

DECADAL SURVEY REPORT

Earth Surface Geochemistry and Mineralogy:
Processes, Hazards, Soils, and Resources

Wendy Calvin, lead author

Authors

- Eyal Ben-Dor, Tel Aviv University, Tel Aviv, Israel
- Janice Bishop, SETI Institute, Mountain View, CA
- Joseph Boardman, AIG LLC, Boulder, CO
- Roger N. Clark, Planetary Science Institute, CO
- Tom Cudahy, CSIRO, Perth, Australia
- Bethany L. Ehlmann, California Institute of Technology, Pasadena, CA
- Robert O. Green, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA
- Bernard Hubbard, United States Geological Survey, Reston, VA
- Raymond Kokaly, United States Geological Survey, Denver, CO
- John Mars, United States Geological Survey, Reston, VA
- John F. Mustard, Brown University, Providence, RI
- Greg Okin, University of California, Los Angeles, CA
- Cindy Ong, CSIRO, Australia
- Roberto de Souza Filho, University of Campinas, Brazil
- Freek van der Meer, ITC, Netherlands
- Gregg Vane, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

Theme V: Earth Surface and Interior: Dynamics and Hazards

- Core, mantle, lithosphere, and surface processes, system interactions, and the hazards they generate.
- **Description:** New spectroscopic measurements of the Earth's exposed surface to derive mineralogy are required to address key science and application targets. These measurements will advance understanding of fundamental geological processes, natural and anthropogenic hazards, soil geochemistry and evolution, and the location of energy and mineral resources.

Primary Goals

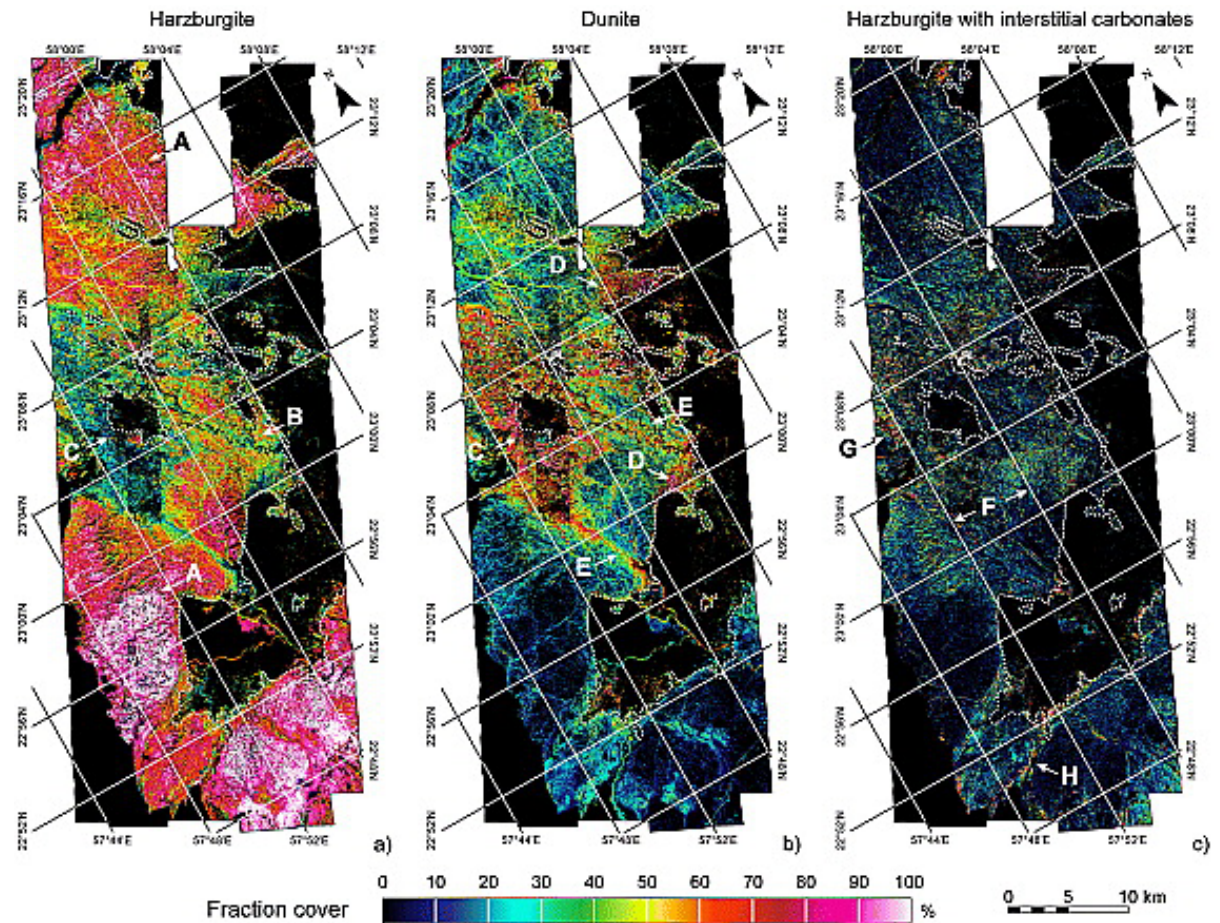
- New insights and constraints on fundamental geological processes.
- Assessment and response to natural and anthropogenic hazards.
- Advance soil composition and process knowledge.
- Surface Resource Identification and Policy Support.

