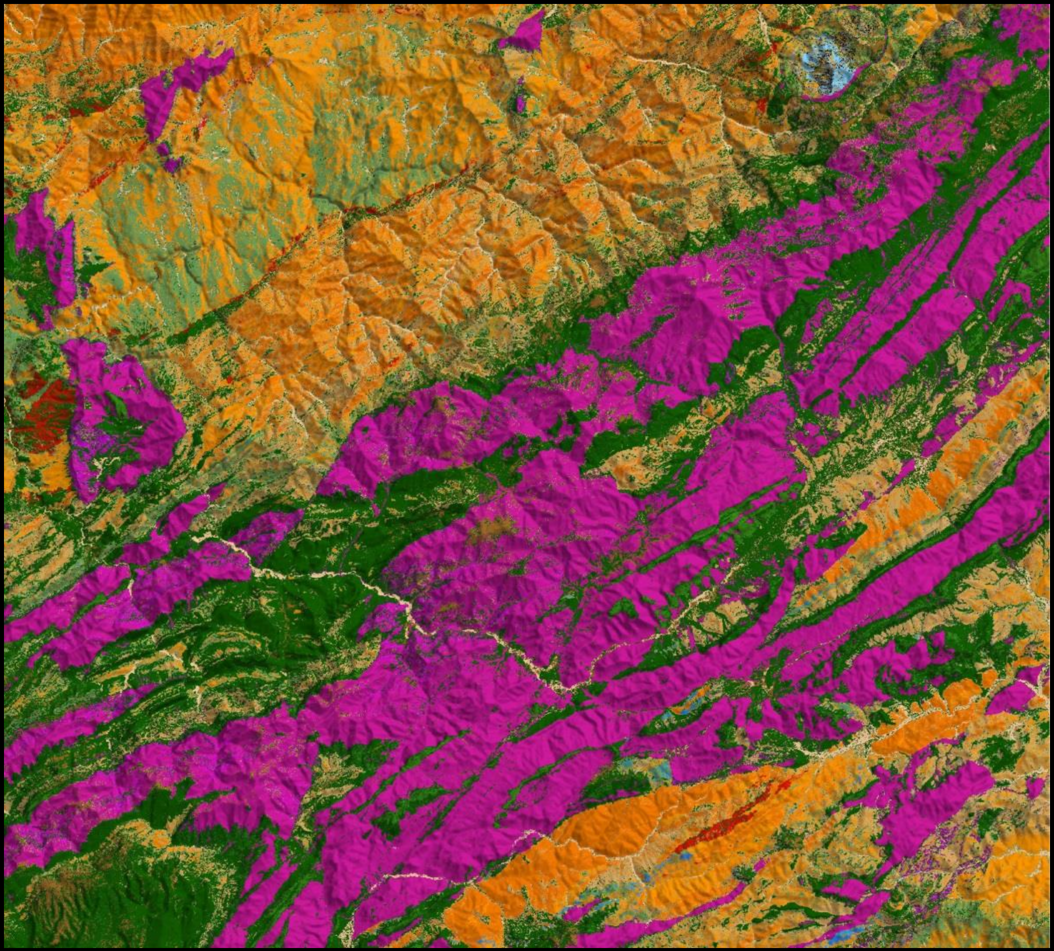
USGS

Hyperspectral Web Map

Unpublished data

USGS

Uruzgan–Ghazni Carbonates



Unpublished data

Science

Making every second count, Robert Tucker liberates a chunk of rare earth minerals from the Khanneshin volcano complex.

Mother of all lodes

The United States is putting scientific boots on the ground in Afghanistan to assess its mineral riches

By **Richard Stone**

In February 2011, Robert Tucker went prospecting in southern Afghanistan's Helmand province, a region dominated by Taliban insurgents. It was not a leisurely field trip. U.S. Marines first arrived at the site to secure a perimeter, then a team of U.S. and Afghan scientists including Tucker, a research geologist with the U.S. Geological Survey (USGS) in Reston, Virginia, swooped in on two Black Hawk helicopters. Weighed down by flak jackets in the searing heat, the group had just a few hours to scale a "very, very steep" volcano, Tucker says, collect samples, and hustle back to the choppers. One of his colleagues collapsed from heat prostration.

"I've never experienced anything like it," says Tucker, who has been clambering over rugged topography ever since his grad school days in the early 1980s, when he studied rock formations along Norway's coastal fjords. But the risky, arduous work in Afghanistan paid off. Tucker's team confirmed that Helmand's Khanneshin carbonatite deposit, last surveyed in the early 1970s by Soviet geologists, is as rich as they suspected. The deposit, chock-full of rare earth elements highly sought components of lasers and magnets and niobium, used to temper steel and in superconducting alloys, is now valued at $89 billion.

