Preparing for surface mineral mapping across the Earth by analyzing existing soil spectral libraries and assembling large area airborne imaging spectrometer coverage

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USGS science for a changing world

Acknowledgments

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- Soil spectral library work done in conjunction with Landsat NEXT crop-residue study team: Phil Dennison, Mickey Campbell Brian Lamb, Dean Hively, Guy Serbin, Craig Daughtry, Jeff Masek, Philip Dabney, Zhuoting Wu
- EnMAP data received by R. Kokaly as member of EnMAP Science Advisory Group on Calibration and Validation
- EMIT data received by R. Kokaly as affiliate member of the EMIT Science Team
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  - Rob Green, David Thompson, and Phil Brodrick at JPL (EMIT)
  - Sabine Chabrillat and Max Brell at GFZ-Potsdam (EnMAP)
  - Gregg Swayze and Chris Crawford at USGS (field work)

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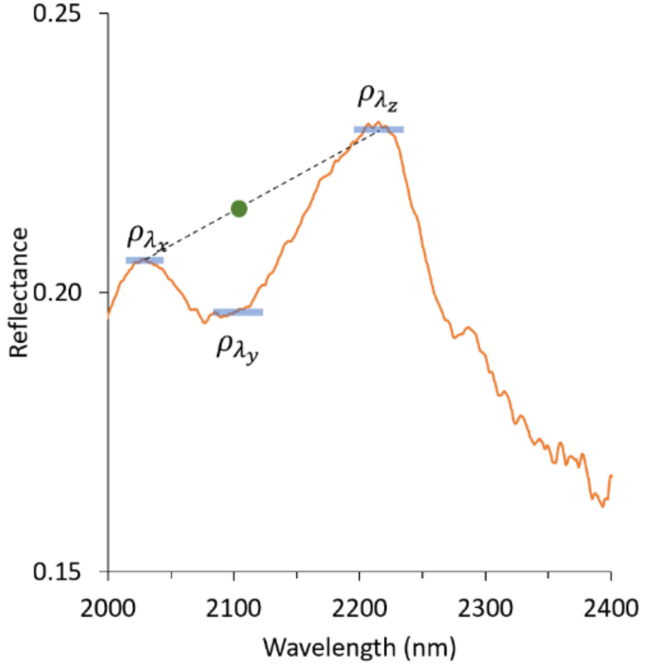
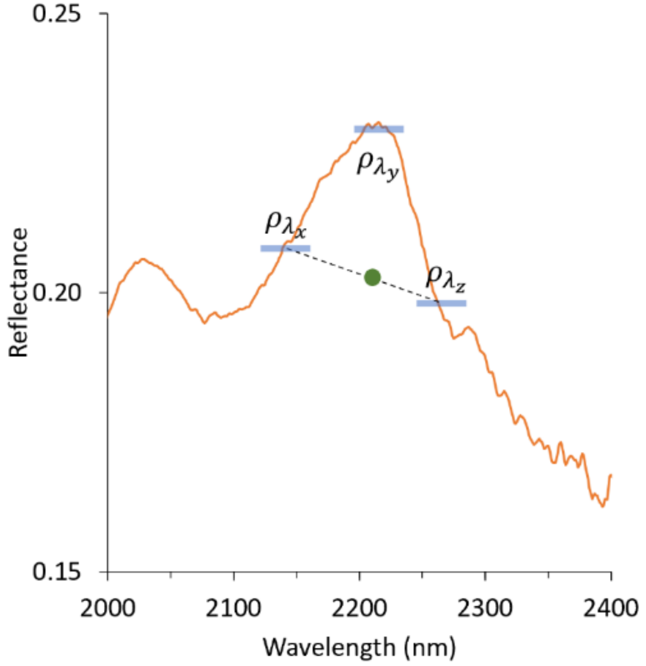
Objectives: Soil Spectral Libraries

- Test prospective performance of crop residue indices as a function of different soil backgrounds for potential Landsat Next multispectral bands, including:
  - bands targeting non-photosynthetic vegetation (NPV) absorption centered near 2100 nm (e.g., CAI, cellulose absorption index)
  - bands targeting the peak between NPV 2100 nm and 2300 nm absorption features

- Analysis of SSLs a useful test of spectral feature matching algorithms, in particular, MICA module of USGS PRISM software developed for mineral mapping of AVIRIS-Classic 2018 coverage of CA/NV.





