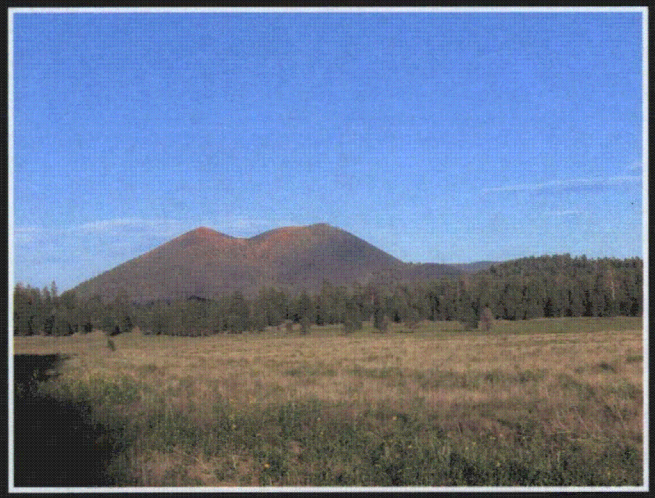
Surface Lithology, Vegetation, and Tephra Characterization Using a Combined Analysis of Optical and Radar Imagery



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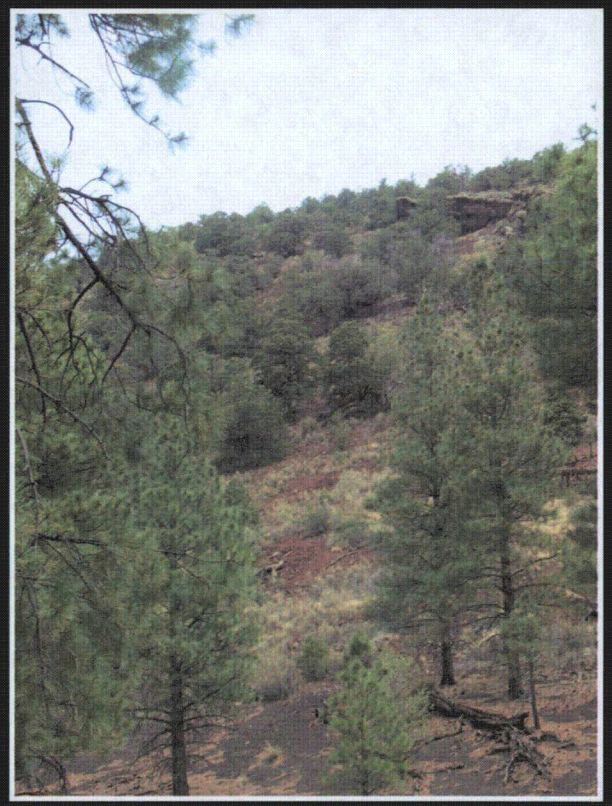
Outline

- Project Overview and Objectives
- Study Area
- Data Collection Considerations
- Targeted Classes
- Optical and Radar Processing
- Results and Discussions
- Conclusions



Introduction

Research at Sunset Crater, Arizona, offers the opportunity to study the evolution of a 900-year-old tephra deposit in a semiarid climate. This feature is an analog for both a potential eruption and the posteruption surface processes near the potential high-level waste repository at Yucca Mountain, Nevada.

Studies at analog sites are important because few data relevant to airborne transport of tephra (volcanic ash), tephra dispersal, and subsequent redistribution processes are obtainable from the Yucca Mountain area.

Introduction (cont.)

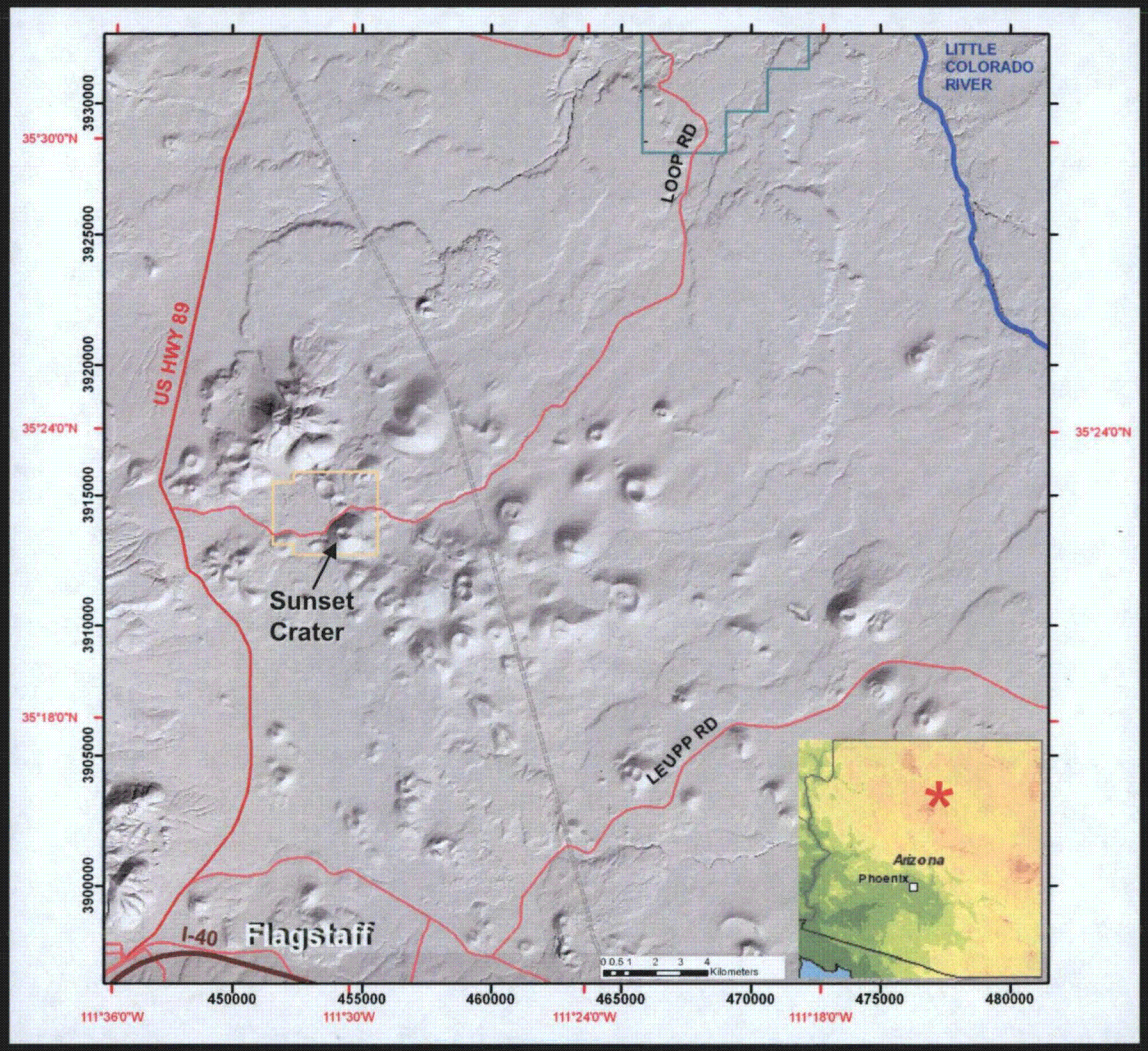
Field and laboratory data collection

- Provide basis (ground truth) for remote sensing analysis and interpretation

This analysis will be used to

- Update process-level models for tephra redistribution
- Refine model parameters for performance assessment calculations for evaluation of safety at the potential repository at Yucca Mountain

Study Area



Sunset Crater National Monument
Wupatki National Monument

DEM: Sun elev. 55 deg; az. 146 deg

Sunset Crater scoria cone viewed from the west

Location: Eastern San Francisco Volcanic Field, AZ
Study area: ~350 sq. miles

Complex environment:
Variable vegetation cover
- dense at higher elevation
- reduced and dry at lower elev.

Stratigraphic sequence describes numerous volcanic events over 1.6 million years

Project Objectives

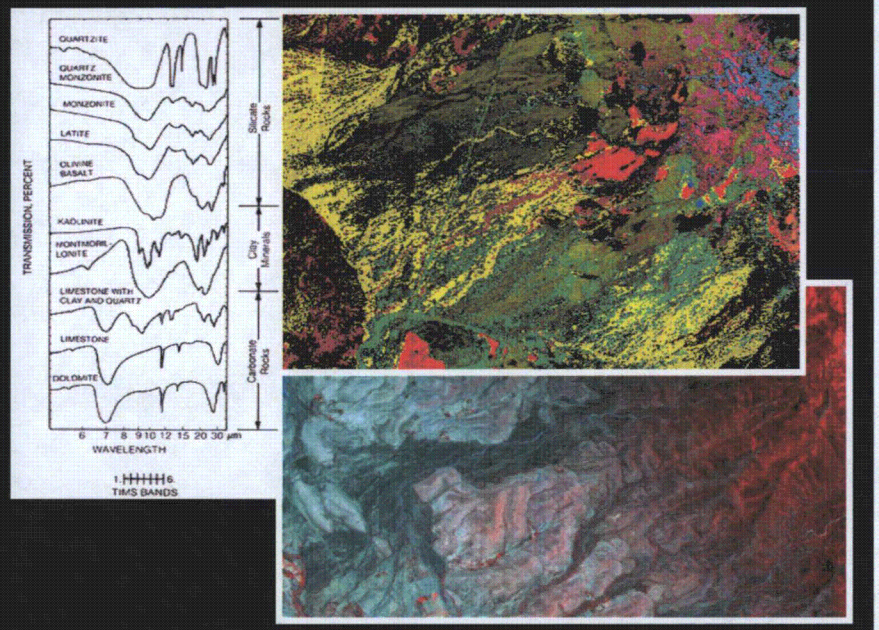
Objective: Characterization of Surface Lithology, Vegetation, and Tephra Regions Using Optical and Radar Imagery

Is it possible to use optical and radar remote sensing to

- distinguish between lava and tephra?
- characterize areas of the tephra deposit?
- detect and distinguish areas of different types of mineral alteration?
- identify and estimate the areal extent of eolian (reworked) tephra deposits?

