Remote Sensing Assessment of Volcanic Debris-Flow Hazards: Synergistic Uses of Spaceborne Hyperspectral, Multispectral, and Digital Topographic Datasets

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INTRODUCTION

Volcanic debris flows are extremely dangerous natural phenomena:

*Capable of moving long distances and affecting large areas
*Debris flows can occur with little precursory warning

Many volcanic debris flows involve slope failures in areas of hydrothermally altered rocks:

*Such rocks contain secondary clay and sulfate minerals and typically are weaker than unaltered rocks
*Alteration commonly is associated with fracture systems that may also contribute to reducing the rock mass strength

OBJECTIVES

*Explore utility of EO-1 data for mapping altered volcanic rocks that may represent potential debris flow source areas.

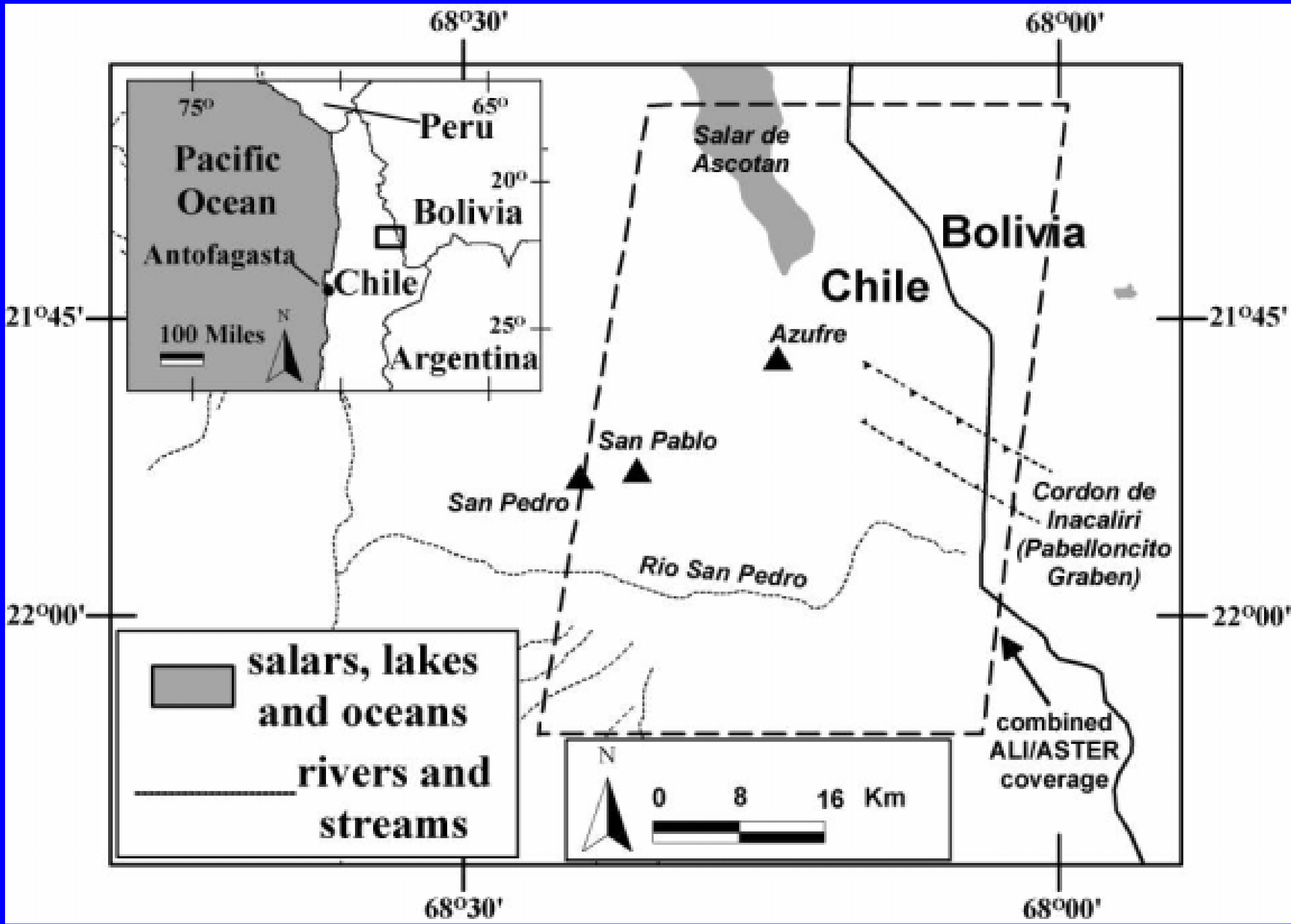
*Develop remote sensing and modeling methods for quantifying and comparing source area characteristics