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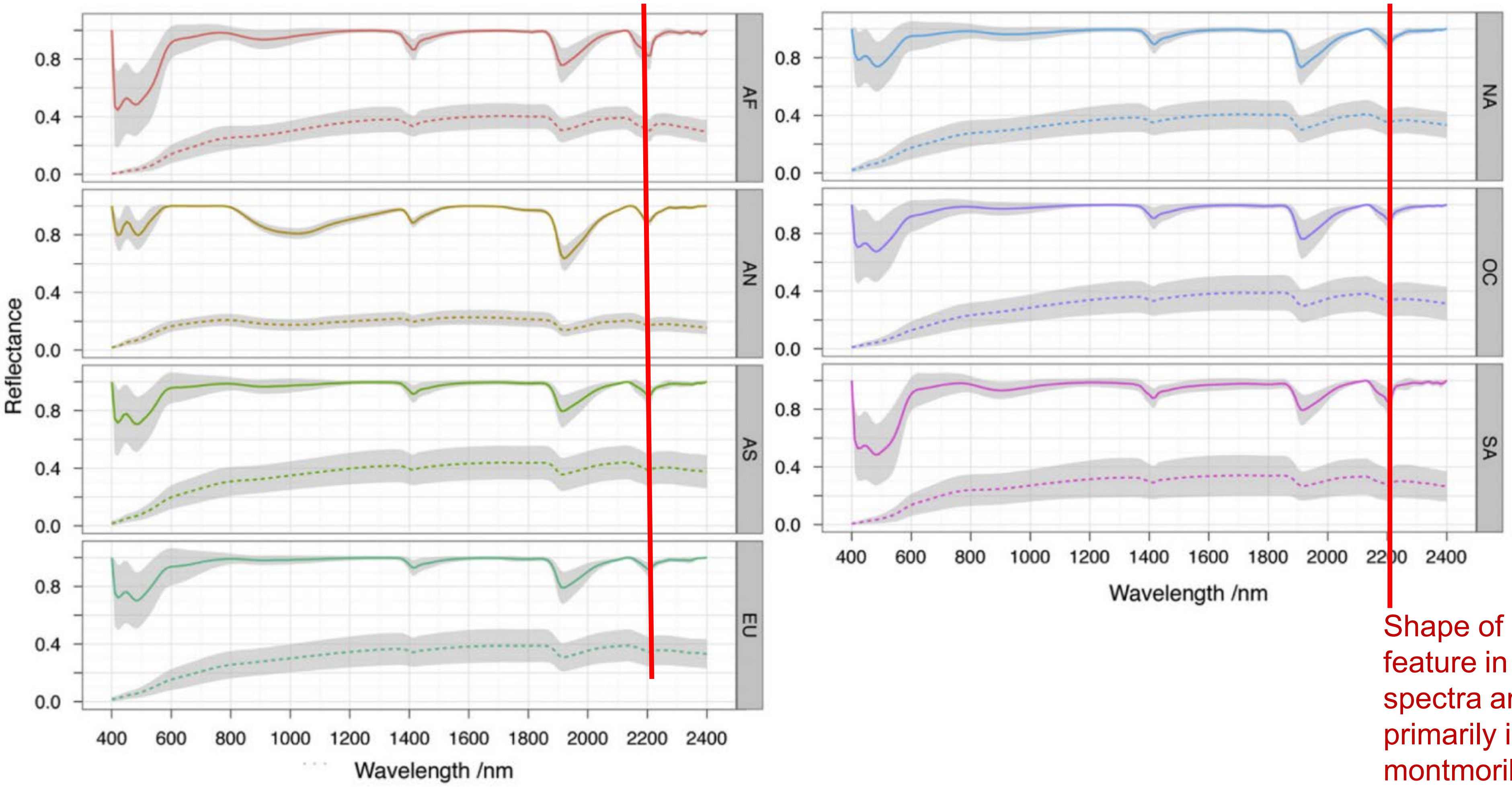
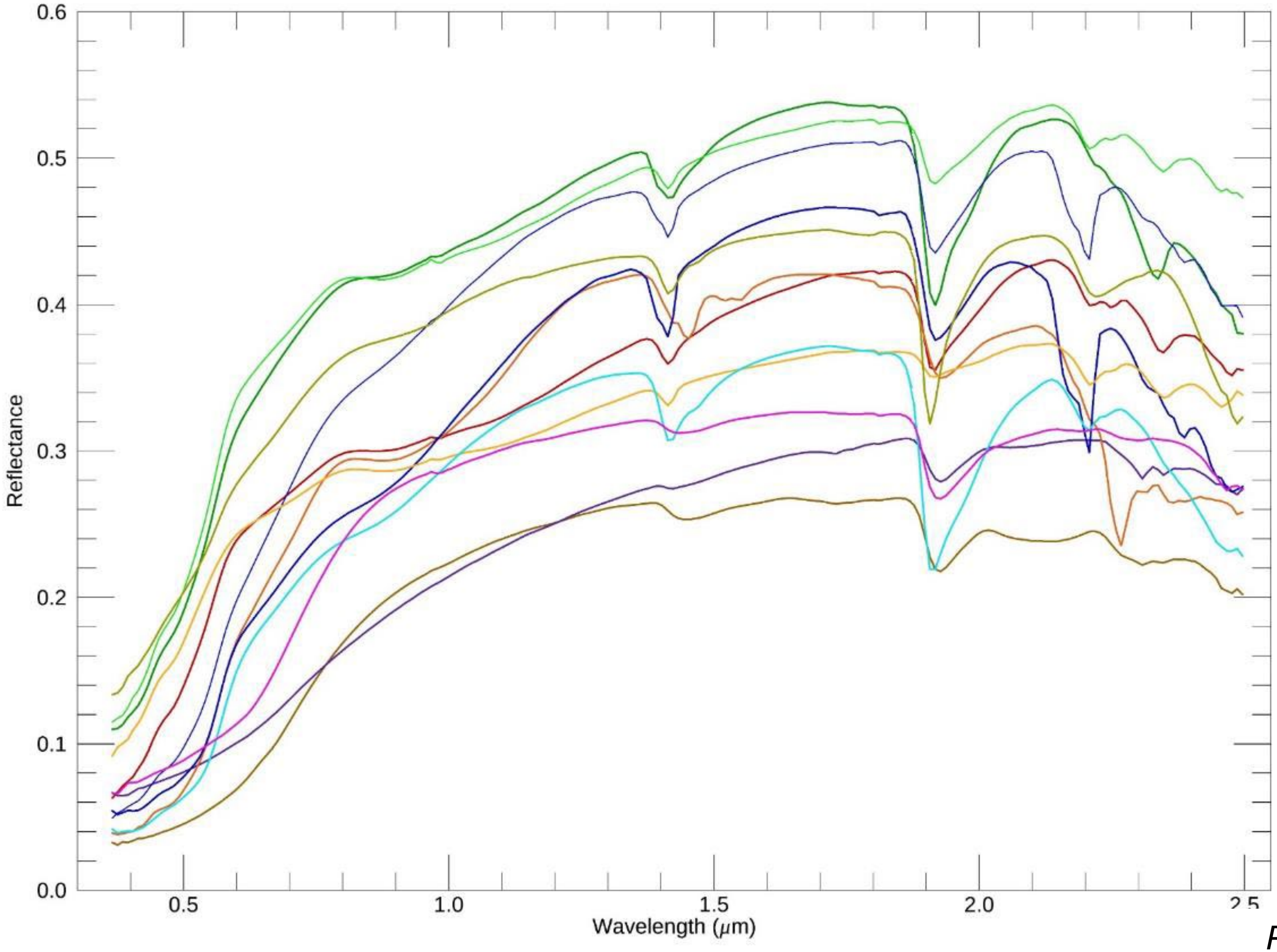
Simple statistical methods produced representative spectra with by feature dominated by a smectite group mineral (montmorillonite)



Shape of absorption feature in representative spectra are primarily indicative of montmorillonite

Fig. 4. Average reflectance spectra by continent (see Table 1 for abbreviations) and their standard deviations. Upper curves are the continuum removed (CR) spectra.