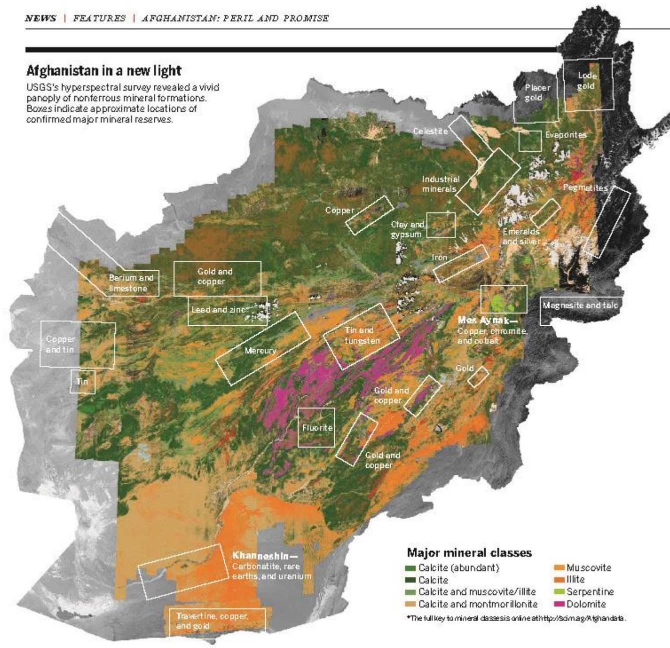
Khanneshin is only a thimbleful of Afghanistan's mineral wealth. Based in part on USGS-led aerial surveys, the U.S. Department of Defense's (DOD's) Task Force for Business and Stability Operations (TFBSO), charged with rebuilding Afghanistan, in 2010 valued the country's mineral resources everything from gold and

PHOTO: TREBO PHOTO/GETTY IMAGES

Published by AAAS

Afghanistan in a new light

USGS's hyperspectral survey revealed a vivid panoply of nonferrous mineral formations. Boxes indicate approximate locations of confirmed major mineral reserves.



*The full key to mineral classes is online at http://scim.ag/Afghandata.

copper to lithium and petroleum at $908 billion. (The Afghan government's preferred figure is $3 trillion.) That bounty is a product of a tortured tectonic history: Afghanistan is an amalgam of at least four pieces of crust squashed together by the collision of the Indian subcontient with Asia. "This is a very, very mineral-rich country," says Jack Medlin, a USGS geologist who leads the agency's work in Afghanistan. Over the past 4 years, USGS and TFBSO have been putting scientific boots on the ground to acquire more data.

The goal, says James Devine, senior adviser for science applications at USGS, is to show mining companies "not only that the minerals are there, but where they are, how much is there, and what you can do about it." As *Science* went to press, the final scoping mission was about to get under way. A team will drill into a dry lakebed about 100 kilometers south of Kabul to sample a potential reserve of lithium, an element used in ceramics and batteries.

As the flood of foreign aid that has buoyed Afghanistan's economy for more than a decade recedes, the country's prosperity may well depend on its prodigious mineral resources. "The conversation has changed from agriculture and opium to minerals and sophisticated development," Devine says. Already, the Afghan government has awarded contracts to a Chinese company to exploit the Mes Aynak copper deposit and to an Indian consortium to tap a massive iron ore lode. A major impediment to developing these and other reserves was removed last month, when Afghanistan's parliament passed the country's first mining law. "Now we have the rules of the game," says Said Mirzad, co-coordinator of USGS's Afghanistan program.

But Afghanistan faces huge challenges in shifting to a minerals-based economy. "The

MAP: ADAPTED FROM USGS

Published by AAAS

Stone, 2014

USGS

Applications of Hyperspectral Imaging

- Mineral resource exploration
- Wildfire effects assessment
- Monitoring land-use changes
- Monitoring climate changes on plant health
- Mapping invasive plant species
- Detecting and measuring deforestation
- Disaster response
- Pollution monitoring and enforcement
- National security

USGS

Wildfire Effects Assessment

Picture of Station Fire taken mid-morning (mid-September) by the Multi-angle Imaging SpectroRadiometer (MISR) instrument on NASA's Terra satellite