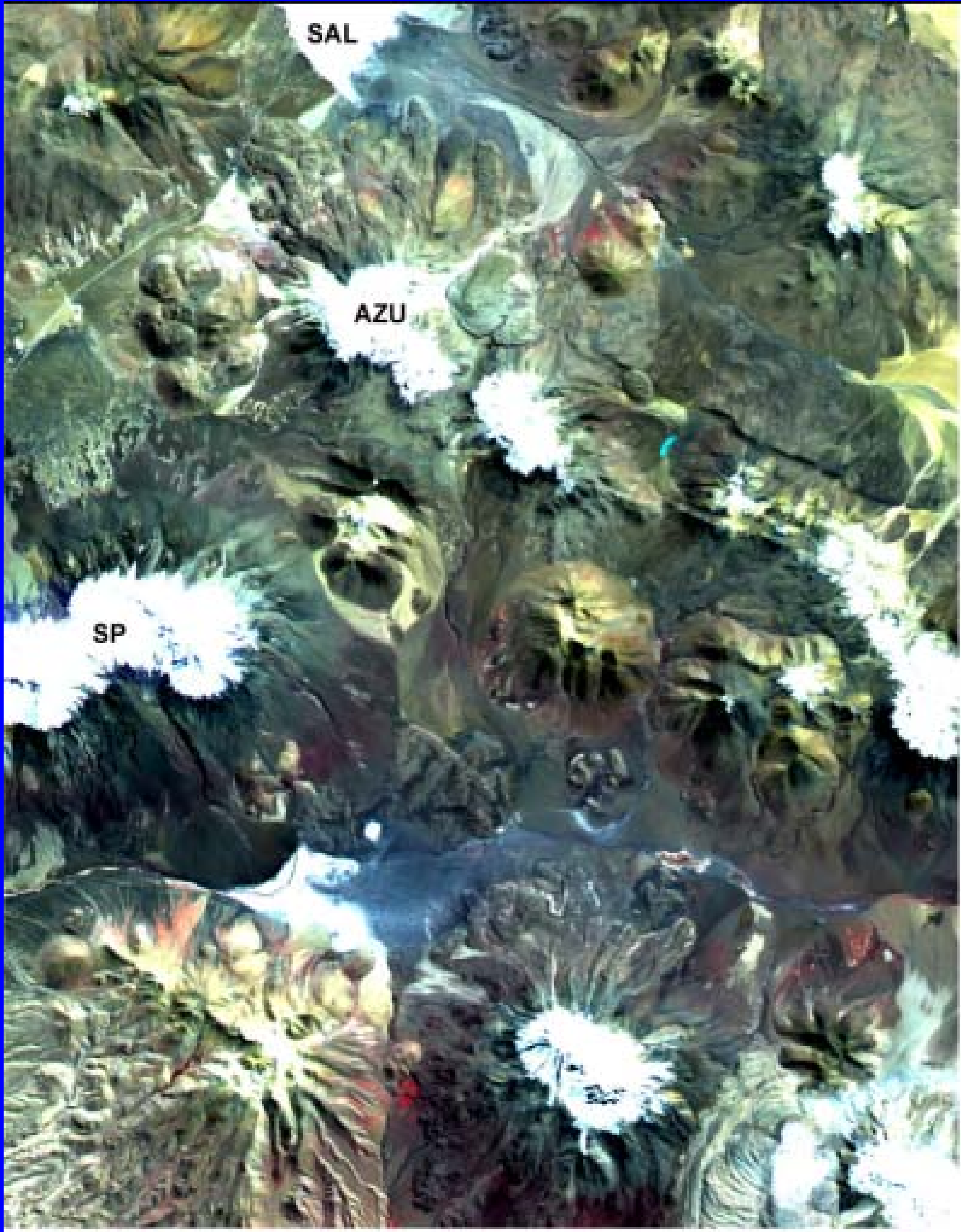
*Examine cross-calibration and other synergies between EO-1 and Terra sensors