Greater variability in mineral composition of soil needs to be tested to capture impact of soil background on crop residue indices



Selected soil spectra from ICRAF-ISRIC database

FS21_FS9596 NPV or other organic
FS21_FS1049 Plastic or natural polymer
FS21_FS737 Calcite
FS15R_FS5104 Calcite +clay/mica (thin line)
FS15R_FS5130 Chlorite dominant (+mica)
FS21_FS1079 Gibbsite
FS21_FS1494 Kaolinite
FS15R_FS4650 Kaolinite + clay/mica (thin line)
FS15R_FS5025 Muscovite or illite (white mica)
FS21_FS176 Hydrated Silica
FS15R_FS5510 Montmorillonite (smectite)
FS21_FS765 Not Matched

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Preliminary results. Not for citation or distribution

Greater variability in mineral composition of soil needed to be tested to capture impact of soil background on crop residue indices

Data

- Surface horizon spectra from published soil spectral libraries (SSL) n=48,327:
  - ICRAF-ISRIC globally distributed SSL (n=754) *doi:10.34725/DVN/MFHA9C*
  - Mediterranean region SSL (n=1,751), *GeoCradle http://datahub.geocradle.eu/dataset/regional-soil-spectral-library*
  - Europe's LUCAS SSL (n=43,560 which includes both of the duplicate spectral measurements of each sample), *Tóth et al., 2019*
  - Australia National Geochemistry Survey (n=1,308) *CSIRO, doi: 102.100.100/42097*
  - USDA NSSC SSL including USA and global soils (n=854), *Brown et al., 2006*
  - Brazilian SSL (selected subset, n=100), *DeMatte et al., 2019*

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Greater variability in mineral composition of soil needed to be tested to capture impact of soil background on crop residue indices

Methods

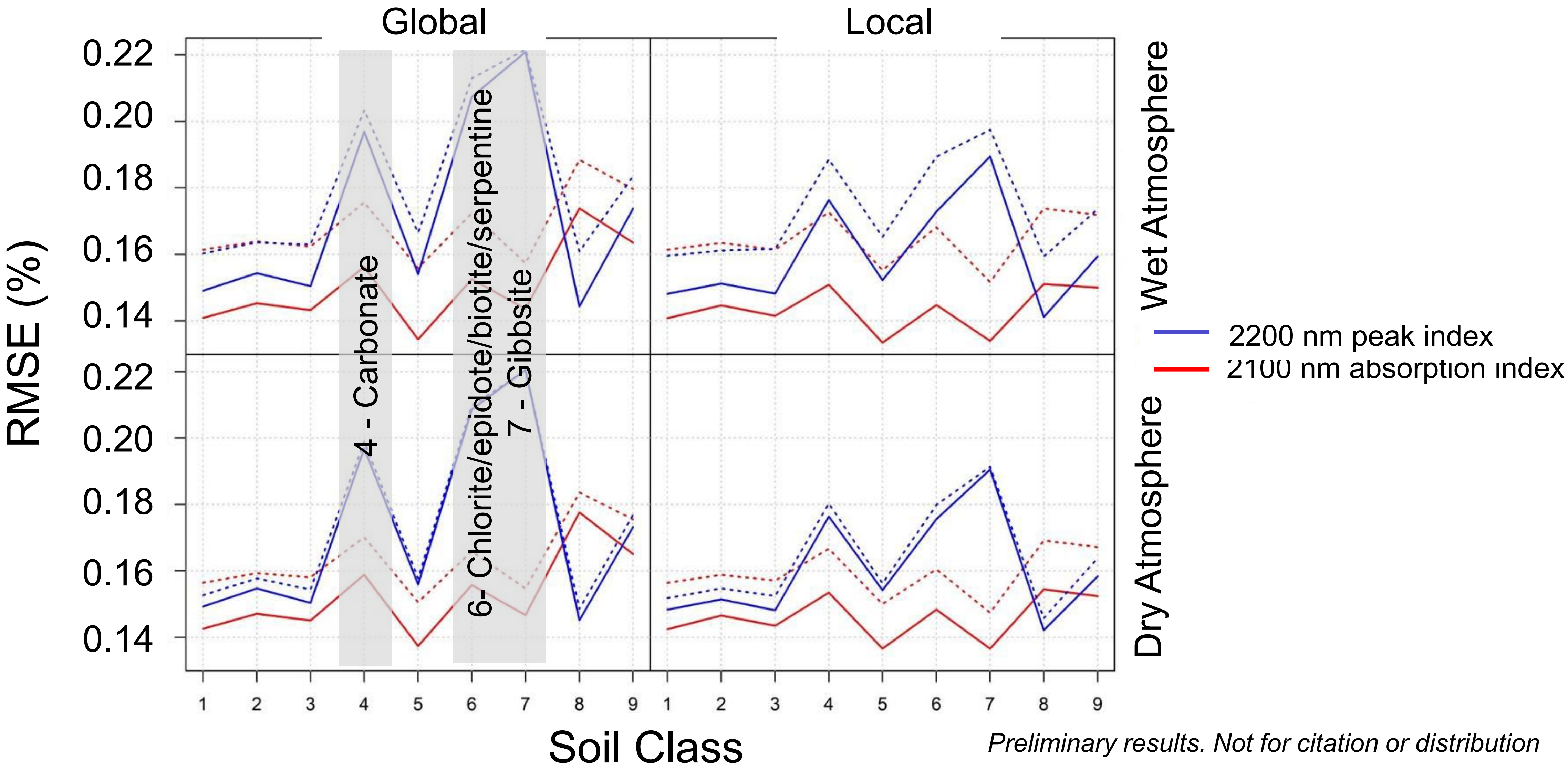
- Conversion of spectra to absolute reflectance from relative reflectance or absorbance, correction of detector offsets, resampling to consistent wavelength interval, assumption of ASD standard resolution spectral characteristics, convolved to AVIRIS-Classic 2018
- Spectral feature comparison using MICA algorithm of the USGS PRISM software to identify spectrally-dominant mineral(s) for the 2-micron group of minerals (not the 1-micron group of iron-bearing minerals)
- Define soil spectral endmembers for mixture analysis
  - Group into classes based on mineral and spectral similarity
  - Random selection of ~200 spectra within each group to approximate frequency distribution in the combined soil spectral libraries
- Resample to prospective Landsat NEXT bands and quantify performance of crop residue indices in estimating NPV fraction in mixtures of spectra in three endmember sets (NPV, green vegetation, soil) using simple linear regression; investigate moving each band's wavelength position and impact on regression results; examine performance by soil class