Remote Sensing and Field Spectroscopy

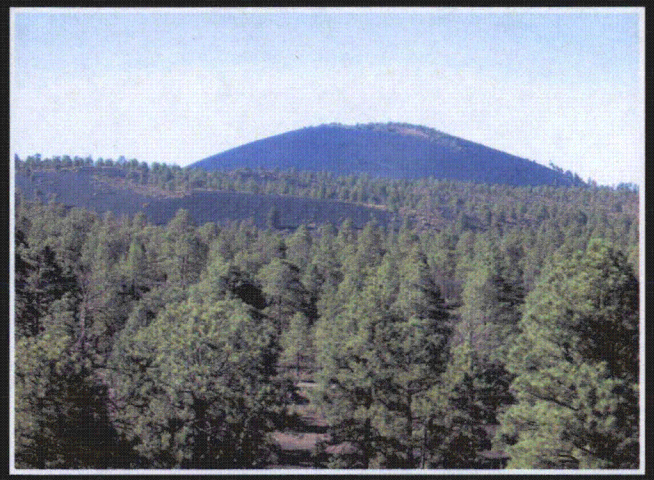
Remote Sensing was used as a methodological procedure for detecting and inventorying surface lithology, vegetation, and tephra deposits in an accurate and quantified manner.



Field/Laboratory Spectroscopy was used to study reflectance properties of vegetation, soils, and rock bodies under solar/calibrated light illumination to support remote sensing study.

Data Collection Considerations

- Staff training
- Use of data collection sheets
- Redundant measurements for quality control



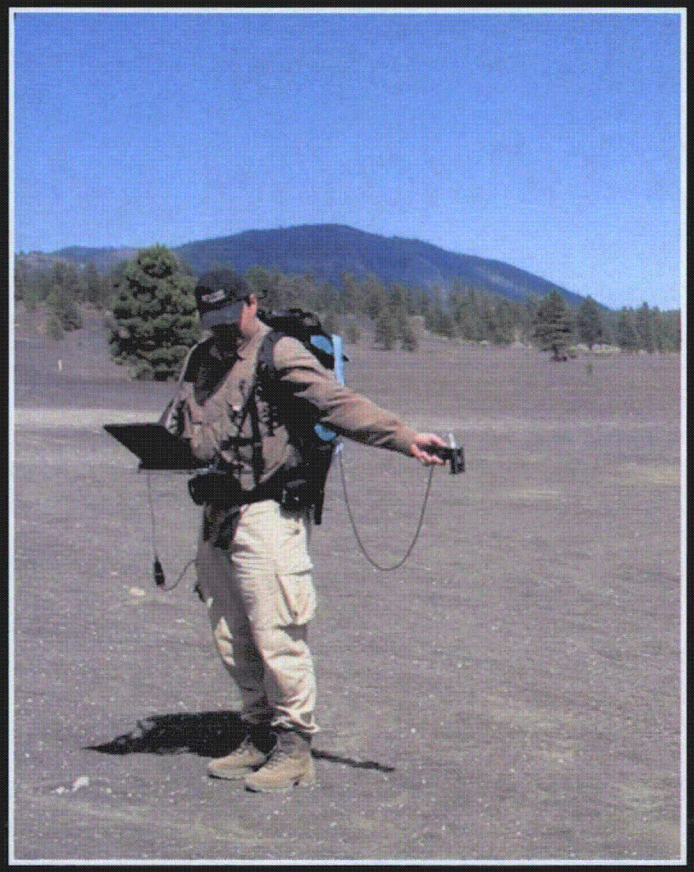
Data Collection Sheet

Weather conditions [Temp, Avg. Wind Speed (m/s), Humidity (%)]

Sample/Day,	Elevation,	Sample_Type,	Digital_Picture,	Comments
MN_mddyy-1,	xxxx.xx,	Tephra (Bare),	m-dd-yy_1.jpg,	…
MN_mddyy-2,	xxxx.xx,	Tephra (Fresh),	m-dd-yy_2.jpg,	…
MN_mddyy-3,	xxxx.xx,	Forest Duff,	m-dd-yy_3.jpg,	…
MN_mddyy-4,	xxxx.xx,	Lava (Weathered),	m-dd-yy_4.jpg,	…
….				

Optical Measurements

- Light measurements required collection of data in clear conditions or stable overcast conditions, +/- two hours centered around noon.
- When optical data collection was not possible, team performed extensive field reconnaissance and collection of geologic samples for later lab analysis.
- Measurements
  - Bare fiber as foreoptic
  - Controlled spot size
  - Reasonable samples per spot/few sample spots
  - Optimization using a Spectralon Panel



Targeted Surface Lithology Classes

Primary Tephra

Moenkopi Formation

Kaibab Formation/Riverbed

Eolian Tephra Deposits

Oxidized Tephra Deposits

Targeted Vegetation Classes

Ponderosa Pine (*Pinus ponderosa*)

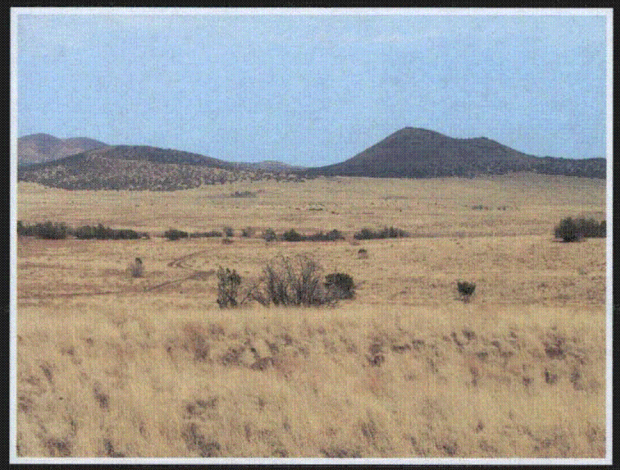
Woodland

Utah Juniper (*Juniperus osteosperma*)
Pinyon Pine (*Pinus edulis*)

Apache Plume (*Fallugia paradoxa*)