Hoefen and others, 2012

USGS

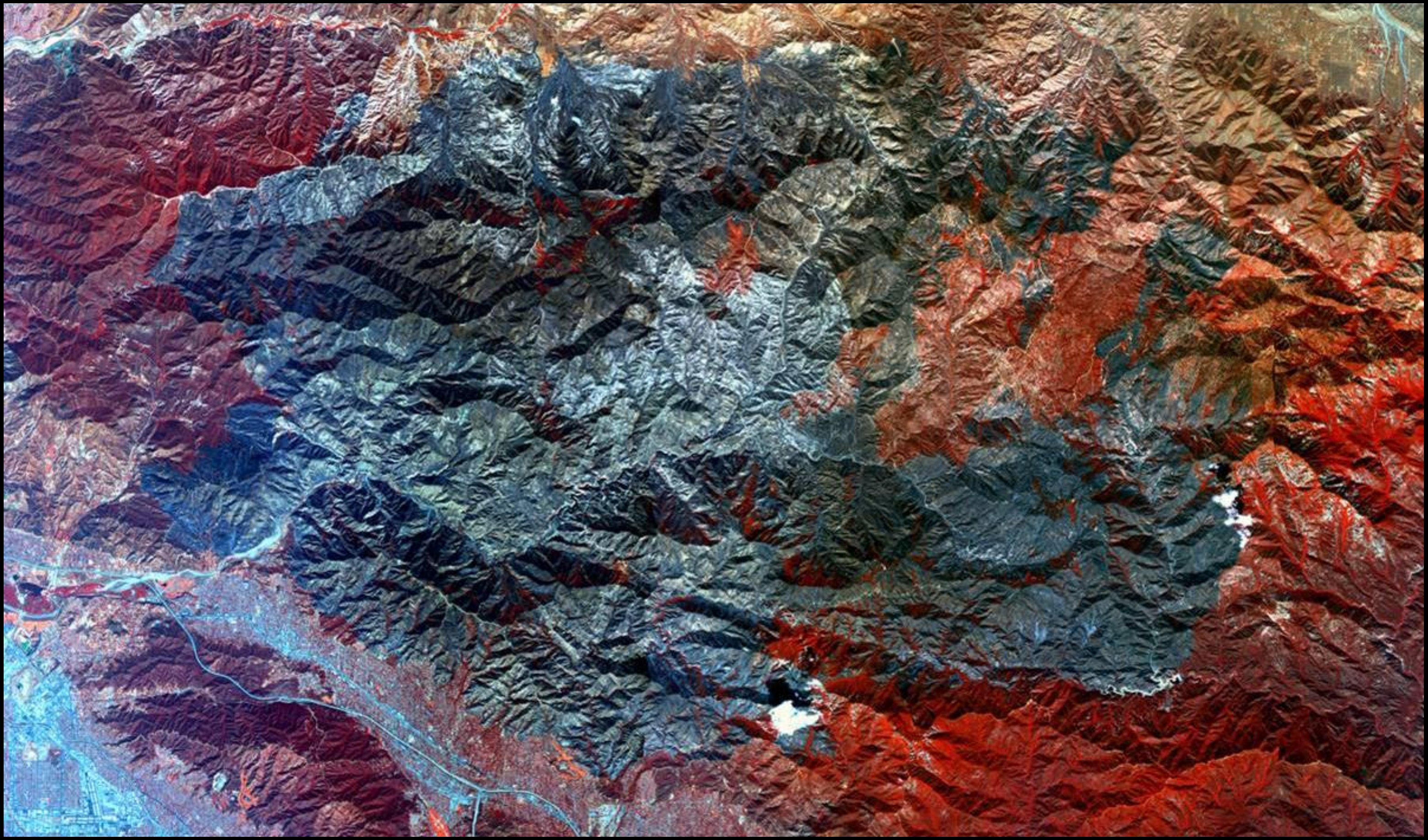
Station Fire, Los Angeles, CA

- **August 26 – October 16, 2009**
- **647 km^2 burned**
- **209 structures destroyed**
- **Fire was located just outside of Los Angeles**
- **After one month of firefighting costs were over $93 million**