- Required Discussion
 - Utility of the measured variables.
 - Key requirements
 - Near term success and affordability

Fundamental Geological Processes

New comprehensive measurements to identify minerals and discriminate lithologies are required with the capability to distinguish carbonate and sedimentary facies, including fine variations in carbonate composition and clay mineralogy, map hydrothermal and metamorphic indicator minerals, and distinguish basaltic, andesitic, and mafic compositional suites.

In the Oman ophiolite, orthopyroxene-rich cumulates, previously undocumented, were discovered using regional imaging spectroscopy and led to the promulgation of a new model for diapirism and creation of magma chambers in oceanic crust formation.



Roy et al. *Geochemistry, Geophysics, Geosystems*

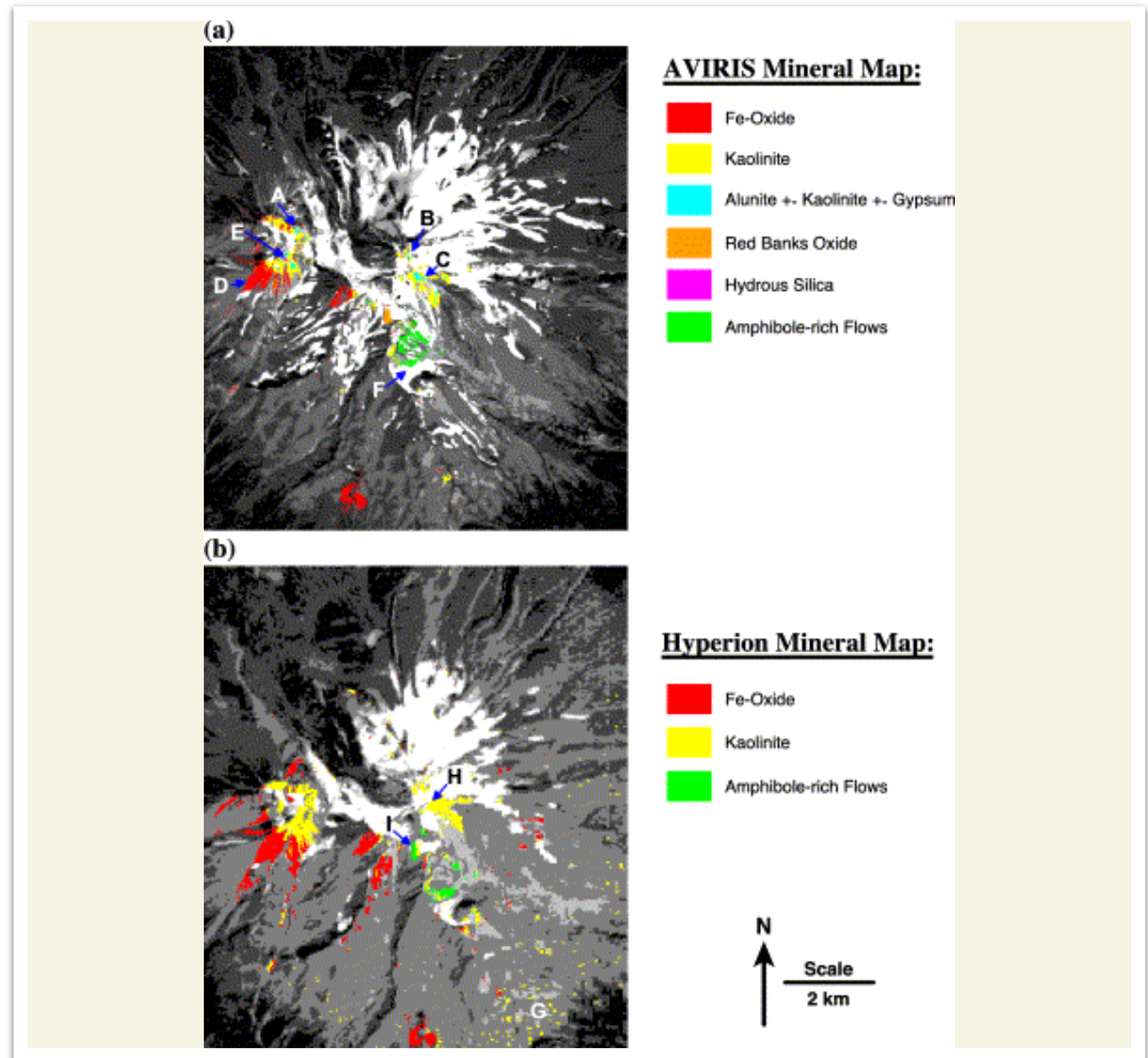
Volume 10, Issue 2, Q02004, 6 FEB 2009 DOI: 10.1029/2008GC002154