M

montmo
kaolinite
kaolinite
muscovi
muscovi
calcite.6
calcite.5
kaolinite
kaolinite
kaolinite
kaolinite
vegetati
calcite.3
muscovi
vegetati
aragonit
calcite.8
calcite.2
calcite.3
montmo
kaolinite
dolomite
clinochlo
illite_GD
calcite

Soil Spectral Class	Dominant Spectral Feature	Samples	Grouped Soil Classes Based of Mineral Composition
1	2200nm	64	mostly montmorillonite, some kaolinite+smectite mixes, with a few gypsum and hydrated silica dominated spectra
2	2200nm & 2300nm	88	white mica (muscovite/illite), kaolinite, kaolinite+white mica(muscovite/illite) mixes, chlorite+muscovite and white mica (muscovite/illite) + carbonate (calcite/dolomite)
3	2300nm & 2200nm	20	carbonate (calcite/dolomite) mixtures with montmorillonite or white mica (muscovite/illite), and a few others
4	2300nm	19	carbonate (calcite/dolomite/aragonite), and a few others (vermicullite, nontronite, saponite)
5	2200nm 2250nm & 2300nm	11	chlorite+white mica(muscovite/illite) or biotite group mineral+white mica(muscovite/illite) or amphibole group mineral+white mica(muscovite/illite) or kaolinite+muscovite or carbonate+smectite/whitemica or biotite group mineral+white mica(muscovite/illite) or amphibole group mineral+white mica(muscovite/illite)
6	2300nm & 2250nm	6	chlorite/epidote or biotite group mineral+white mica(muscovite/illite) or amphibole group mineral+white mica(muscovite/illite) or other smectite group mineral (hectorite) or sepentine group mineral
7	2270nm	4	gibbsite - likely important for tropical soils
8	2070nm 2200nm & 2300nm	1	topaz bearing - probably very rare
9	WeakFeatures	15	relatively featureless but still showing weak 2200 nm and 2300 nm features that are too weak to conclusively identify mineralogy

Impact of soil background on crop residue indices -
Performance of crop residue indices as a function of soil mineral class



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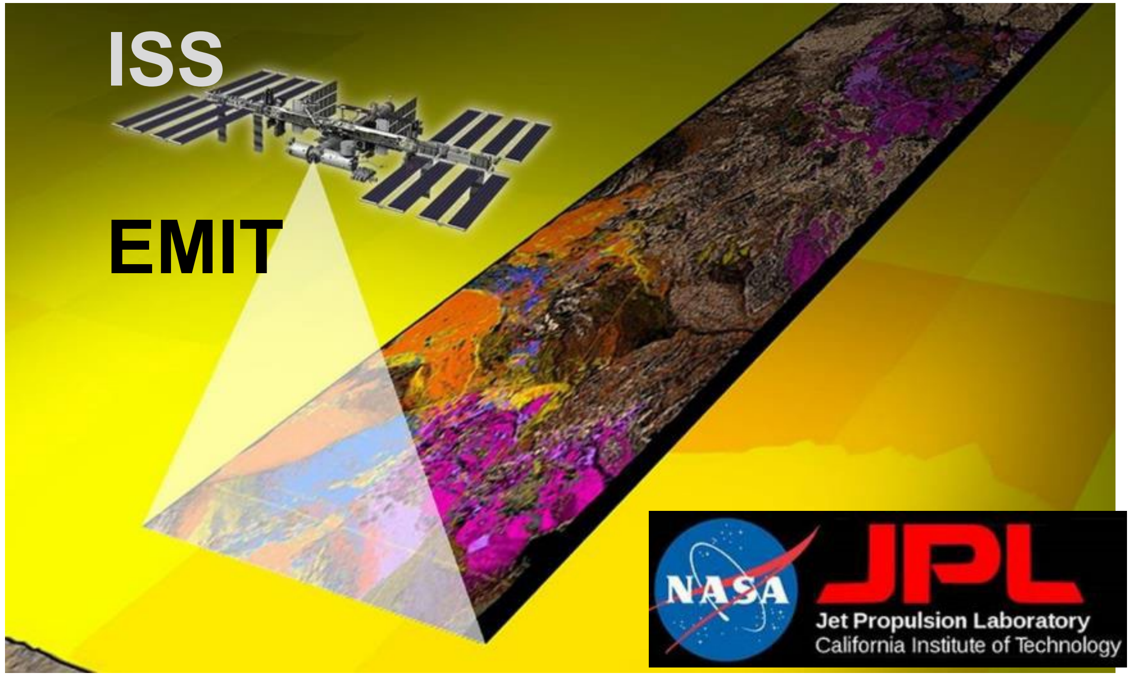
Conclusions from analyzing existing soil spectral libraries in relation to potential crop residue indices

- Existing soil spectral libraries were found to helpful in defining a subset of spectra that capture mineral-spectral variation for testing crop residue indices.
- Indices for crop-residue (NPV fraction) estimation with good r^2 & RMSE, and
  - Crop residue indices targeted at the 2100 nm absorption feature of NPV have the best performance and were robust across soil classes
  - Indices targeted at the peak between the 2100 nm and 2300 nm NPV absorption features had slightly poorer results in general and reduced performance on class 4 (containing carbonate minerals), class 6 (containing chlorite/epidote/biotite/serpentine group minerals), and class 7 soils (containing gibbsite), even with local training (class specific regression analysis)

Using airborne imaging spectrometer data as cal/val reference for the most recent developments in surface mineral mapping: EMIT & EnMAP imaging spectrometer data from orbit.