Hoefen and others, 2012

USGS

The Station Fire Burn Perimeter: AVIRIS Data – October 6, 2009

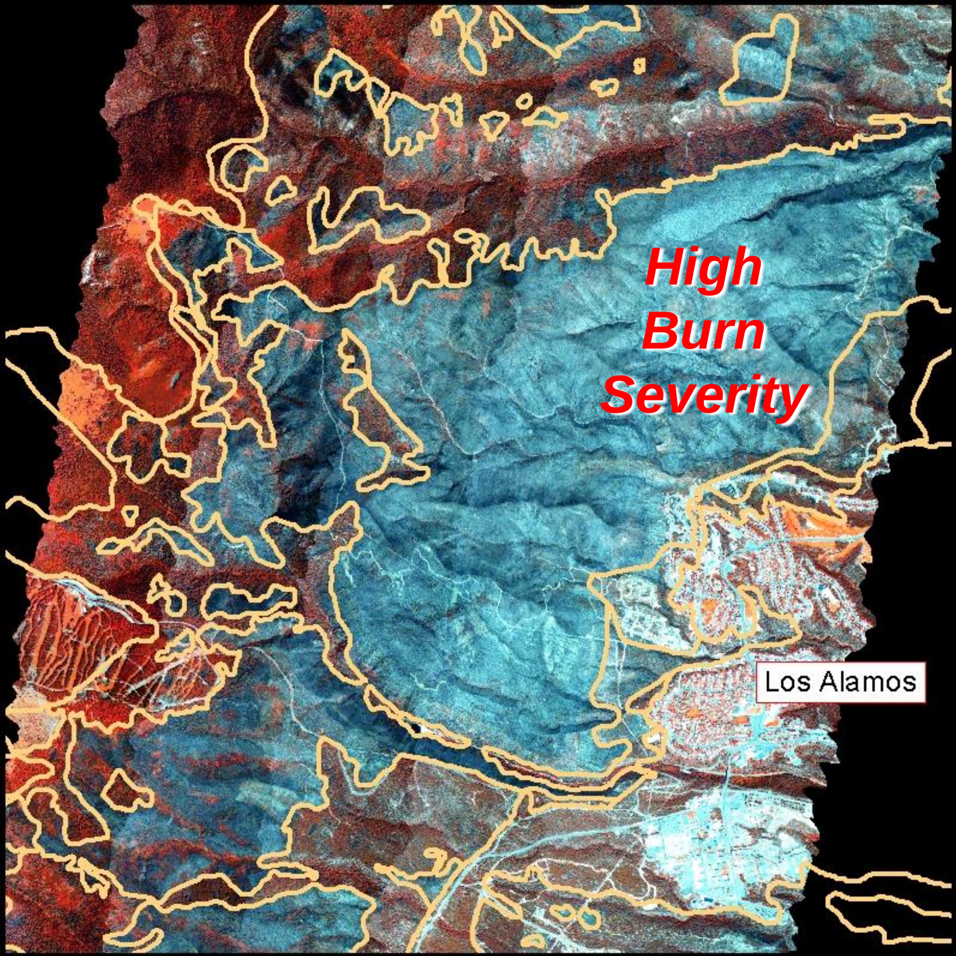


Hoefen and others, 2012

USGS

Cerro Grande Fire, Los Alamos, NM

- Prescribed fire started May 4, 2000
- Declared a wildland fire on May 5
- >45,000 acres burned
- AVIRIS data collected September 2-4, 2000 at high spatial resolution (3m pixel size)

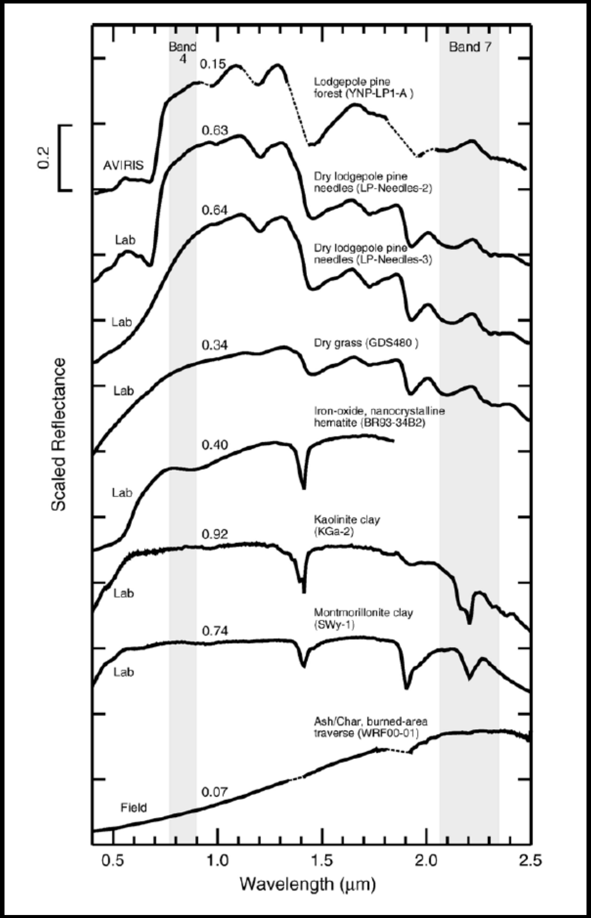


Kokaly and others, 2007

USGS

Spectra Added to the Spectral Library for Mapping Surface Materials

- Lodgepole Pine Forest
- Dry Lodgepole Pine Needles
- Dry Lodgepole Pine Needles #2
- Dry Grass
- Iron-Oxide nano-crystaline Hematite
- Kaolinite Clay
- Montmorillonite Clay
- Ash/Char Abundant