<http://onlinelibrary.wiley.com/doi/10.1029/2008GC002154/full#qgge1402-fig-0014>

Assessment and response to natural and anthropogenic hazards

Advancing the science of Earth surface hazard monitoring requires the ability to accurately identify surface mineral constituents, map their distribution, and estimate their abundance. Key mineralogies are the smectite clays related to landslides and weak zones in volcanic terrain. Iron oxides and sulfates are important for natural and mine-related acid drainage hazards. Serpentine and dust source region mineral mapping can be used to assess and mitigate dust-related hazards. Space-based, accurate, uniform mineral maps would enable high-resolution inputs to hazard models to be applied globally, serving developing and advanced countries in a rapid and cost effective way.

Imaging spectroscopy measurements in the Cascades have demonstrated detection of mineral zones with hazards not previously found in ground based surveys of the rugged, hard-to-access terrain

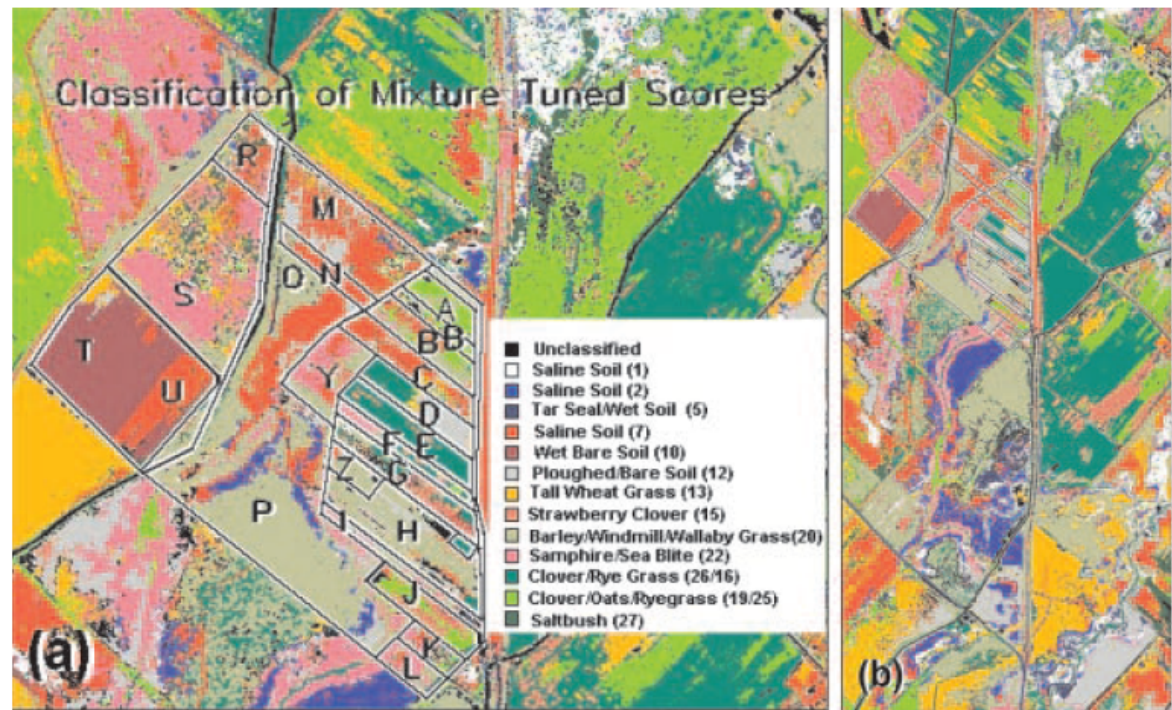


Crowley, J.K., Hubbard, B.E., Mars, J.C. Analysis of potential debris flow source areas on Mount Shasta, California, by using airborne and satellite remote sensing data. *Remote Sensing of Environment*, 87, 2-3, 345-358, 2003.