Earth Surface Mineral Dust Source Investigation (EMIT)
NASA/JPL
VSWIR coverage 418 to 2500 nm in 285 channels
w/ spectral bandpass from 8.4 nm to 8.8 nm
Spatial sampling 60 m with swath width ~80 km
Covering global dust producing regions within ±50° latitude
International Space Station (ISS) with ~1 year mission



Environmental Mapping and Analysis Program (EnMAP)
German Space Agency (DLR)
VSWIR coverage ~415 to 2500 nm in 224 channels
w/ spectral bandpass from 5 nm to 11 nm
Spatial sampling 30 m with swath width
Sampling mission with full global reach and +/- 30° tilt
Free flying satellite with 5+ year mission

Black Rock Playa Zero – Cal/Val Site

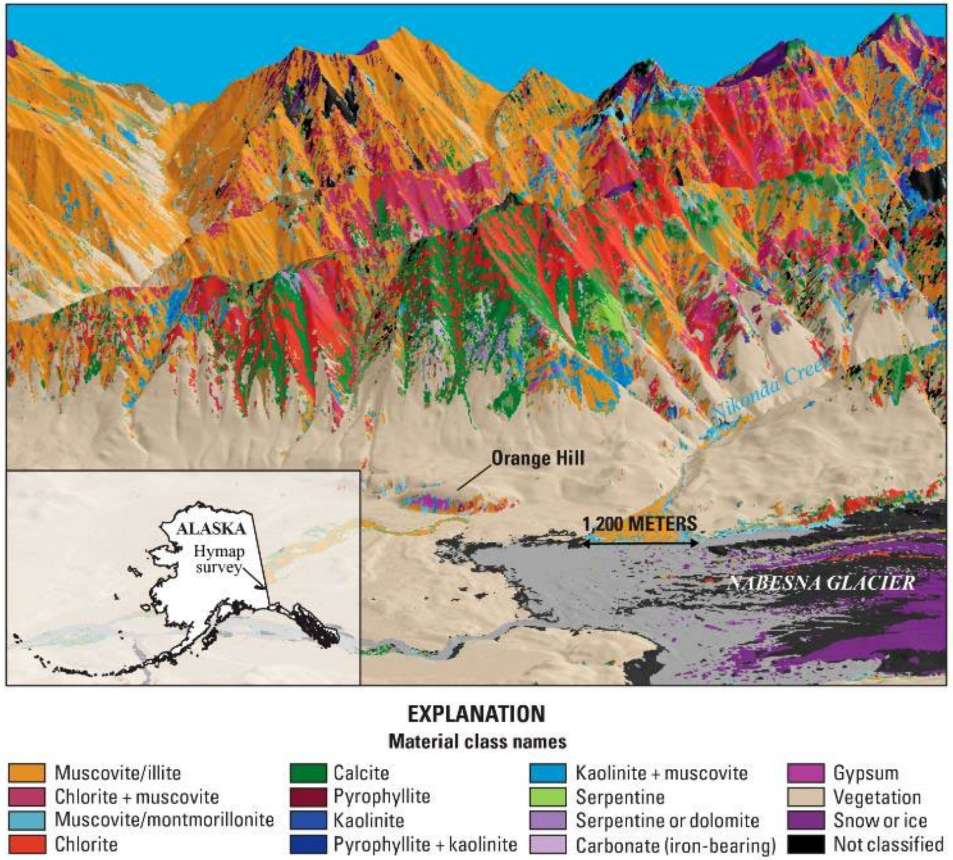
- **High elevation playa site with typically dry, bright surface**
- **Surrounding area has geologic and surface mineral diversity**
- **Large areas (up to 240 x 240 m) measured with field spectrometers in May and August 2022**

Mineral Mapping Method

- MICA algorithm, a module of USGS PRISM software (https://pubs.usgs.gov/of/2011/1155/; contact raymond@usgs.gov)
  - a spectral feature comparison method that compares image spectra to selected spectra from reference spectral library (USGS Spectral Library Version 7; https://doi.org/10.3133/ds1035)
  - two maps produced:
    - 1-micron absorption feature map for minerals with dominant iron absorption features
    - 2-micron absorption feature map for minerals with dominant absorption features in the longer wavelengths (1000 to 2500 nm), such as, clays, carbonates, sulfates, etc.
- Mineral maps applied to both standard reflectance products and data directly ground-calibrated using Black Rock Playa Zero in Nevada
  - AVIRIS-Classic from ER-2 high altitude aircraft acquired June 8, 2018 (run09)
    - part of hyperspectral imaging of critical mineral resources project, funded by USGS Mineral Resources Program; continued data collection under USGS Earth Mapping Resources Initiative (Earth MRI)
- EMIT from ISS acquired August 14, 2022
  - atmospheric correction with isofit, destriping; new version of reflectance product is planned
- EnMAP from satellite acquired June 28, 2022 (also July 29, 2022, not shown)
  - data processor and calibration version V01.01.00. NOTE: current mission version is newer
  - atmospheric correction with PACO, destriping not yet implemented but planned.