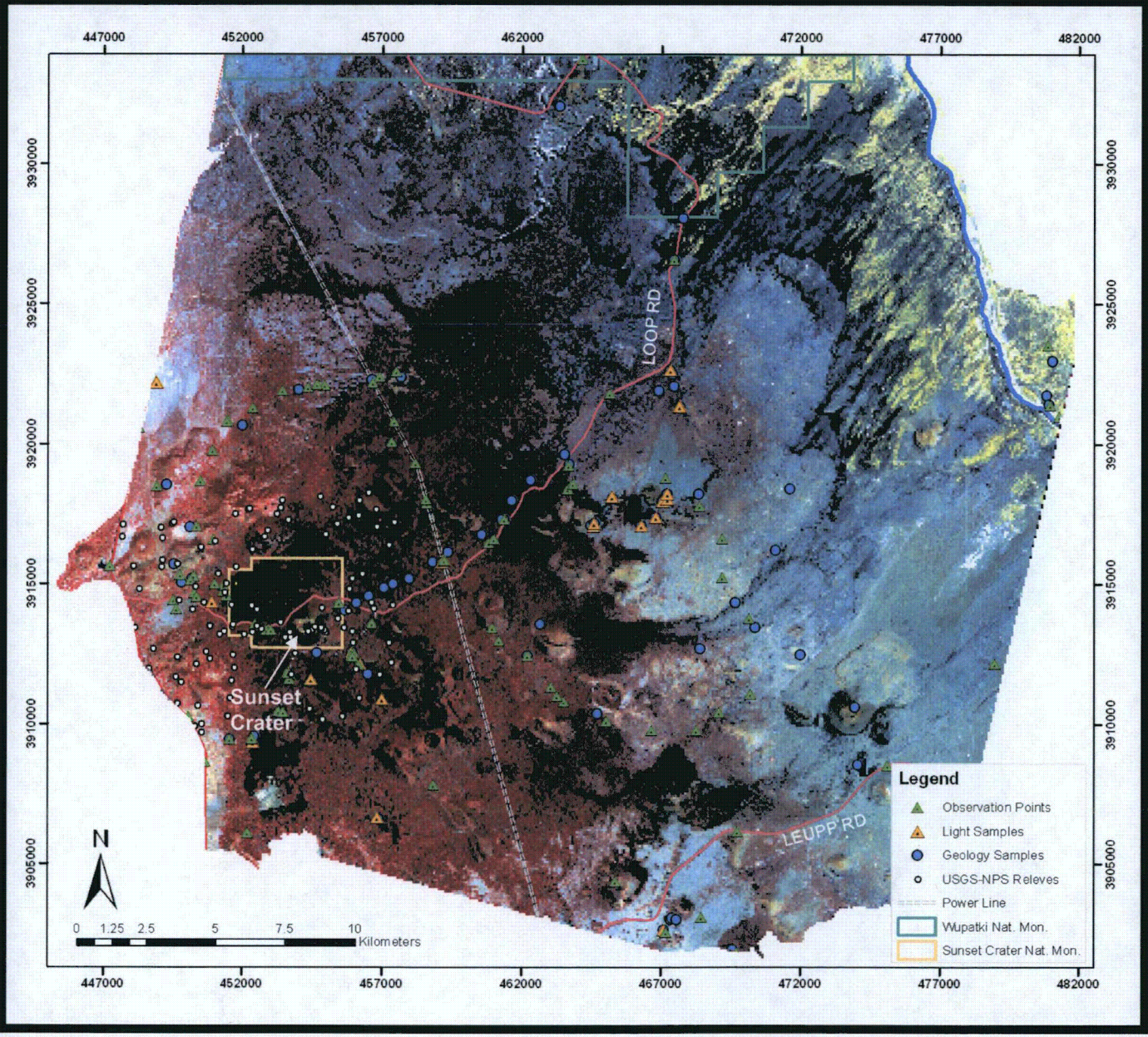
Shrubs

Grasslands / Herbaceous Vegetation



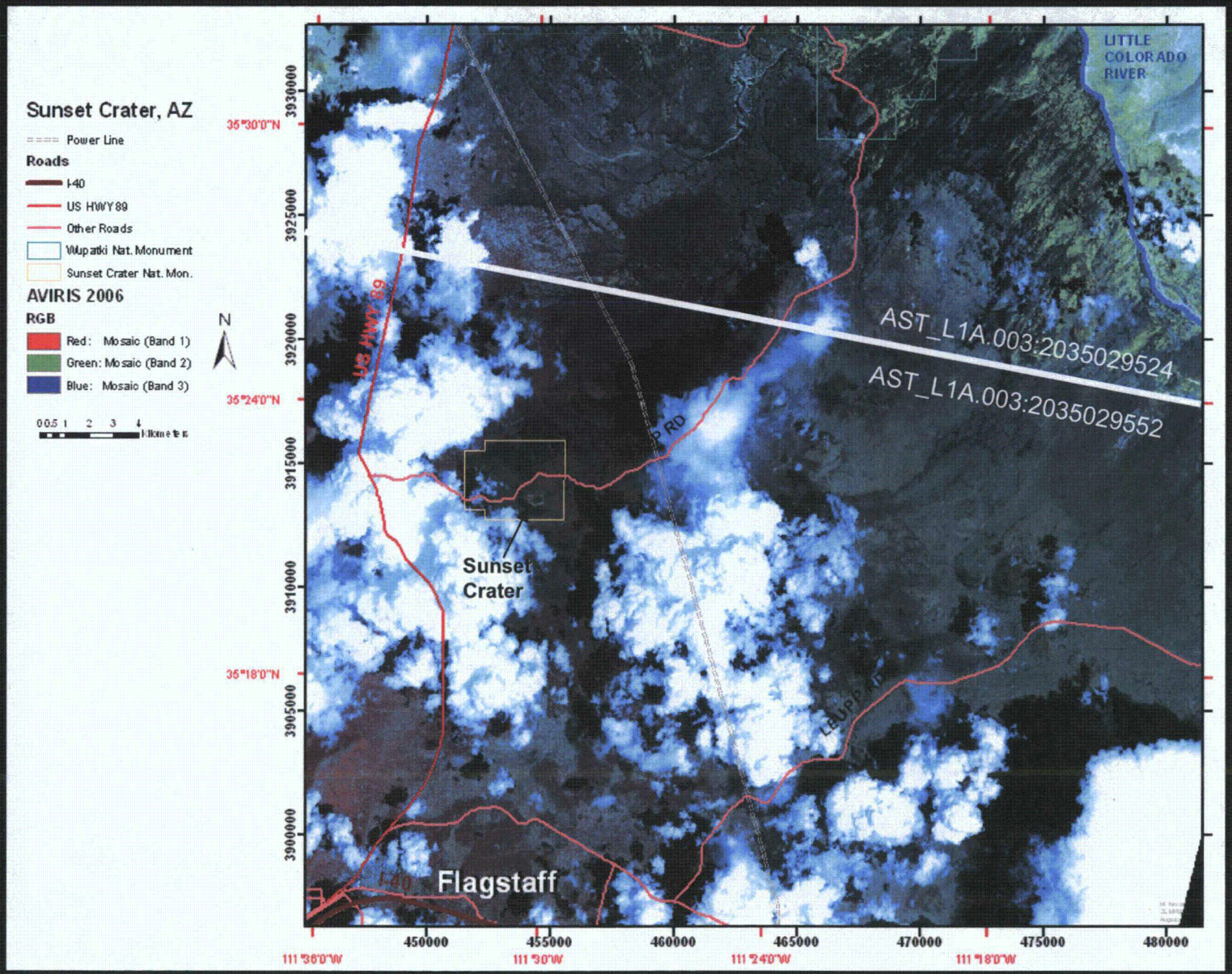
Blue Gramma (*Boutelua gracilis*)

Data Collection Sites



2006 ASTER Data

over 51% of area unusable



Comprehensive GIS Database of Field and Ancillary Data

A. Imagery Data

Satellite

-ASTER and Landsat

-ETM optical datasets (NASA, USGS)

Airborne

- AIRSAR polarimetric radar dataset (JPL)
- Orthoimagery (via NRCS)

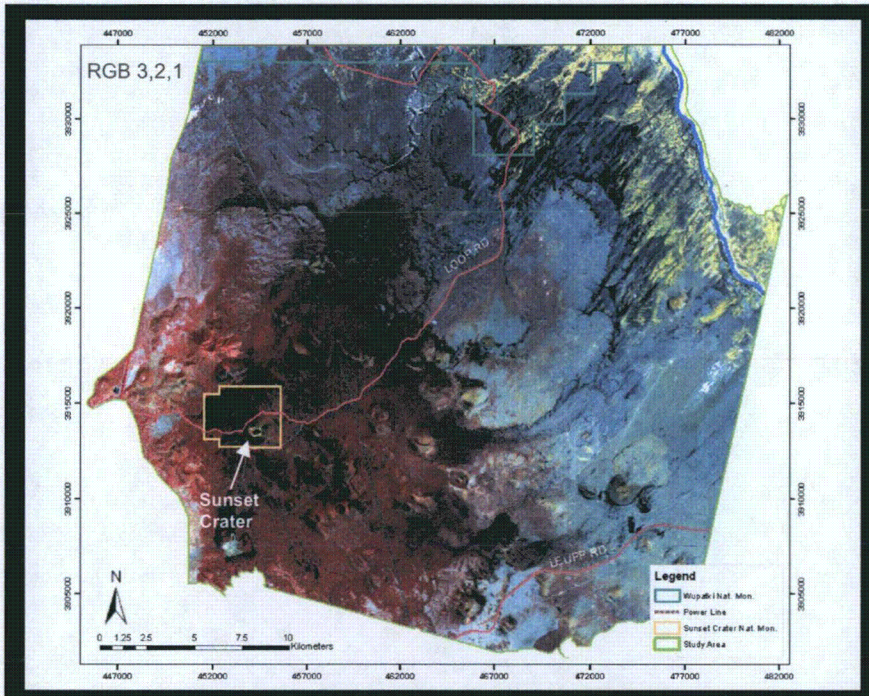
Imagery	Date and Time (GT)	Spectral Range/ Radar Band	WRS
ASTER	April 2, 2002	VIS/NIR	
Landsat ETM+ 00	June 6, 2000 17:55:03	VIS/NIR	P037 R035
Landsat ETM+ 99	Sept 8, 1999 17:56:06	VIS/NIR	P037 R035
AIRSAR POLSAR	March 29, 2002	C,L,P	

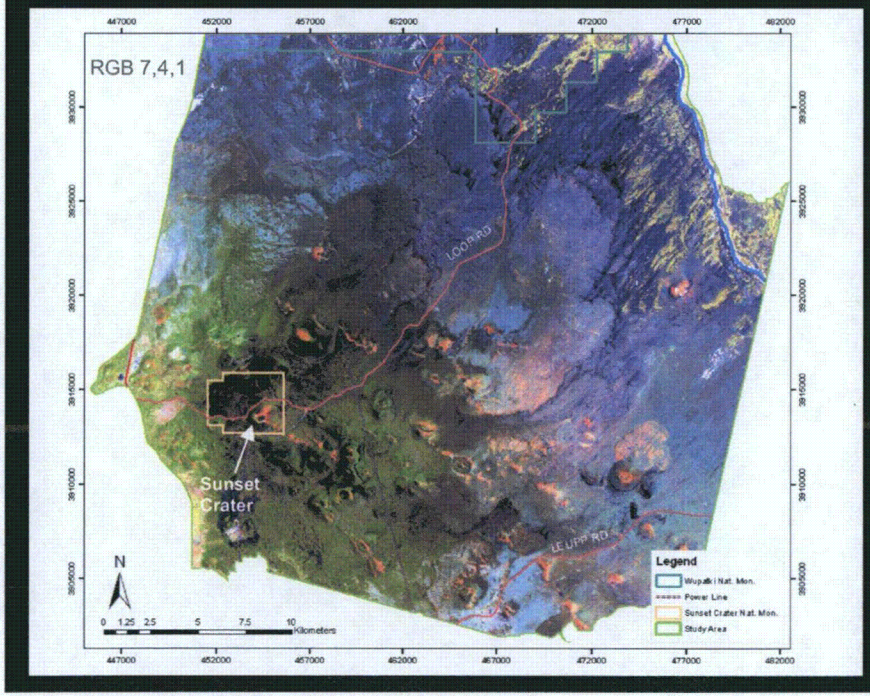
B. Grid Data

- 10m NED datasets (USGS)