Advance soil composition and process knowledge

To advance soil science, new measurement of the surface composition of arid lands, fallow fields, sparsely vegetated, and temporarily cleared areas are required to update global soil databases with uniformly measured mineralogical information and to provide estimate of iron oxide, clay, organic carbon, carbonate, and salinity metrics for input into geochemical, vegetation, carbon cycling, and radiative forcing models.

Among the important large-scale changes that humans make to soils is salinization, a major form of soil degradation worldwide. Surface geochemical and reflectance signatures can reveal levels of soil salinization.

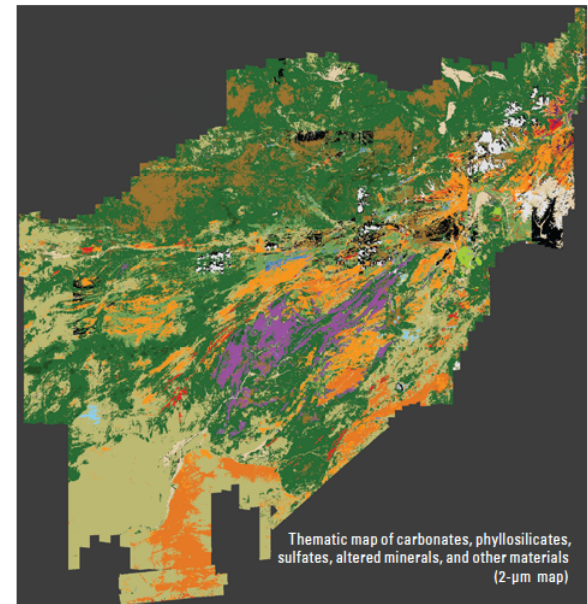
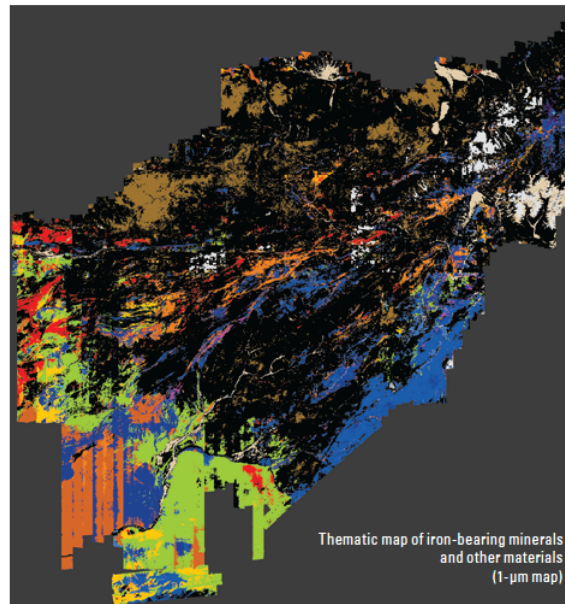


Dehaan, R., & Taylor, G.R. (2003). Image-derived spectral endmembers as indicators of salinisation. *International Journal of Remote Sensing*, 24, 775-794

Surface Resource Identification and Policy Support

New global measurements of the exposed surface that allow detail characterization of hydrothermal alteration suites, temperature dependent mineralogy, and features associated with hydrocarbons are required.