USGS Earth Mapping Resources Initiative (Earth MRI, EMRI)

- Modernize the Nation’s mapping of resources
- Collects fundamental geoscience data including:
  - Airborne geophysical surveys
  - Lidar surveys for high-resolution elevation and topography
  - Geochemical surveys
  - Geologic mapping by State geological surveys
  - **Hyperspectral surveys (new in FY22)**
- Contacts:
  - Warren Day (EMRI Science Coordinator)
  - Darcy McPhee (Mineral Resources Program, EMRI Program Manager)
  - Raymond Kokaly & Bernard Hubbard (Hyperspectral task co-leads)
  - Remote sensing personnel: Todd Hoefen, John Meyer, Evan Cox, Federico Solano



Spectral Vectors to Copper and Gold:
Adapted from Graham et. al.,2018,
Economic Geology 113 (2), 489-510

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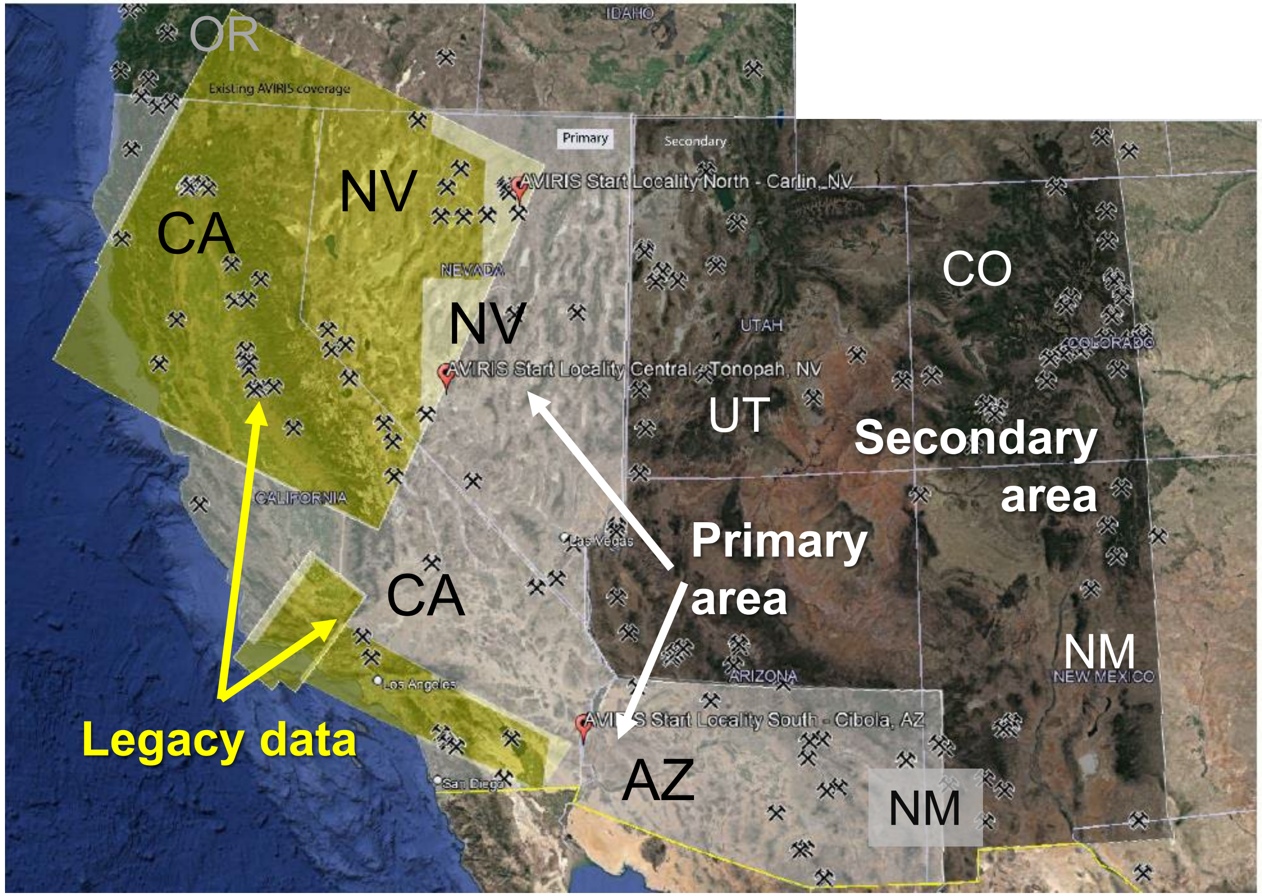
USGS mineral mapping using airborne imaging spectrometer data: Reference data and maps for satellite sensors and data products

Earth MRI data acquisition of AVIRIS class VSWIR imaging spectrometer data for the arid western US will be at least 500,000 sq. km over next 4 years. Secondary HyTES (TIR) imaging spectroscopy data, as available.

NOTE: existing AVIRIS coverage of 380,000 sq. km is being analyzed under separate project of the USGS Mineral Resources Program.

Hyperspectral image pixel size 10 to 17 m.



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EXPLANATION

- Critical mineral deposit
- 2018 legacy NASA AVIRIS data
- Proposed new 500,000+ km^2
- Additional secondary area of selected coverage, dependent on and following clear sky acquisition of primary area

AVIRIS data to be collected by NASA with Earth MRI funding under the Geologic Earth Mapping experiment (GEMx) branding

GEOLOGICAL EARTH MAPPING EXPERIMENT GEMx NASA • USGS

See also:
https://www.usgs.gov/centers/gggsc/science/hyperspectral-imaging-mineral-resources-new-and-old-origins-minerals-nations
https://www.mining.com/usgs-nasa-to-map-southwestern-united-states-for-critical-mineral-potential/
https://www.usgs.gov/special-topics/earth-mri