C. Vector Data

- National forest boundaries (U.S. Forest Service, Southwestern Region)
- Sunset Crater Volcano National Monument vegetation map (USGS/NPS)
- Terrestrial survey of the Coconino National Forest (U.S. Forest Service)
- Geology data (via NPS)
- Climate, elevation, soils (via NRCS)
- GIRAS Landuse/Landcover data at 1:250,000 (USGS)
- ESRI data (ESRI)





ASTER

16-bit AST_07 Surface Reflectance Product

Data previously corrected for solar illumination effects, gaseous absorption, and molecular scattering

Atmospheric corrections
Sources:

- Aerosol Product - Climatology
- Column Ozone Product - NCEP/TOVS
- Climatology Temperature/Pressure/Moisture Profile - NCEP/GDA

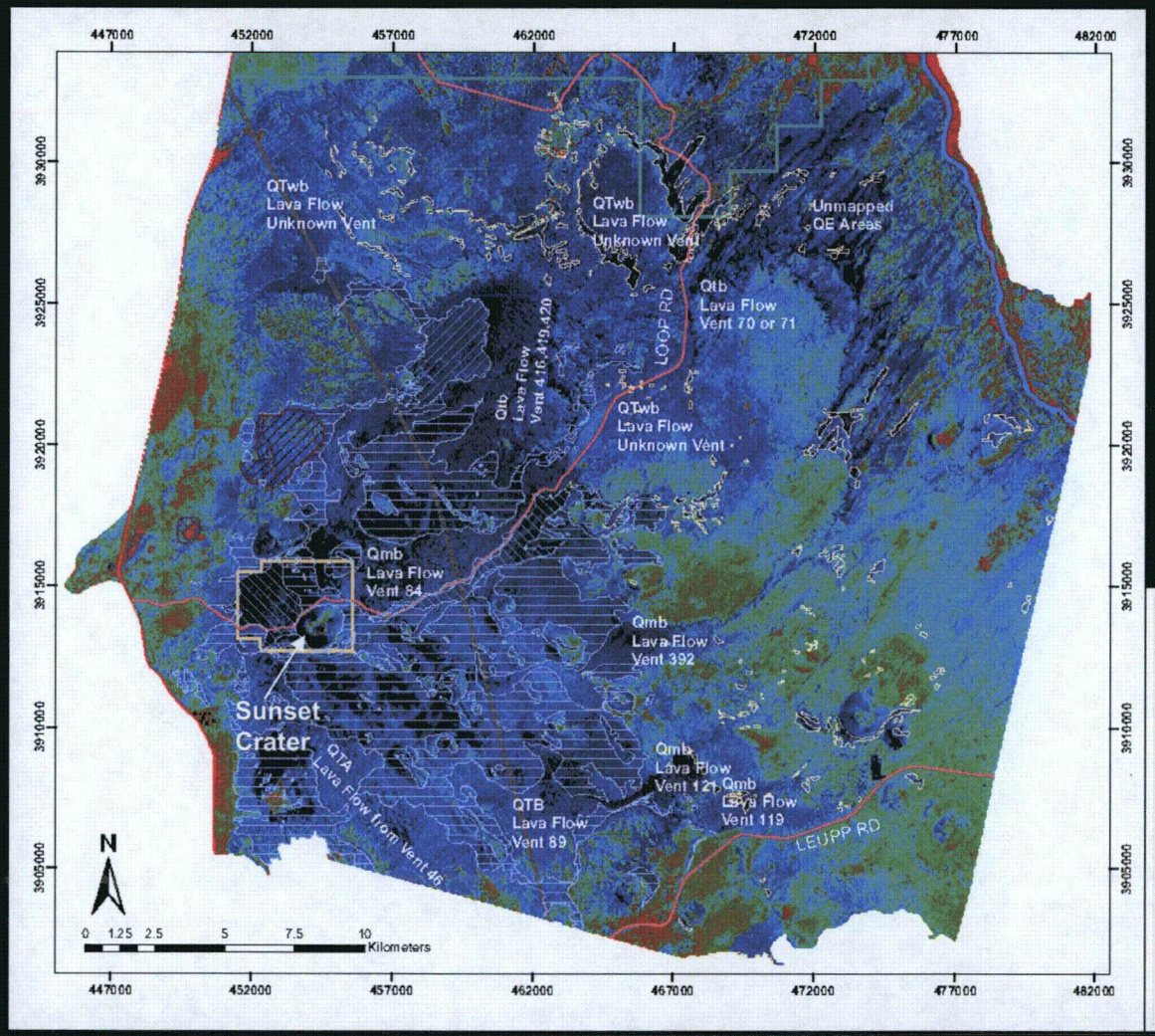
Conversion to reflectance (factor 0.001)
Subset and reprojection
Registration to 1m orthoimagery

Landsat ETM+

Level 1G data
Conversion to radiance
Radiance to reflectance
Subset and reprojection
Registration to 1m orthoimagery

Landsat ETM+

Kauth-Thomas Tasseled Cap Transformation



Brightness Channel

Legend

- Wupatki Nat. Mon.
- Power Line
- Sunset Crater Nat. Mon.
- Quarries

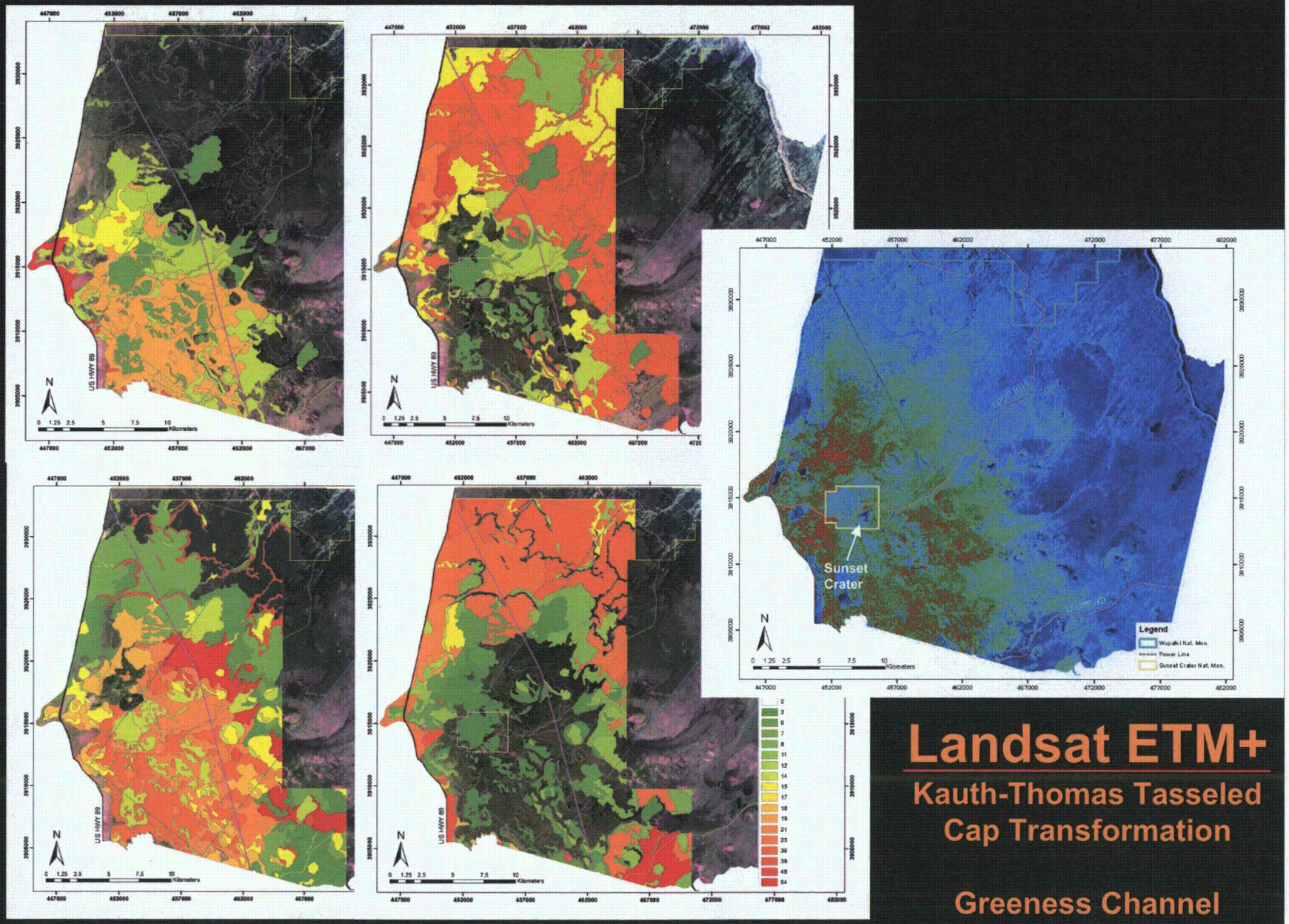
Geologic Units

GLG_SYM

- Eolian Deposits - Qe
- BA Flow - Qma
- Bonito & Kana-a flows - Qsb
- Basalt Cinder Cone of SC - Qsc
- Rhyodacite Obsidian Flow- Qoo
- Rhyodacite Obsidian Flow Vent - Qoov
- Rhyodacite Dome - Qorr
- Basaltic Pyroclastic Sheet - Qsp

% Ponderosa Pine (CNF)

% Pinyon Pine/Junipers (CNF)



Landsat ETM+

Kauth-Thomas Tasseled Cap Transformation

Greeness Channel

% Shrubs (CNF)

% Grasses (CNF)

Why Data Fusion?