Global strategic areas include development of raw material inventories, monitoring development, assessment of future resource demand, and balancing development with environmental impacts and human health hazards associated with resource extraction. This requires accurate and comprehensive measurement of mineralogy exposed at the surface. Despite potential for mineral development, many remote areas remain largely under-explored. Mineral mapping, primarily with airborne measurements, has occurred in remote and vegetated regions such as Greenland and Alaska, over large regional areas such as Afghanistan and the Western USA.

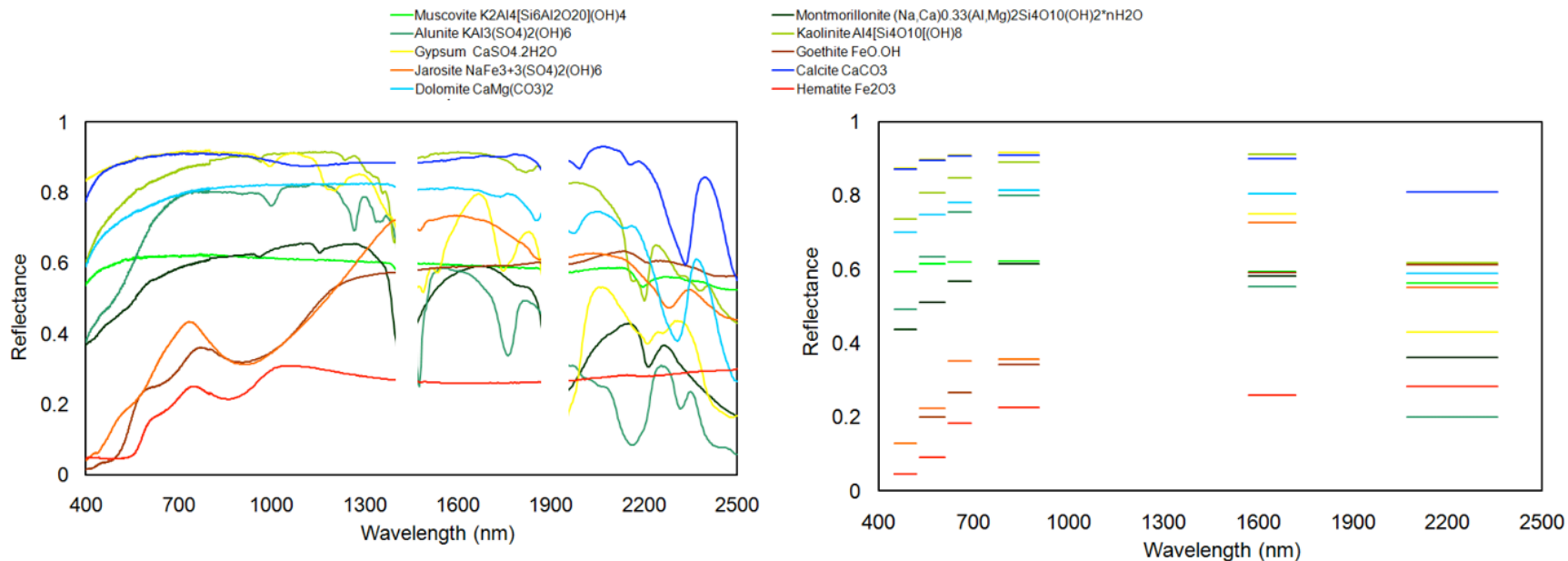


Kokaly, R.F., King, T.V.V., and Hoefen, T.M. (2013). Surface mineral maps of Afghanistan derived from HyMap imaging spectrometer data, version 2: U.S. Geological Survey Data Series 787, 29 p., <http://pubs.usgs.gov/ds/787/>.