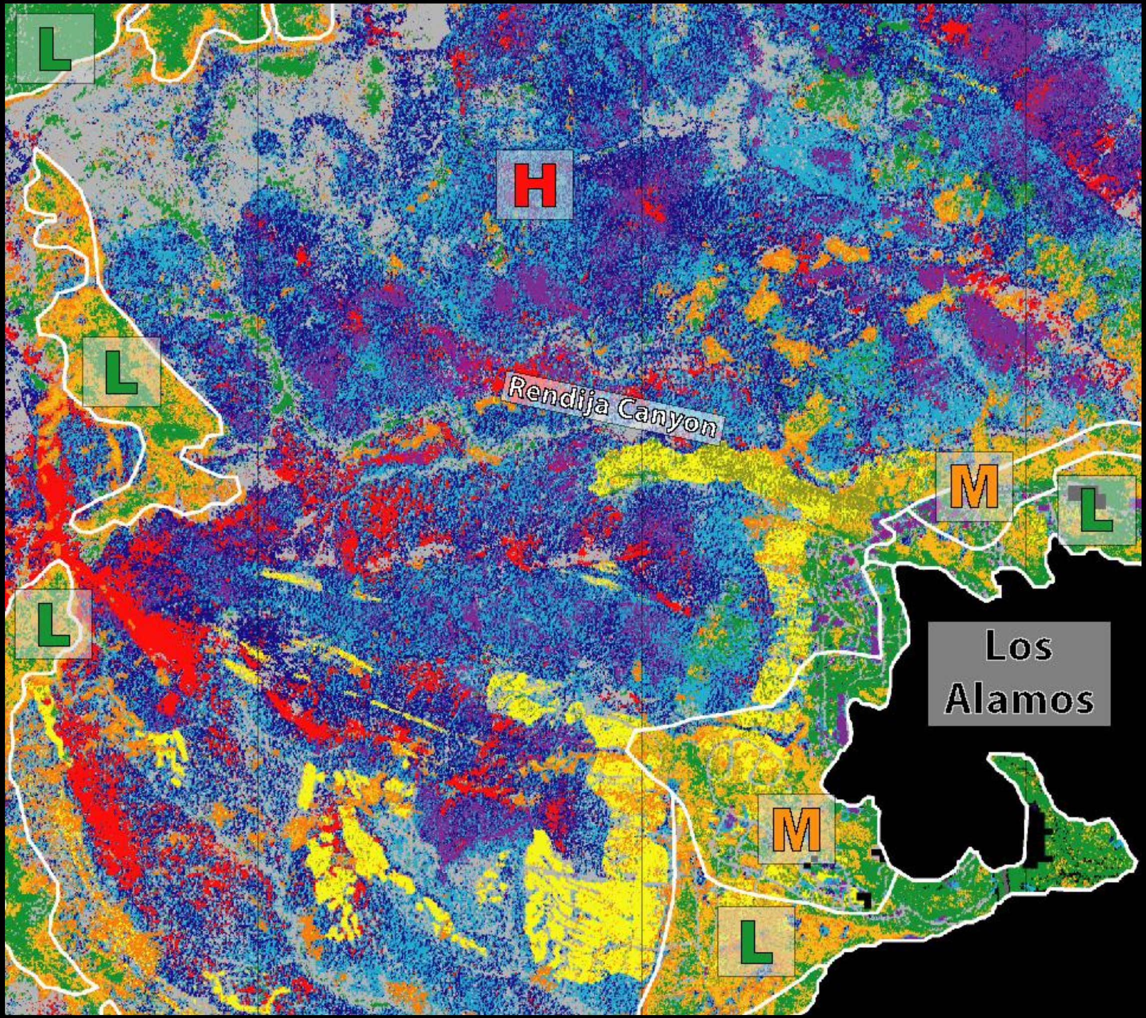


Kokaly and others, 2007

USGS

Post-fire Surface Cover

- Ash/Charcoal
- Mineral/Ash
- Mineral-1μm
- Mineral-2μm
- Dry Conifer
- Dry & Green Conifer
- Straw matting
- Straw matting & Green grass
- Green Vegetation