Factors that could cause misclassifications include

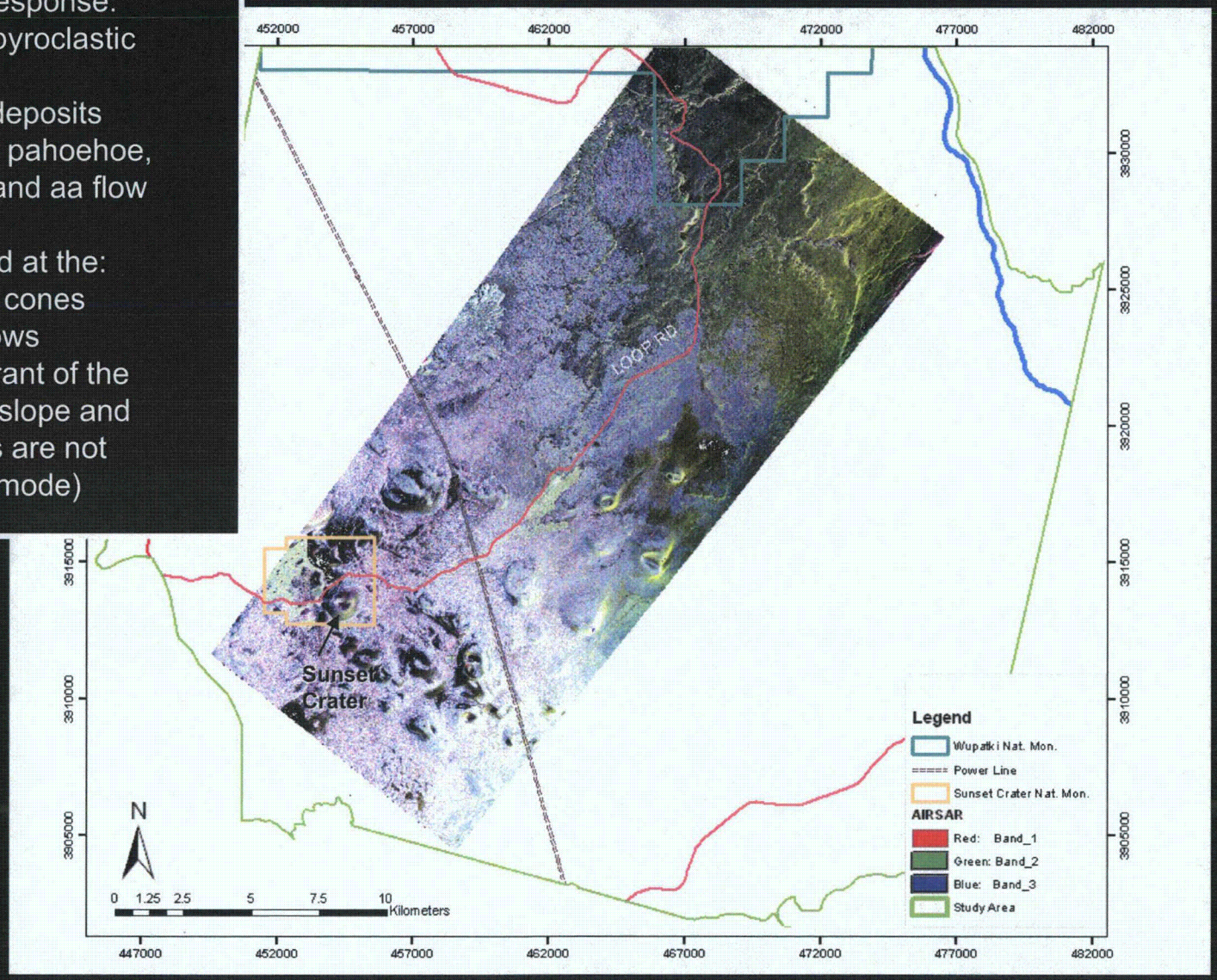
- Similar soil/rock composition, which results in similarly detected optical or radar signal

- Movement of weathering products or rock types covering other units

- Inadequate spectral/frequency range, radiometric or spatial resolution for correct identification of ground targets

AIRSAR

- Low backscattering response:
  - Fresh basaltic pyroclastic deposits (QSP)
  - Fresh primary deposits
  - Lava flows with pahoehoe, slab pahoehoe, and aa flow surfaces
- Fresh tephra localized at the:
  - Slope of cinder cones
  - Edge of lava flows
- Artifacts on SE quadrant of the image (corrections for slope and backscatter law effects are not corrected in POLSAR mode)



Noncoherent Decomposition via Freeman-Durden Model

Models the covariance matrix as the contribution of three scattering mechanisms:

- Volume scattering where a canopy scatterer is modeled as a set of randomly oriented dipoles

$$\langle [C_3] \rangle_v = f_v \begin{bmatrix} 1 & 0 & 1/3 \\ 0 & 2/3 & 0 \\ 1/3 & 0 & 1 \end{bmatrix}$$

$$P_v = \frac{8 f_v}{3}$$

- Double-bounce scattering modeled by a dihedral corner reflector

$$[C_3]_d = f_d \begin{bmatrix} |\alpha|^2 & 0 & \alpha \\ 0 & 0 & 0 \\ \alpha^* & 0 & 1 \end{bmatrix}$$

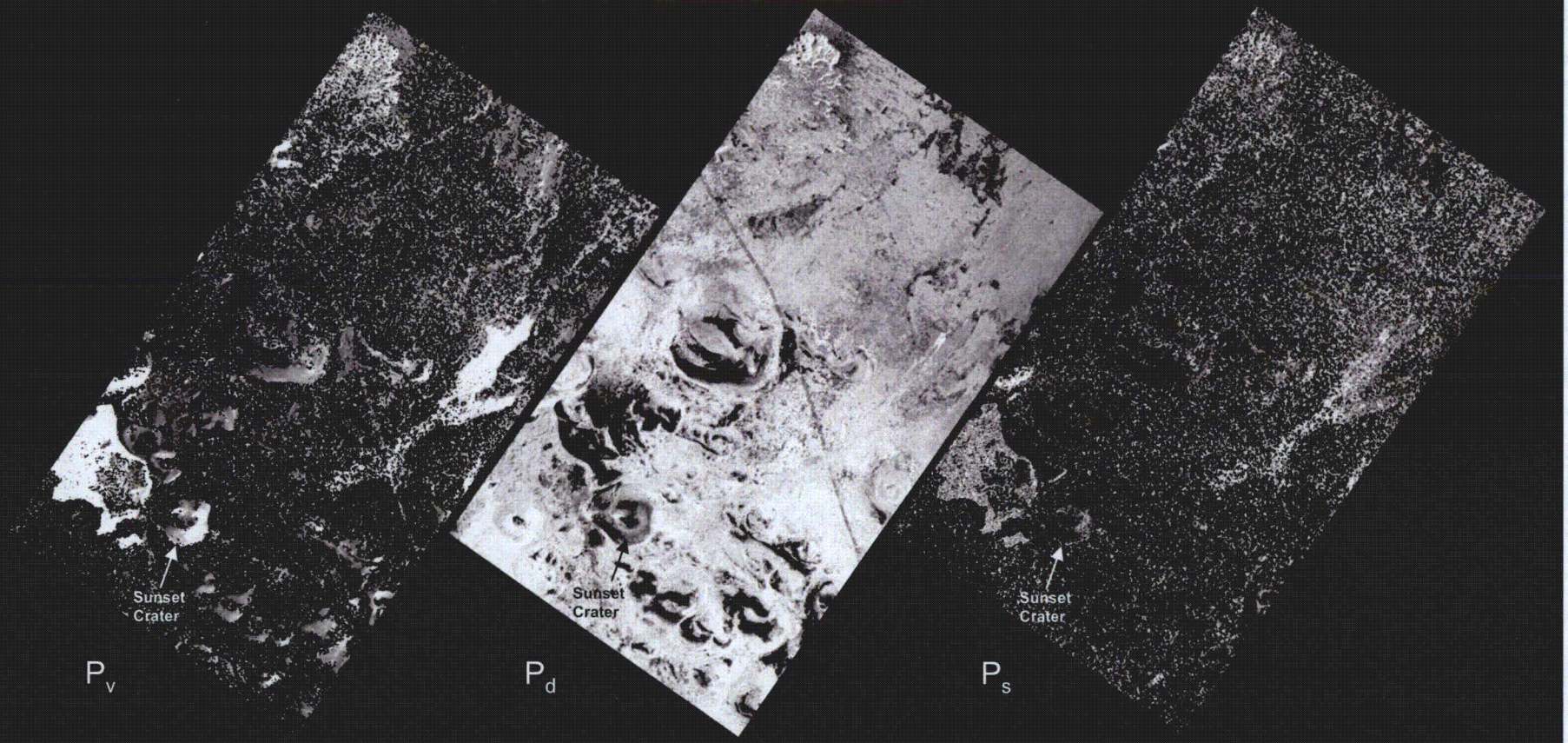
$$P_d = f_d \left(1 + |\alpha|^2\right)$$

- Surface or single-bounce scattering modeled by a first-order Bragg surface scatterer

$$[C_3]_s = f_s \begin{bmatrix} |\beta|^2 & 0 & \alpha \\ 0 & 0 & 0 \\ \alpha^* & 0 & 1 \end{bmatrix}$$

$$P_s = f_s \left(1 + |\beta|^2\right)$$

Noncoherent Decomposition via Freeman-Durden Model (cont.)