Traceability Matrix

Science and Applications Target	Objectives	Physical Parameter	Observable	Measurement Requirements	Other Measurement Characteristics
<p>V. Earth Surface and Interior: Dynamics and Hazards: Core, mantle, lithosphere, and surface processes, system interactions, and the hazards they generate.</p> <p>Earth Surface Geochemistry and Mineralogy for Geologic Processes, Hazards, Soils, and Resources</p>	<p>O1. New insights and constraints on fundamental geological processes</p> <p>O2. Assessment and response to natural and anthropogenic hazards</p> <p>O3. Advance soil composition and process knowledge</p> <p>O4. Surface Resource Identification and Policy Support</p>	<p>Occurrence and fractional abundance estimate (0-1.0 with uncertainty) of minerals and geochemicals expressed at exposed surface:</p> <ul style="list-style-type: none"> • Iron oxides • Sulfates • Clays • Carbonates • Amphiboles • Mafic minerals • Hydrocarbons <p>Estimation of confounding factors:</p> <ul style="list-style-type: none"> • Fractional surface cover for green and non-photosynthetic vegetation • Water vapor, cirrus clouds, and aerosols 	<p>Spectral reflectance of the exposed surface from atmospherically corrected top of atmosphere spectral radiance</p>	<p>Spectral</p> <ul style="list-style-type: none"> • 450 to 2450 nm range • ≤ 10 nm sampling • ≤ 15 nm FWHM • ≤ 1 nm calibration uncertainty <p>Radiometric</p> <ul style="list-style-type: none"> • 0 to max Lambert range • 99% linear of 5 to 95 % of range • SNR see figures 5, 6 • $\leq 5\%$ calibration uncertainty <p>Spatial</p> <ul style="list-style-type: none"> • ≥ 90 km swath • ≤ 30 m sampling • ≤ 30 m 1σ uncertainty <p>Uniformity</p> <ul style="list-style-type: none"> • $\leq 10\%$ cross-track spectral variation • $\leq 10\%$ spectral IFOV variation 	<p>Sun synchronous ~11am crossing for good illumination and prior to cloud build up.</p> <p>Cloud free measurement for $\geq 80\%$ terrestrial exposed surface.</p> <p>At least two years of measurement for capture of seasonal low vegetation states and fallow agricultural fields.</p> <p>Pointable for 3 day revisit for event response.</p>