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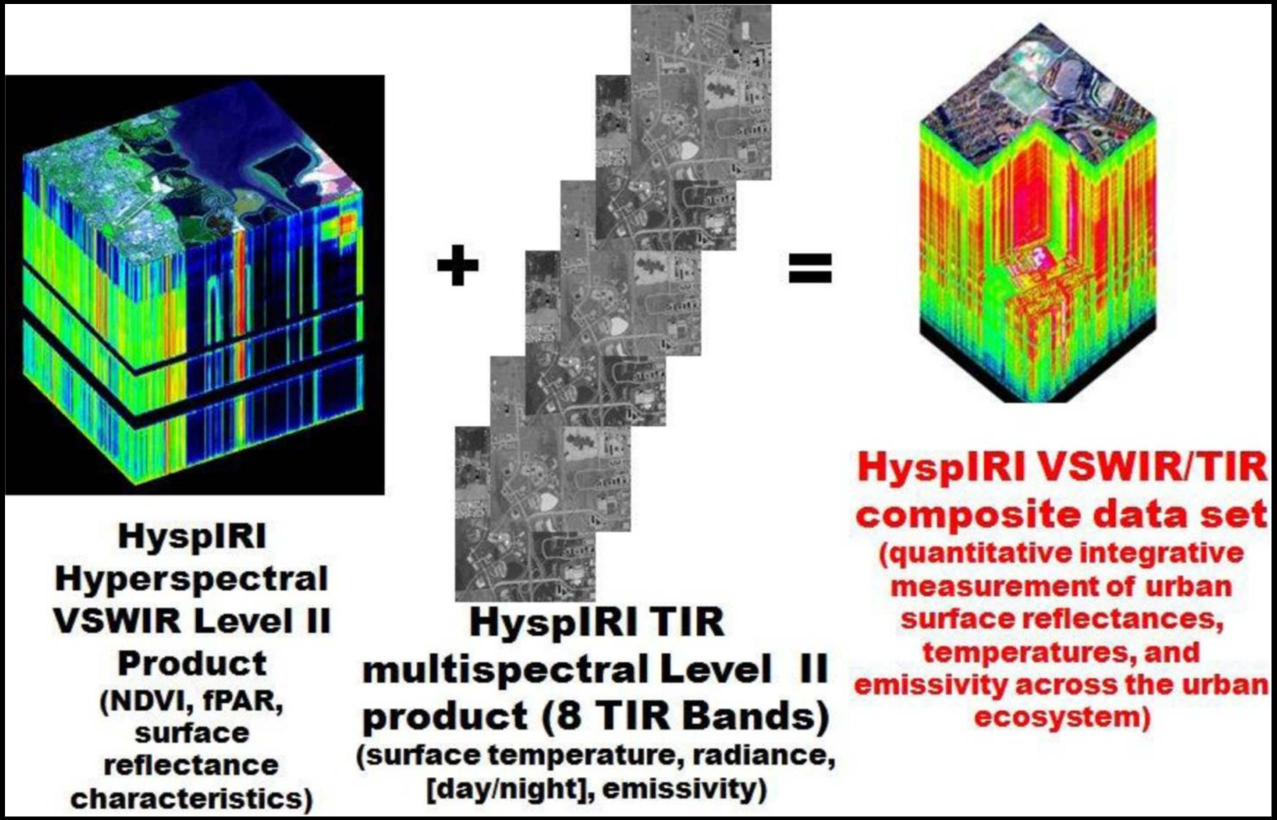
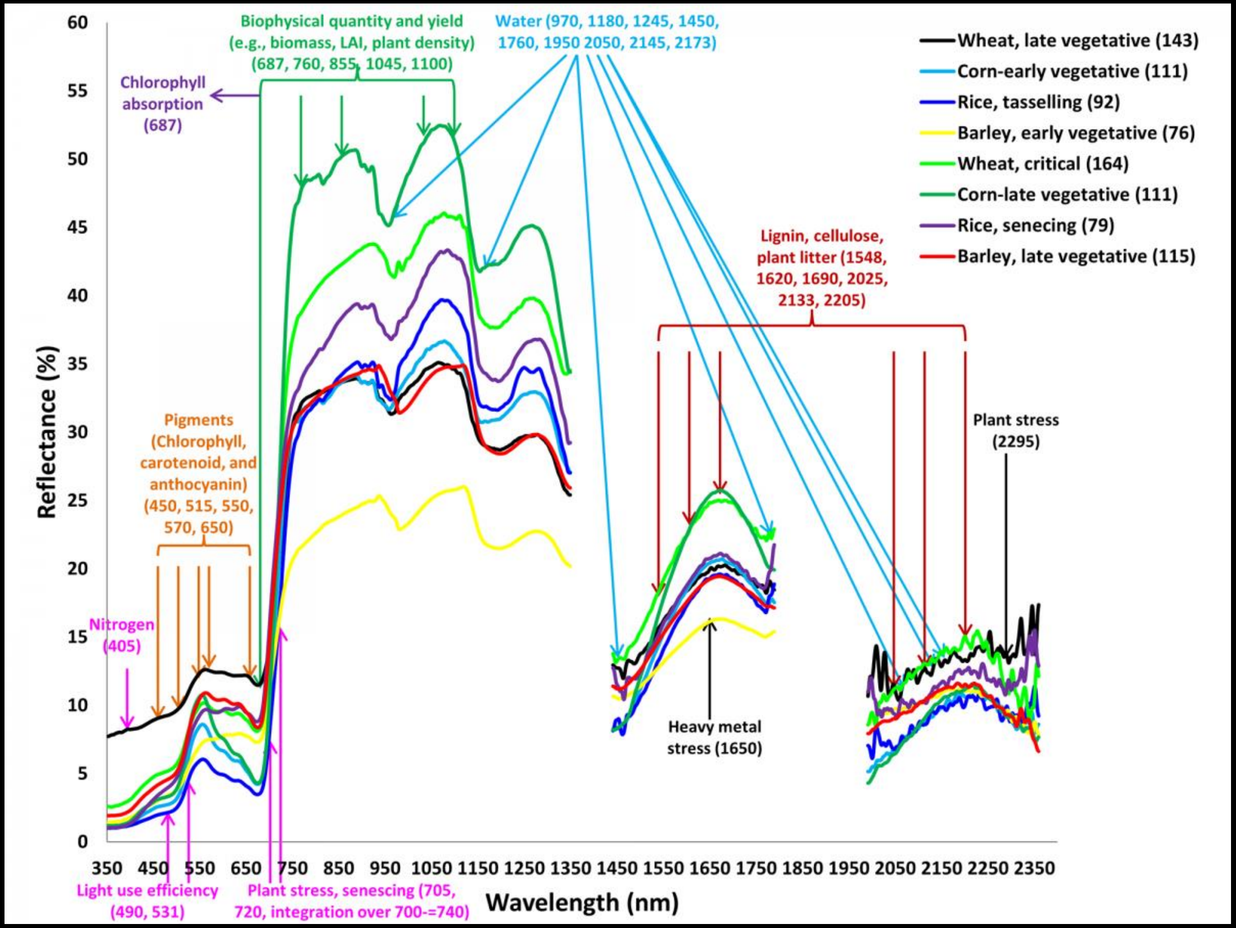
Kokaly and others, 2007