APPROACH

*Utilize data from relatively well-known Cascade volcano sites as well as data from poorly-known South American sites

AZUFRE, CHILE, STUDY AREA





ALI Browse Image—

Azufre Study Area

(approx. 36 X 42 km)

Azufre, Chile: General views

METHODS—Azufre, Chile

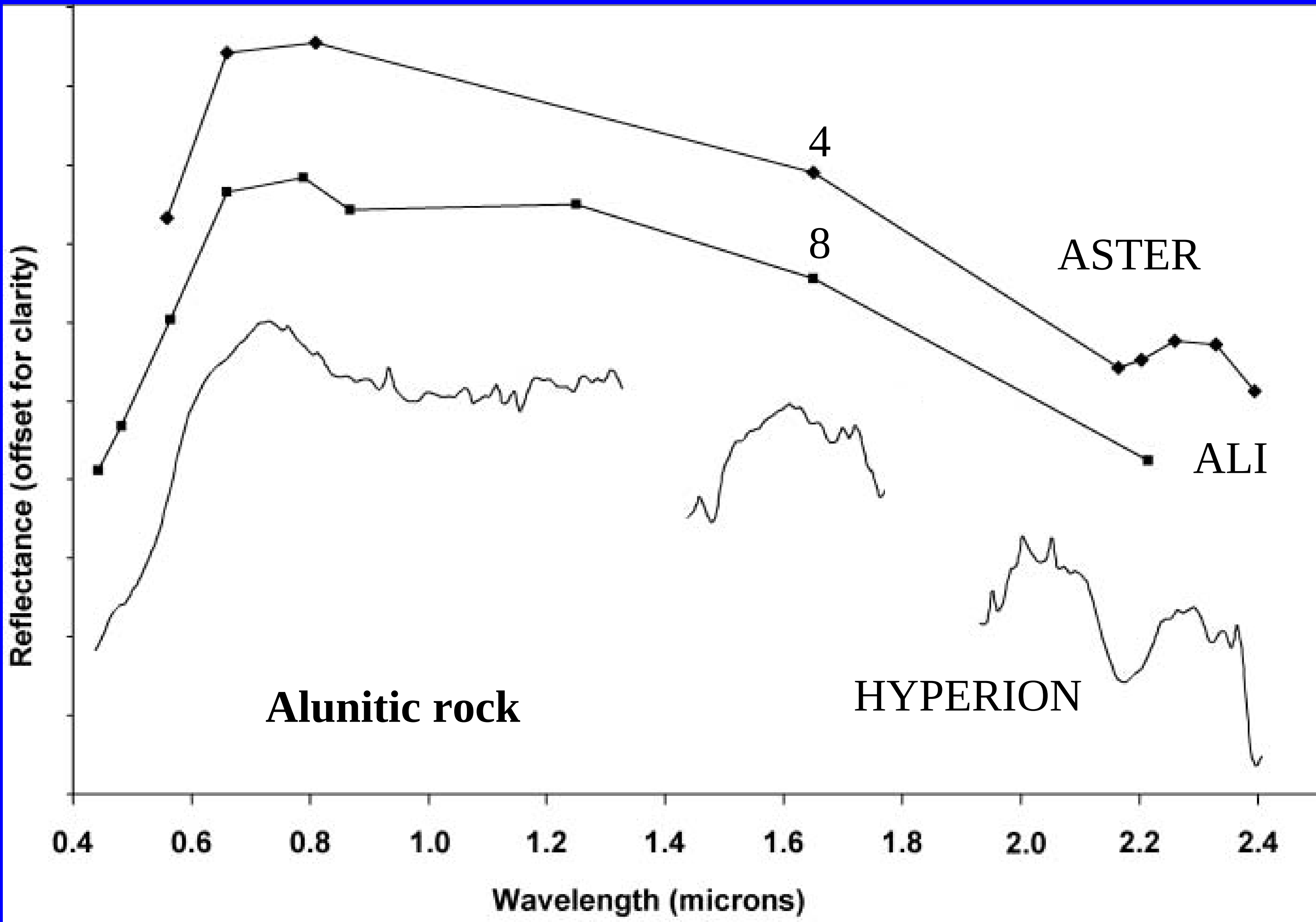
*Hyperspectral to multispectral calibration