Examples of Sparse λ Coverage

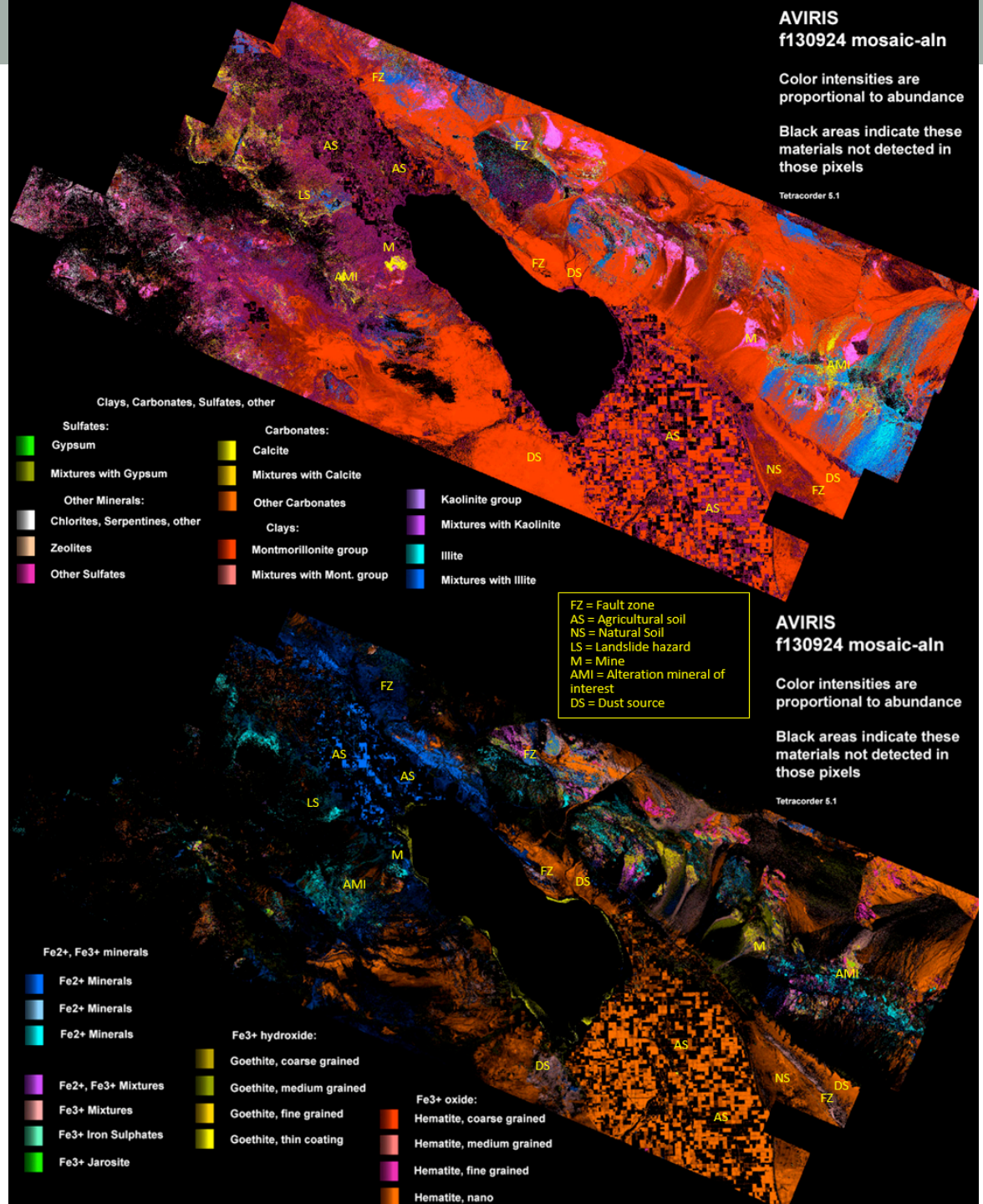


(left) Ten mineral reflectance spectra showing the diversity of absorption and scattering signatures tied to composition available for measurement in the 400 to 2500 nm region of the spectrum. Acquisition of such data enables highly accurate identification of Earth surface materials and assessment of their abundances. (right) The same mineral spectra convolved to the Landsat TM bands showing the loss of spectroscopic information required for unambiguous identification and abundance estimation. The broad-band sampling provided by the TM bands limits the analysis of the data largely to the relative brightness within each of the bands. Brightness is complicated by sun angle, slope effects, shading, and other factors. The utility of imaging spectroscopy is thus greatly enhanced over broad-band multispectral imaging.

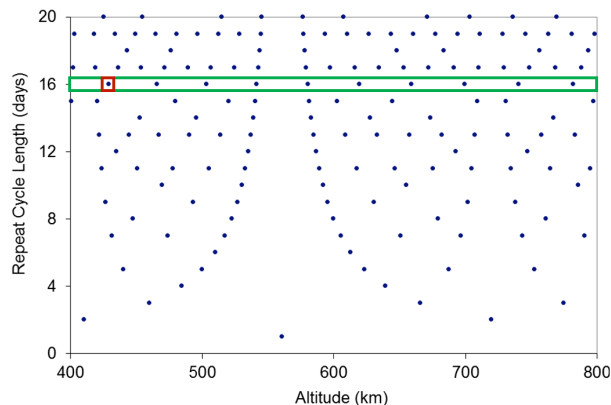
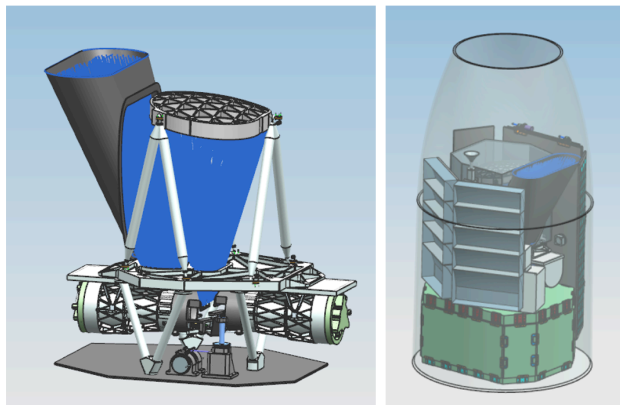
Surface mineral mapping example using USGS tetracorder algorithm, using spectral feature fitting