Monitoring Land Use Changes



Wentz and others, 2014

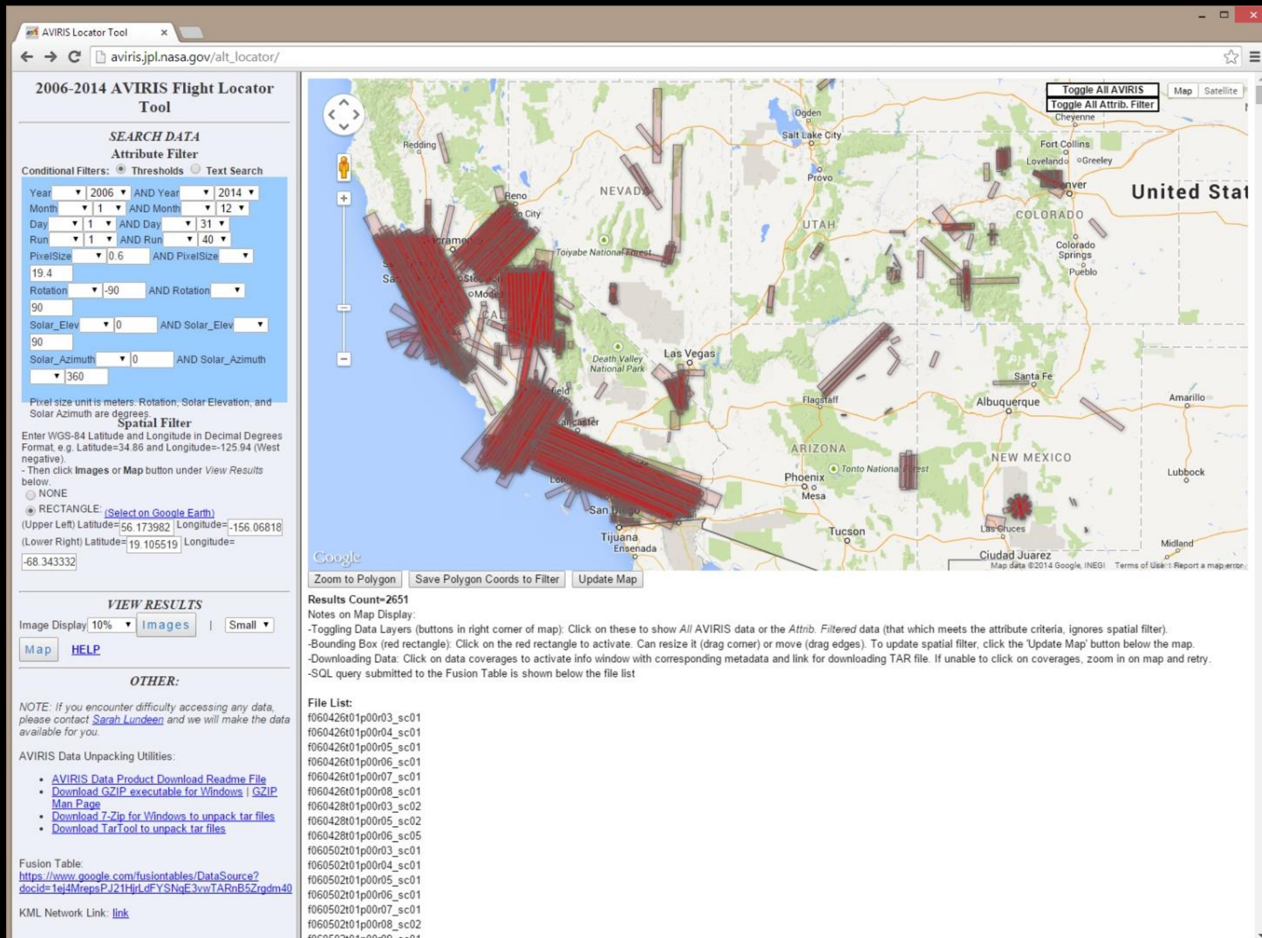
Monitoring Vegetation Health



Thenkabail and others, 2011

USGS

Hyperspectral Coverage in the American Southwest

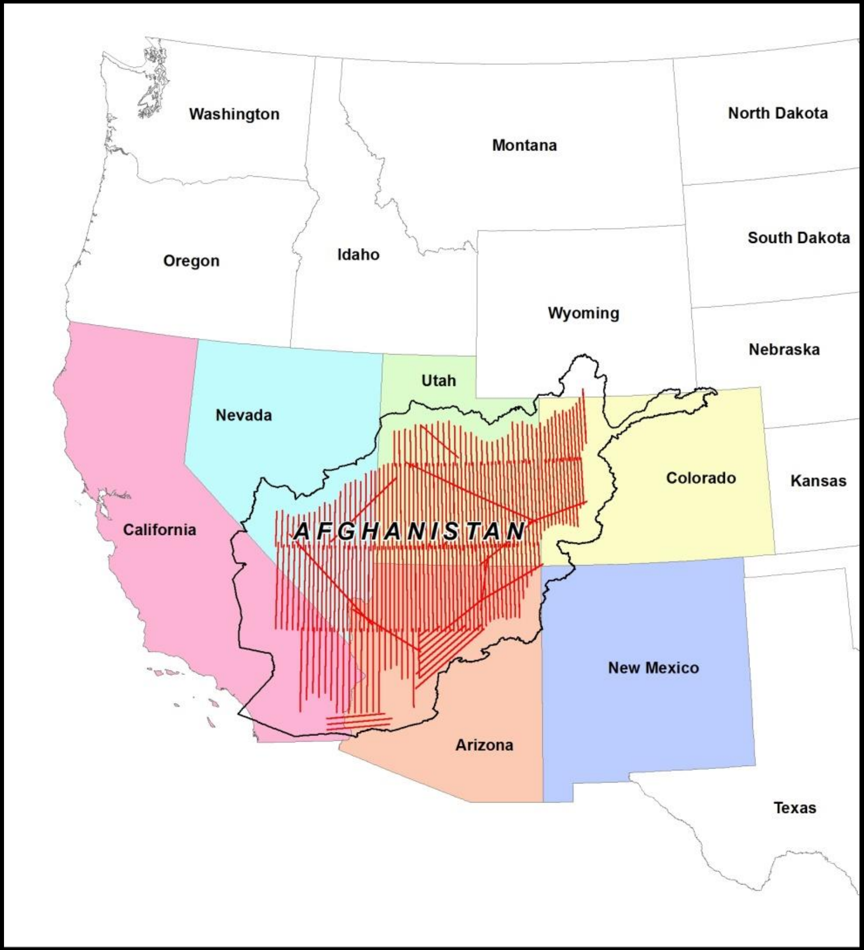


aviris.jpl.nasa.gov/alt_locator

USGS

Hypothetical Statewide Imaging Survey

- Flightlines
- Coverage
- Fewer constraints
- Lower Cost



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Advantageous Conditions

- Climate
  - Low precipitation/few clouds
  - Weather is short-lived
  - Dust, haze, and smoke tend to be short-term problems
- Vegetation
  - Sparse
  - Late spring/early summer avoids dry cheatgrass
- Sunlight
  - Days clear of clouds
  - Incidence angle
- Logistics

USGS

Stakeholders

- Mining and exploration companies
- Foresters and wildfire protection districts
- Land managers and government regulators
- Disaster management agencies
- Property owners
- Environmentalists
- Climate scientists, biologists, geologists
- GIS Analysts

USGS

Sources

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- King, T.V.V., Johnson, M.R., Hubbard, B.E., and Drenth, B.J., eds., 2011a, Identification of mineral resources in Afghanistan—Detecting and mapping resource anomalies in prioritized areas using geophysical and remote sensing (ASTER and HyMap) data: U.S. Geological Survey Open-File Report 2011–1229, 327 p.
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- Stone, Richard, 2014, Mother of All Lodes: Science, vol. 345, issue 6198, pp. 725-727.
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Links

- AIRIS spectrometer
  - aviris.jpl.nasa.gov
- HyMap spectrometer
  - www.hyvista.com
- SpecTIR spectrometer
  - www.spectir.com
- USGS Spectral Library
  - http://speclab.cr.usgs.gov /spectral.lib06/
- Science Journal on Afghanistan
  - http://www.sciencemag.org /content/345/6198
- USGS projects in Afghanistan
  - afghanistan.cr.usgs.gov
- Airborne survey flight line planning and data collection
  - pubs.usgs.gov/of/2008/1235
- Surface mineral maps and hyperspectral data
  - pubs.usgs.gov/ds/787
- Countrywide surface material wall maps
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  - pubs.usgs.gov/sim/3152/B
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USGS