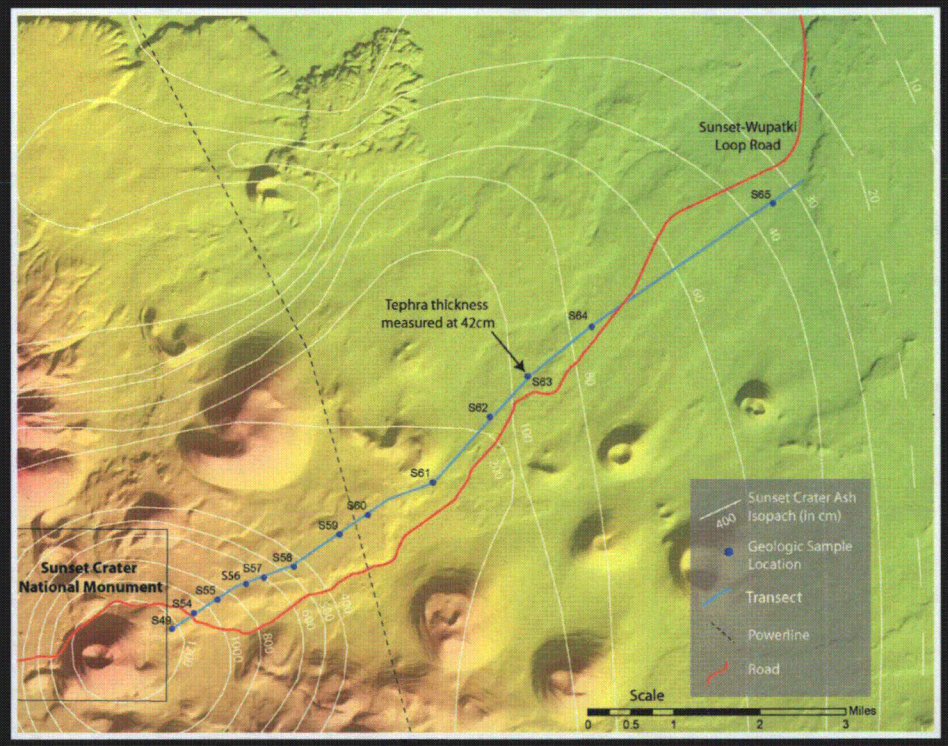
P_v — surface or single-bounce scattering

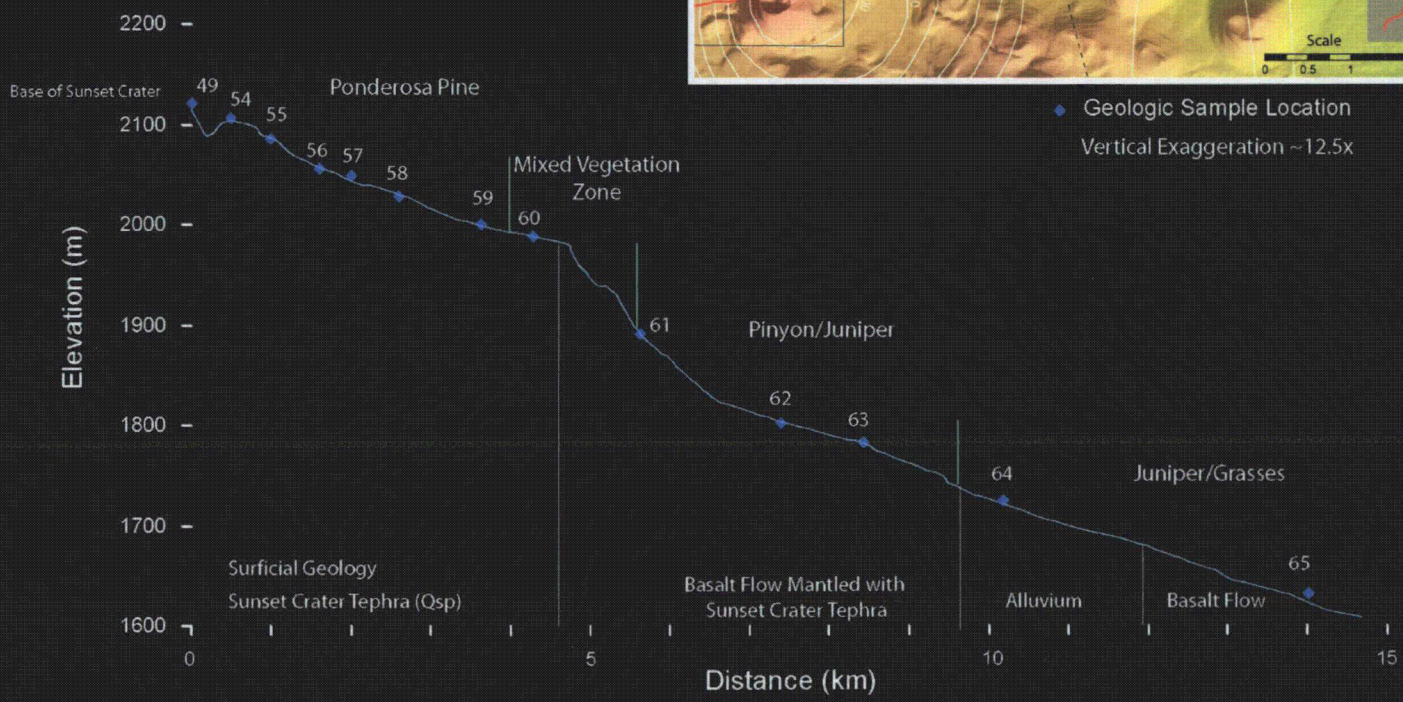
P_d — volume scattering

P_s — double-bounce scattering

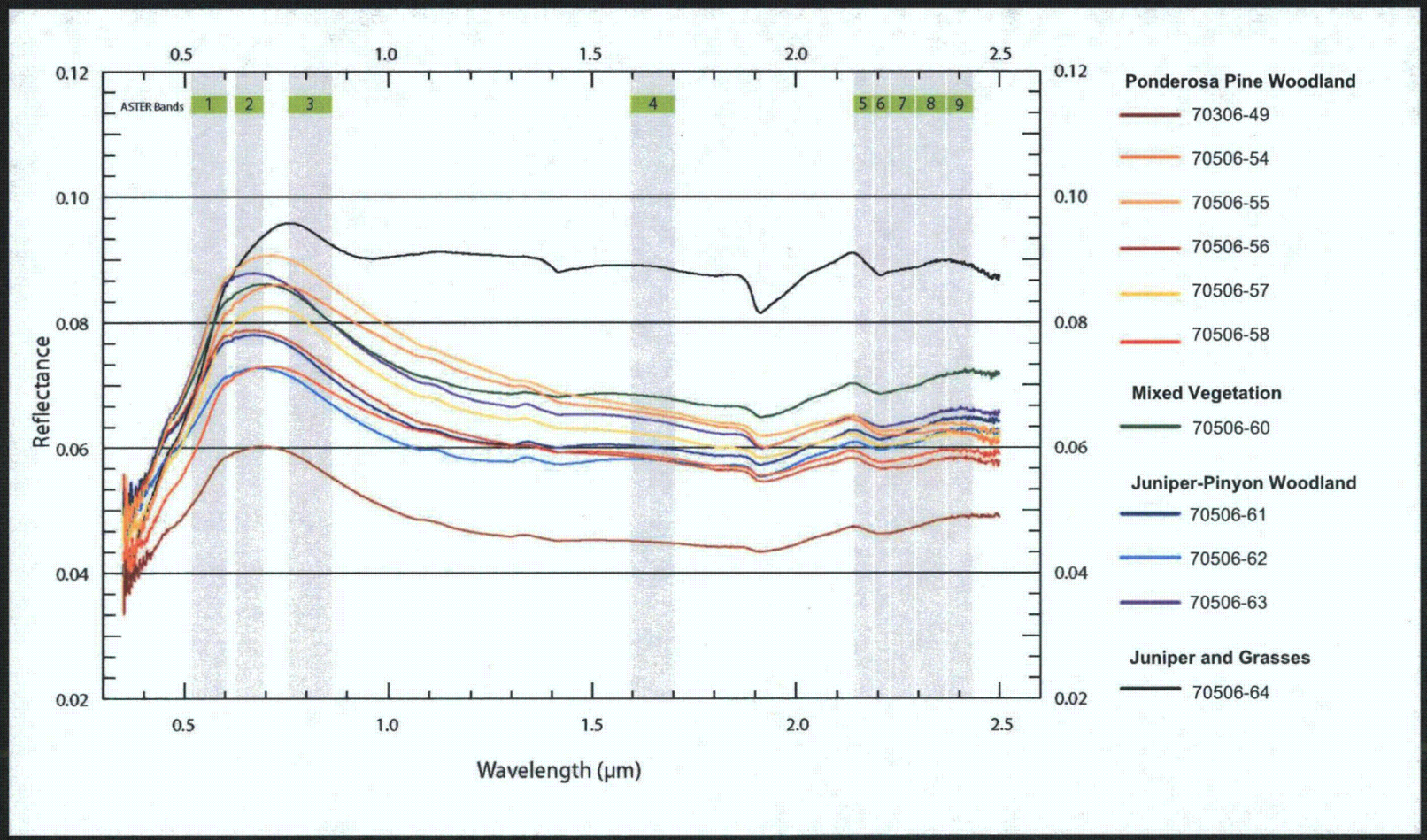
Intensities corresponding to the Freeman-Durden decomposition Pv, Pd, and Ps. Images are shown in a dB scale.