Courtesy of Roger Clark

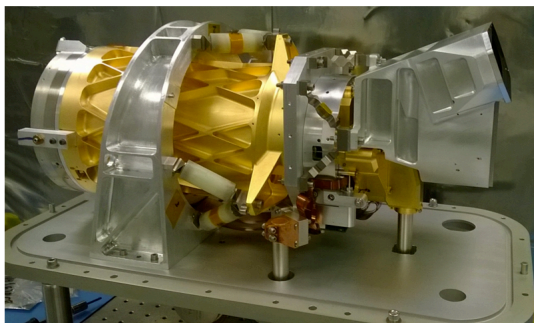
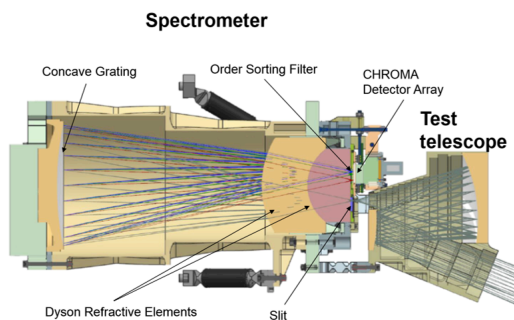
The detailed geochemistry and gradients revealed provide insight into related tectonic processes along the San Andreas fault (e.g. fault offset, fluid alteration). Landslide risk as related to mineral composition in steep terrain can be assessed. The Salton Sea region is a known mineral dust source hazard area, and the surface composition of exposed shorelines can be used to constrain models and predict risks. The soil composition of the fallow agricultural fields and adjacent lands are measured, and repeat acquisition can capture different fields with exposed soil for comprehensive mapping. Information on current mining activities and potential future mineral resource extraction is revealed through identification of alteration mineral exposures. This example from airborne measurements demonstrates the approach that would be used to address science and applications targets globally for the exposed terrestrial surface of the Earth.



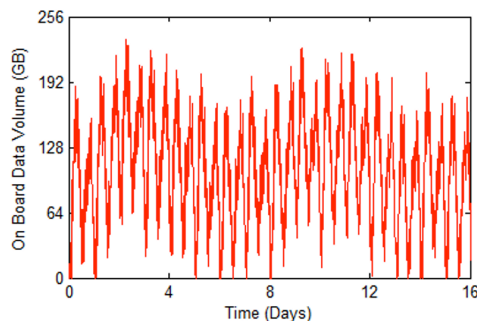
Near Term Success & Affordability



Opto-mechanical configuration, two field split swath. Accommodation in a Pegasus shroud. Orbital altitude and repeat cycle.



Dyson design and benchtop model.



Illuminated surface coverage every 16 days. On board storage usage.

Submission & Next Steps

- Submitted to Earth Science RF2 call on 5/15/16
- Full white paper available on HypsIRI web site
- <http://hyspiri.jpl.nasa.gov/nrc-decadal-survey>
- Outgrowth is to capture some of this and expand on it in a peer-reviewed article.
 - Target was special issue on Geological Remote Sensing of Int. J. Applied Earth Obs. & Geoinf.
 - Likely won't make the 10/31 deadline.
 - Get the paper written then decide where it goes

The Future of Imaging Spectroscopy for Global Geologic Mapping

- Outline
- Introduction
 - What is the future of global geologic mapping?
 - Global geologic maps for other solar system objects as accomplished by NIMS, VIMS, CRISM, OMEGA, M3, TES, etc. (Mercury to Pluto)
 - Geology on a vegetated and cloudy planet – the case of “seeing through the dust” on Mars.
- Review of airborne imaging spectroscopy for geologic applications
 - VNIR/SWIR
 - LWIR
- Geology from Current Satellite Sensors
 - Returns from ASTER (multi-channel but global)
 - Often supplemented with AVIRIS or HyMap
 - Returns from Hyperion (full spectral, but limited cover, lower SNR)
 - Newest sensors (e.g. WV3, Sentinel-2 – higher spatial res but with Landsat or ASTER-like spectral coverage)
- Trade Space Among Planned Systems
 - EnMap
 - HypIRI
 - Others (?)
 - LWIR trades – cooling, swath, channels, cost (SEBASS-MAKO-ECOSTRESS)
 - Dealing with large data volumes from satellite IS systems
- Future science enabled
 - Fundamental Geological Processes and Mapping
 - Natural and Anthropogenic Hazards
 - Energy and Mineral Resources
- Summary
- Current authors: Calvin, Kokaly, Hecker – please see me if you are interested in contributing.