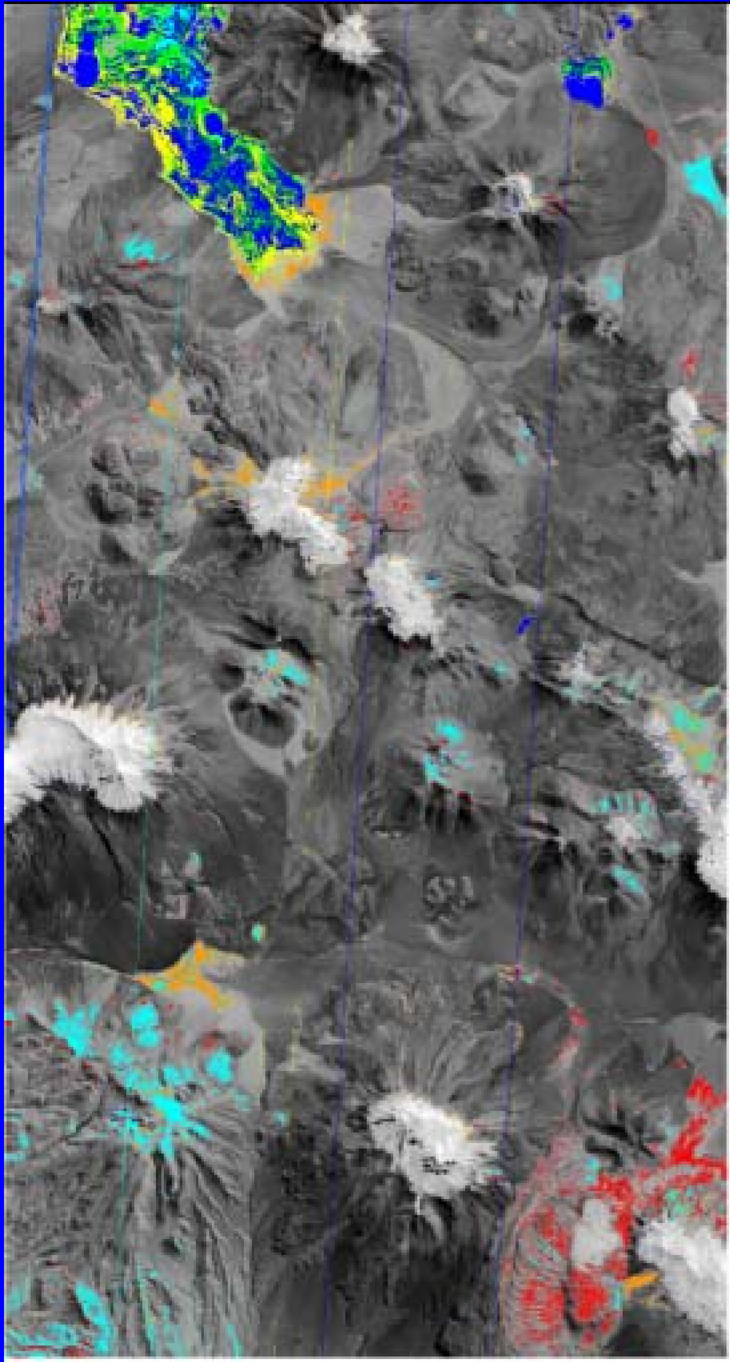
*ALI and ASTER combined into 13-channel VIS-SWIR data cube