Geologic Sample Locations on a 15km Transect With Vegetation Distribution by Elevation





Spectral Response of Tephra Samples



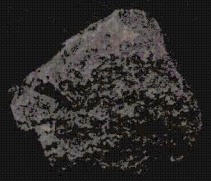
81505-1
Tephra

81505-2
Fresh Tephra

81505-3
Forest Duff

81505-4
Weathered Lava

81505-5
Alluvium

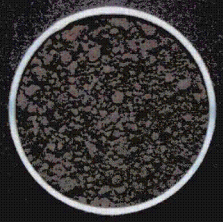

81505-6
Old Lava

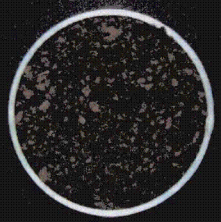
81505-7
Moenkopi Sandstone

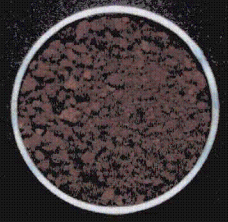
81505-8
Eolian Tephra

81505-9
Kaibab Sandy Limestone

81705-1
Reworked Tephra - Forest


81705-2
Reworked Tephra

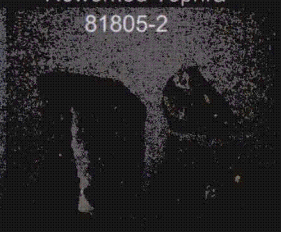

81705-3
Reworked Tephra


81705-4
Oxidized Tephra

81705-5
Oxidized Tephra

81705-6
Fumarolic Altered Rocks

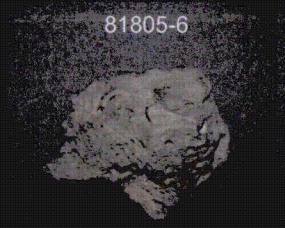
81805-1
Weathered Rhyodacite

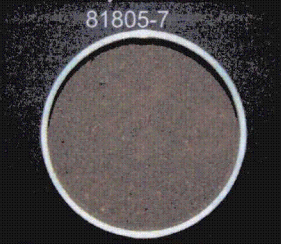

81805-2
Rhyodacite

81805-3
Strawberry Crater

81805-4
Moenkopi Sandstone

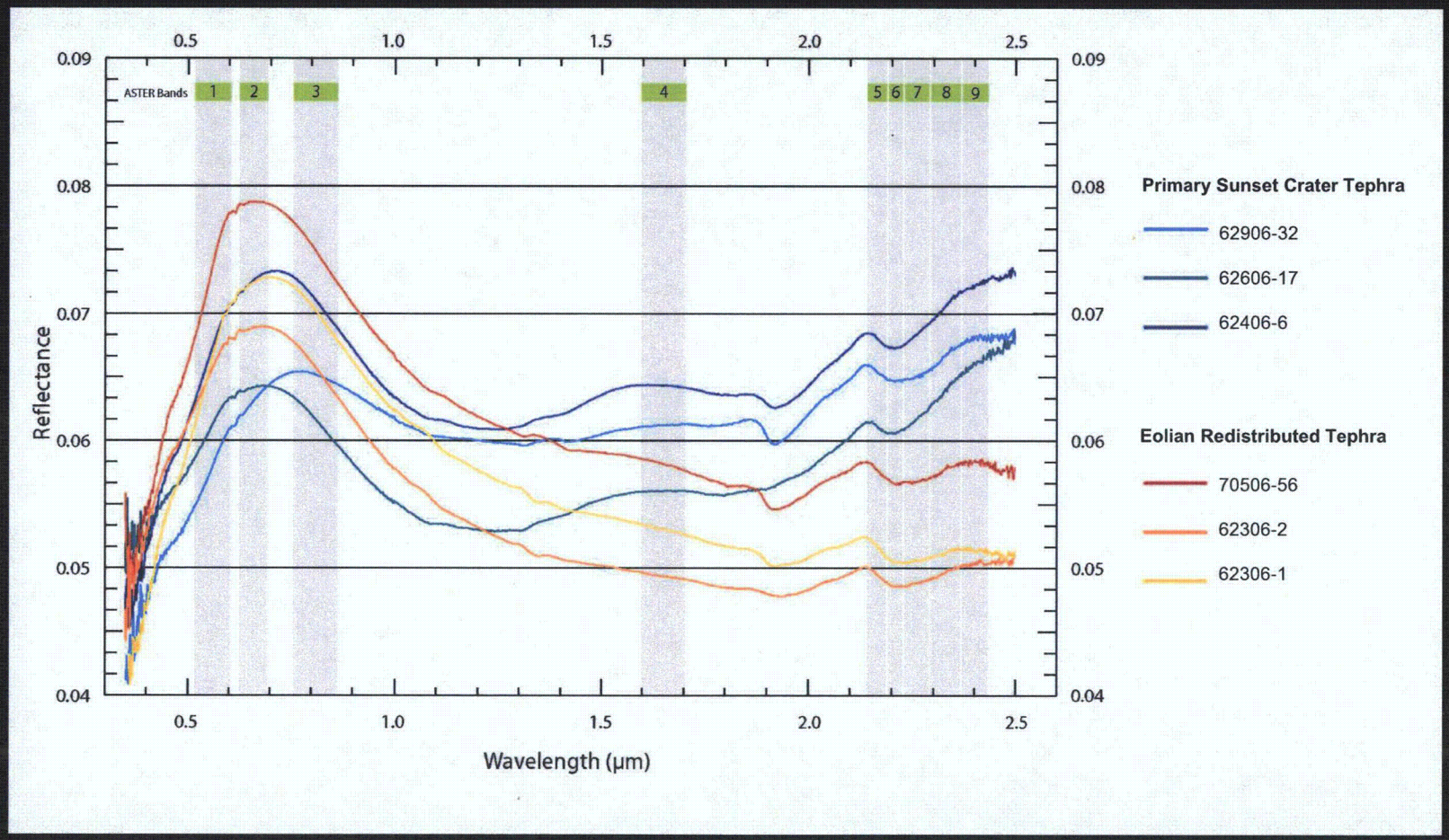
81805-5
Fluvial Sand


81805-6
Basalt

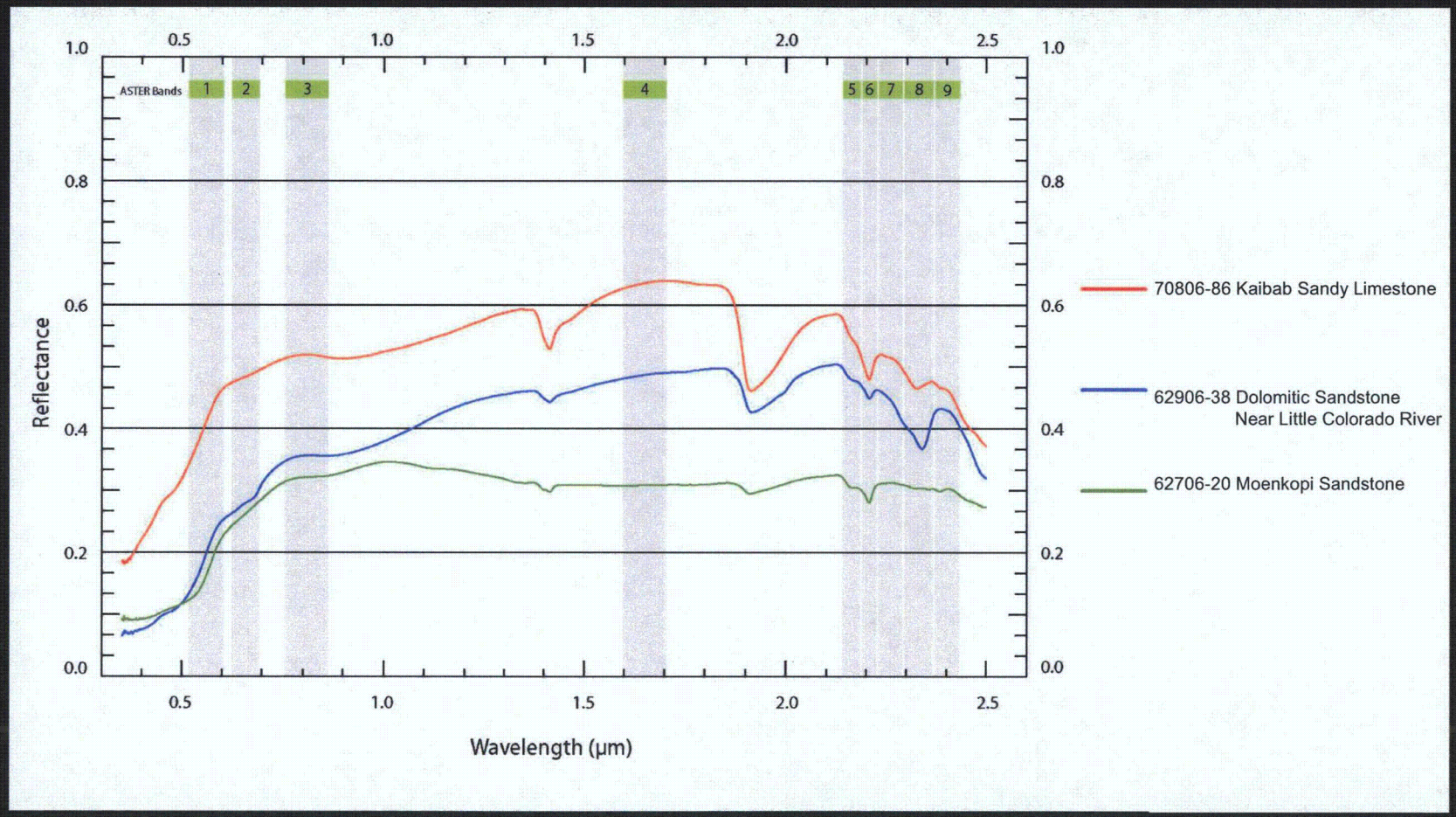

81805-7
Tephra - Little Colorado

81805-8
Kaibab Sandy Limestone

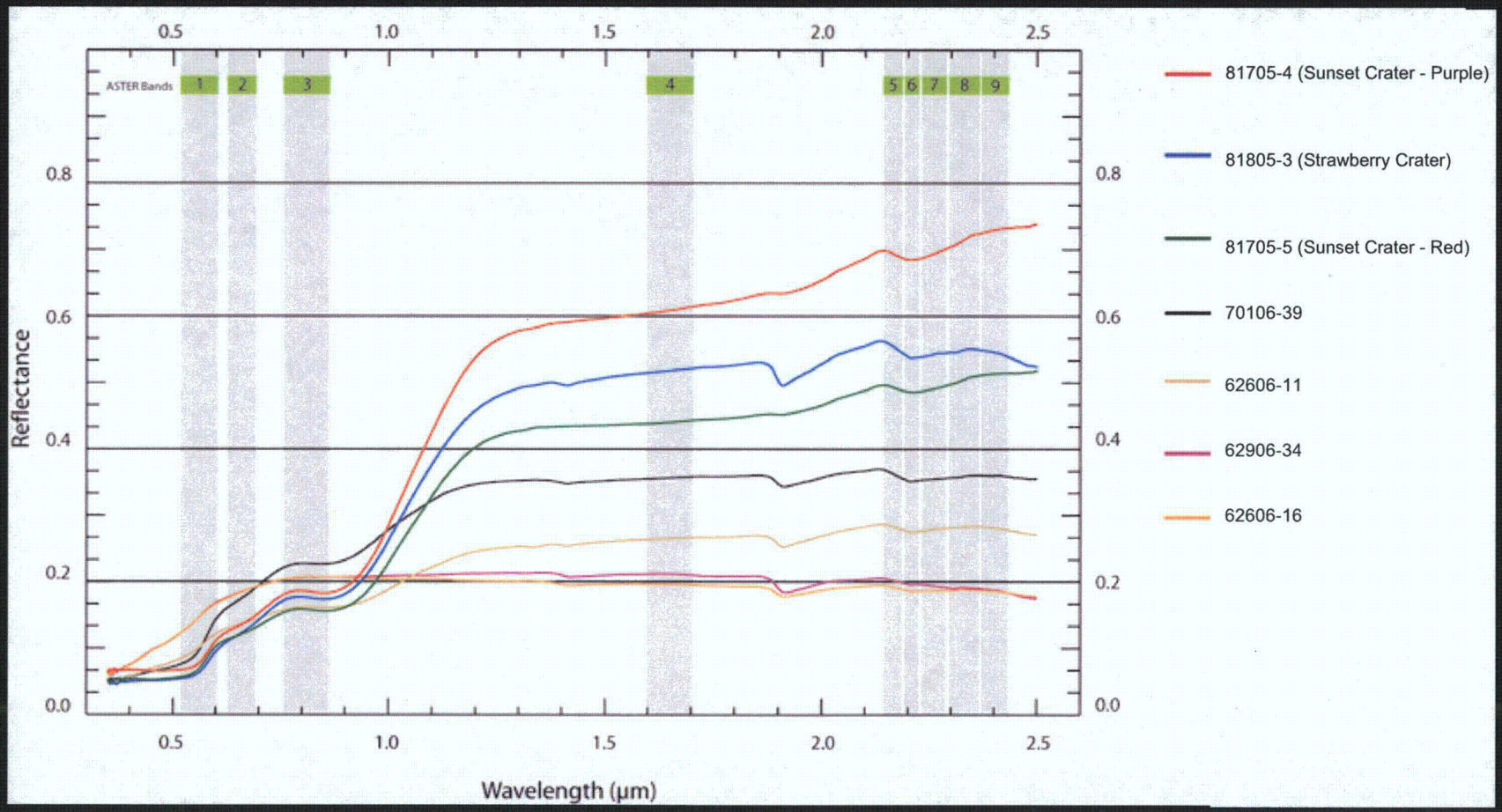
Spectral Response of Primary Sunset Crater Tephra vs. Eolian Redistributed Tephra



Spectral Response of Sedimentary Rocks

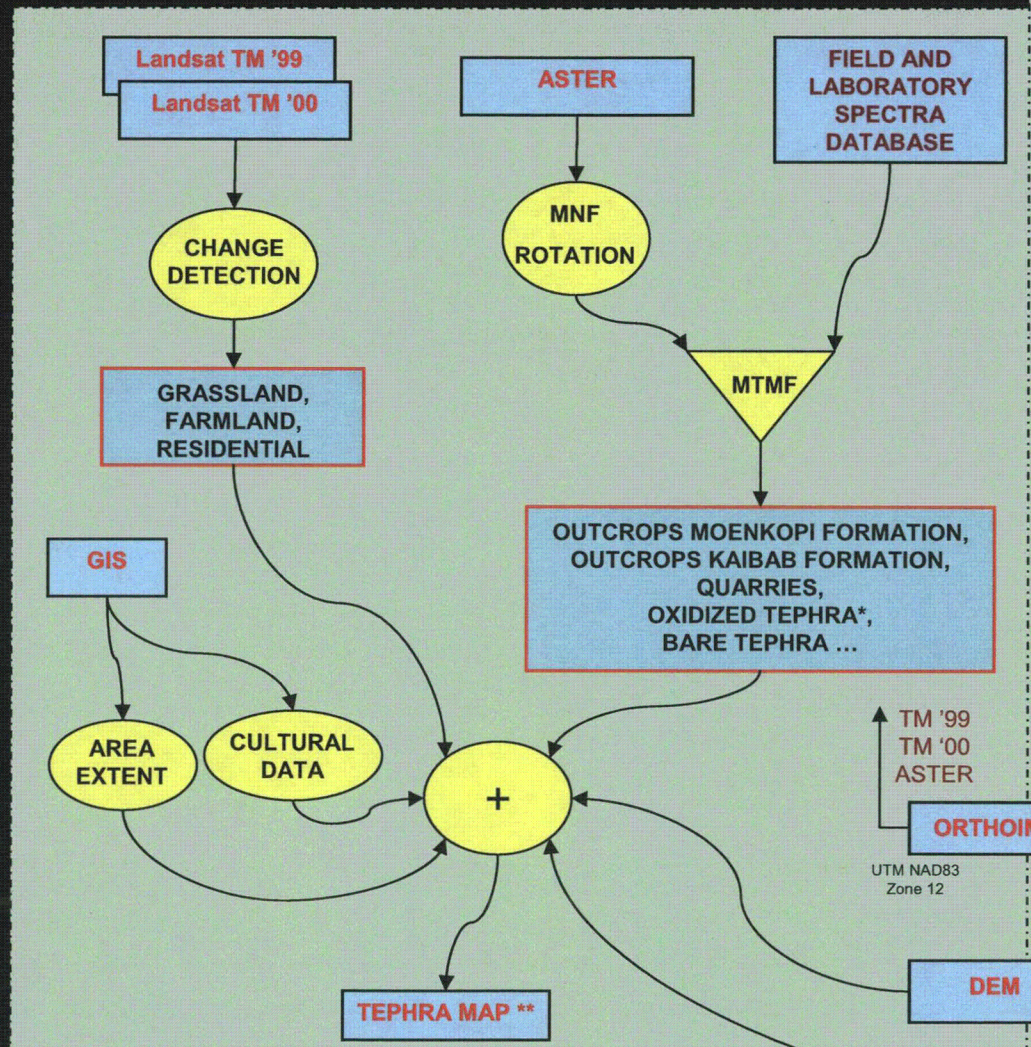


Spectral Response of Oxidized Tephra



0.86 µm Hematite
1.4, 1.9, 2.2-2.3 µm Phyllosilicate

Knowledge-Based Approach for Analysis of Field Data and Imagery



MNF = Minimum Noise Fraction; MTMF = Mixture Tuned Matched Filter
* Strawberry Crater, Sunset Crater, Old Oxidized Tephra
** Primary, Eolian, Alluvium Tephra + Expert System by Simple Decision Rules

The Knowledge-Based Approach

Advantages

- Rule sets are focused on each particular sensor, and the results could be updated at a later time when new sources of optical or radar data become available.