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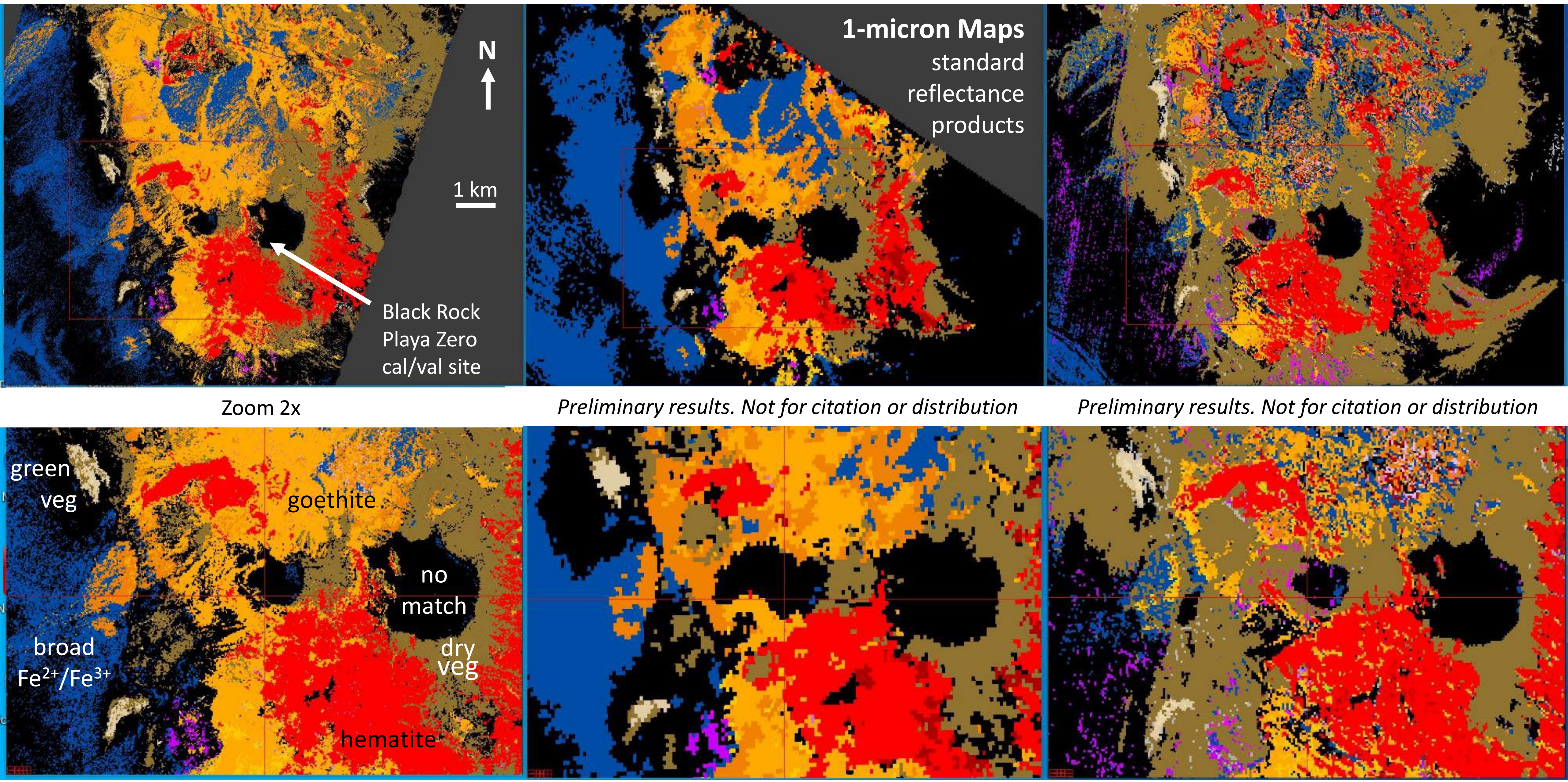
AVIRIS-Classic from high-altitude aircraft
June 8, 2018 (15 m pixel size)

EMIT ISS-based
August 14, 2022 (60 m pixel size)

EnMAP satellite-based
June 28, 2022 (30 m pixel size)



Ground-calibrated using site 190 km distant

From L2 reflectance product (ver20220908)

From L2a reflectance (Atm Corr Ver 01.00.01)

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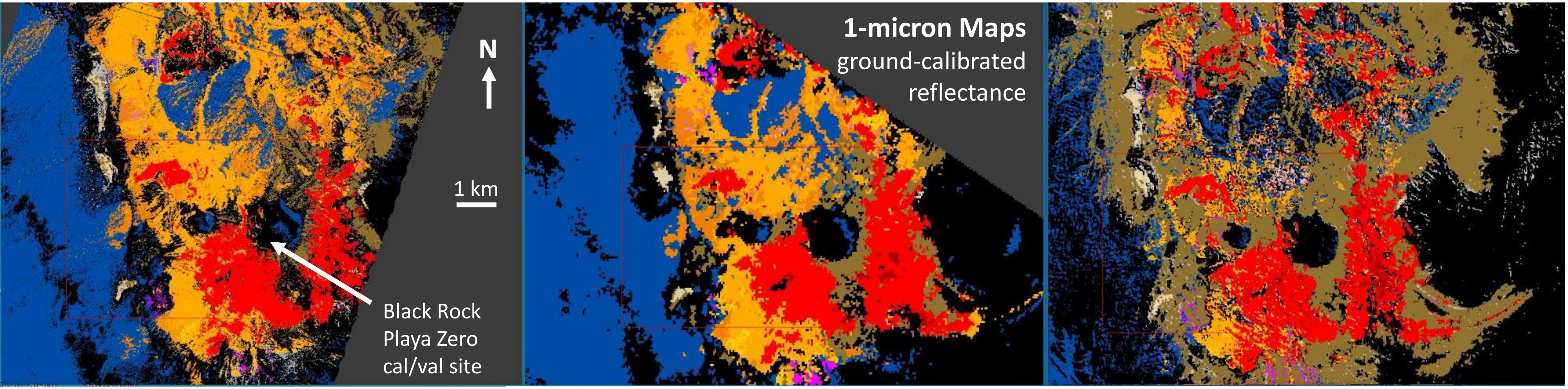