- This approach allows for the introduction of *a-priori* knowledge into the classification process, reducing errors of omission and commission.

Conclusions

- The methodology uses a knowledge-based approach to decompose the multisource, multisensor problem into a set of individual analyses that are later combined for a joint analysis.

- AIRSAR proved to be a valuable tool for separating lava- versus tephra-covered areas. It had, however, limited power to map the volcanic material due to highly vegetated areas covering tephra.

- Each scatterer was accurately identified to a basic scattering mechanism using efficient polarimetric indicators. The results of this identification were used to map lava deposits and supplement the overall classification of the study area.

Conclusions (cont.)

- Optical remote sensing data proved to be useful in detecting areas affected by eolian remobilization. Large eolian deposits could be relatively easily extracted; however, difficulties in misclassification occurred for areas affected by mixed surface covering.

- Spectral analysis of geologic data provided means to separate primary from eolian tephra and oxidized Sunset Crater from Strawberry Crater and pre-Sunset material, aiding the overall classification process.

- Refining and validating this problem-driven approach is planned for mid-2007.

Acknowledgments

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John Roseberry, Ronald N. McGinnis, Lawrence McKague (SwRI)

Credits

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USGS-NPS National Vegetation Mapping Program: Sunset Crater Volcano National Mon., AZ;

Terrestrial Ecosystem Survey of the Coconino National Forest, AZ, U.S. Forest Service.

Disclaimer

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