Zoom 2x

Preliminary results. Not for citation or distribution

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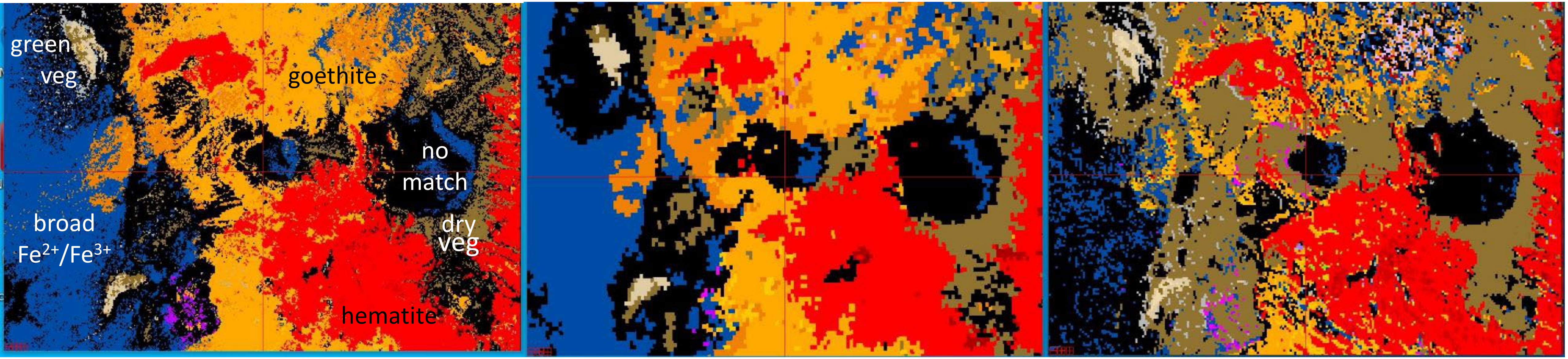

All image directly ground-calibrated w/ Black Rock Playa Zero (NOTE: spatial change from previous slide due to my cropping of images)

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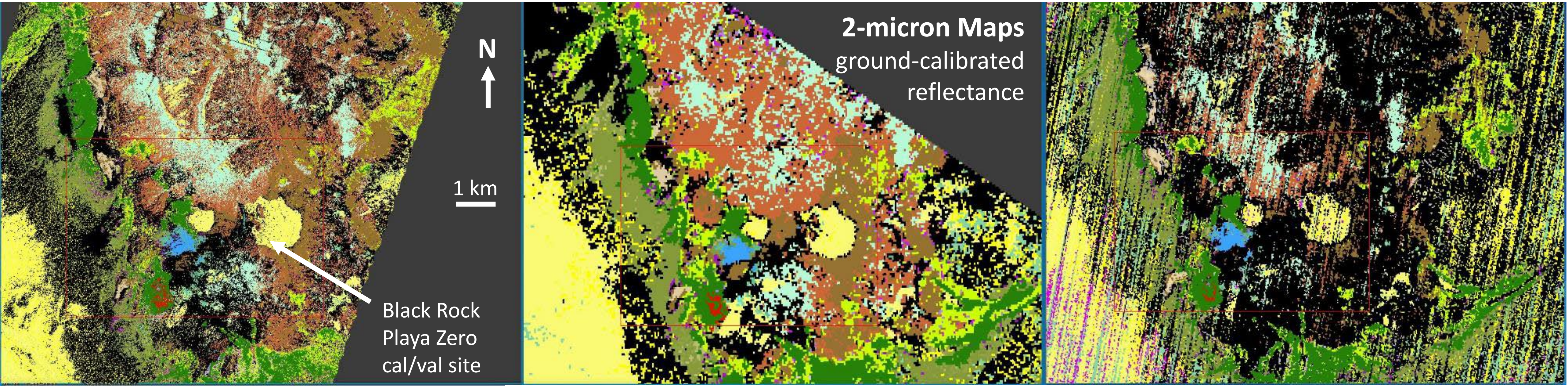

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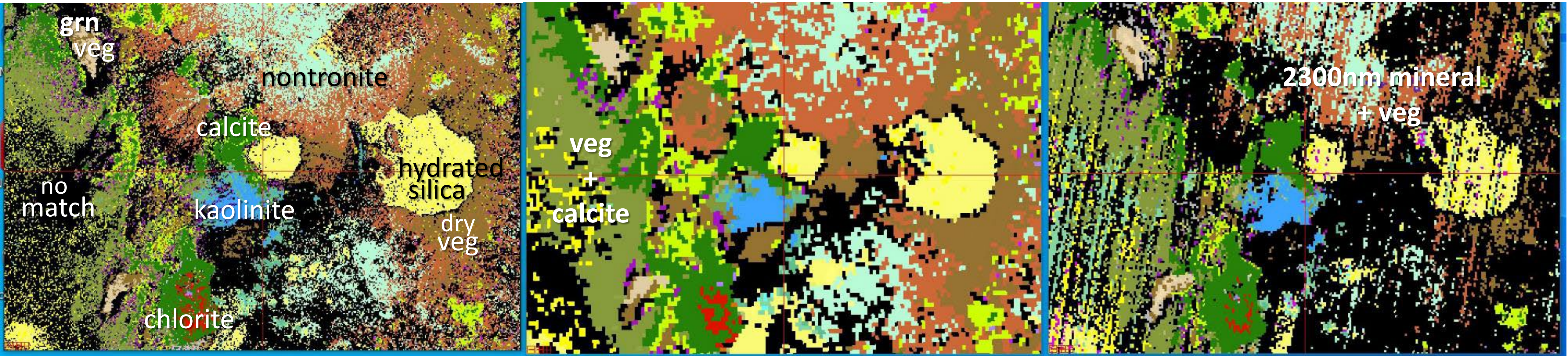

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Mineral mapping from orbit: EMIT & EnMAP

- Initial good comparisons of mineral maps derived from space-based sensors relative to AVIRIS-Classic airborne imaging spectrometer, but more comparisons needed.
- Room for improvement in atmospheric correction to reduce artefacts that limit utility of some wavelength regions (for example, 1460 to 1530 nm, 1730 to 1780 nm) and affect mapping ot surface minerals (for example, identification of alunite, separation of gypsum from clays).
- Room for improvement in cross-track artefacts (such artefacts are inherent in detectors utilized for pushbroom sensors)
- NOTE: updates to L2A reflectance are underway for EnMAP and EMIT!
- As a result of seeing change in mineral maps in AVIRIS-Classic data and also EnMAP data collected at later date (July 29, 2022):
  - long-term monitoring of sensor performance and product quality over time is suggested with update to radiometric and spectral parameters, as required
  - utilize onboard cal/val, field measurements of radiance and reflectance, and repeat mineral mapping at reference sites
- Assemble global validation dataset for surface mineral composition (field and lab spectra, geologic description, XRD and other analytical results)

Thank you

22° halo during USGS fieldwork
Black Rock Desert
May 16, 2022
Photo by Raymond Kokaly