*Spectral endmember determination by using PPI and linear spectral unmixing (LSU) analysis

*Spectral mapping by subsetting data and by using LSU and SAM

*Data dimensionality and S/N comparisons


Reflectance (offset for clarity)
Wavelength (microns)
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
4
8
ASTER
ALI
HYPERION
Alunitic rock



Linear Spectral Unmixing* (LSU) Results:

- Hematite
- Sulfur + Alunite + Kaolinite
- Hematite + Kaolinite + Alunite
- Wet Brines (Moist Halite - 2 classes)
- Gypsum (2 classes)
- Ulexite (2 classes)

*Constrained using 12 endmembers (incl. snow/ice & vegetation classes) + simulated shade/featureless class

FULL ALI SCENE MAPPING RESULTS

8 Km

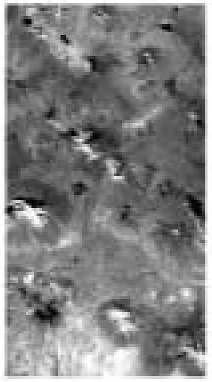
Dimensionality Limits of Full ALI+ASTER Spatial & Spectral Coverage

MNF-1

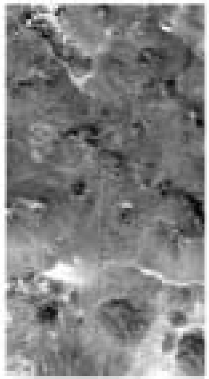
MNF-2

MNF-3

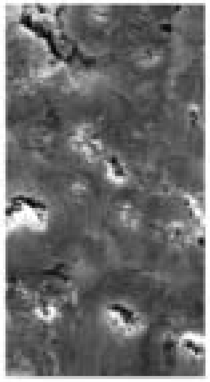
MNF-4



MNF-5



MNF-6



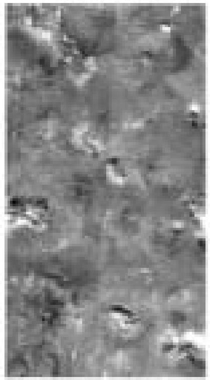
MNF-7

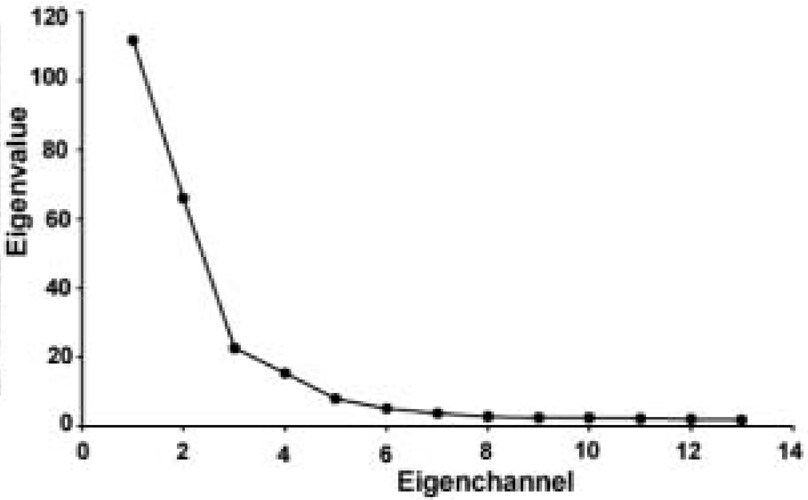
MNF-8

MNF-9

MNF-10

MNF-11



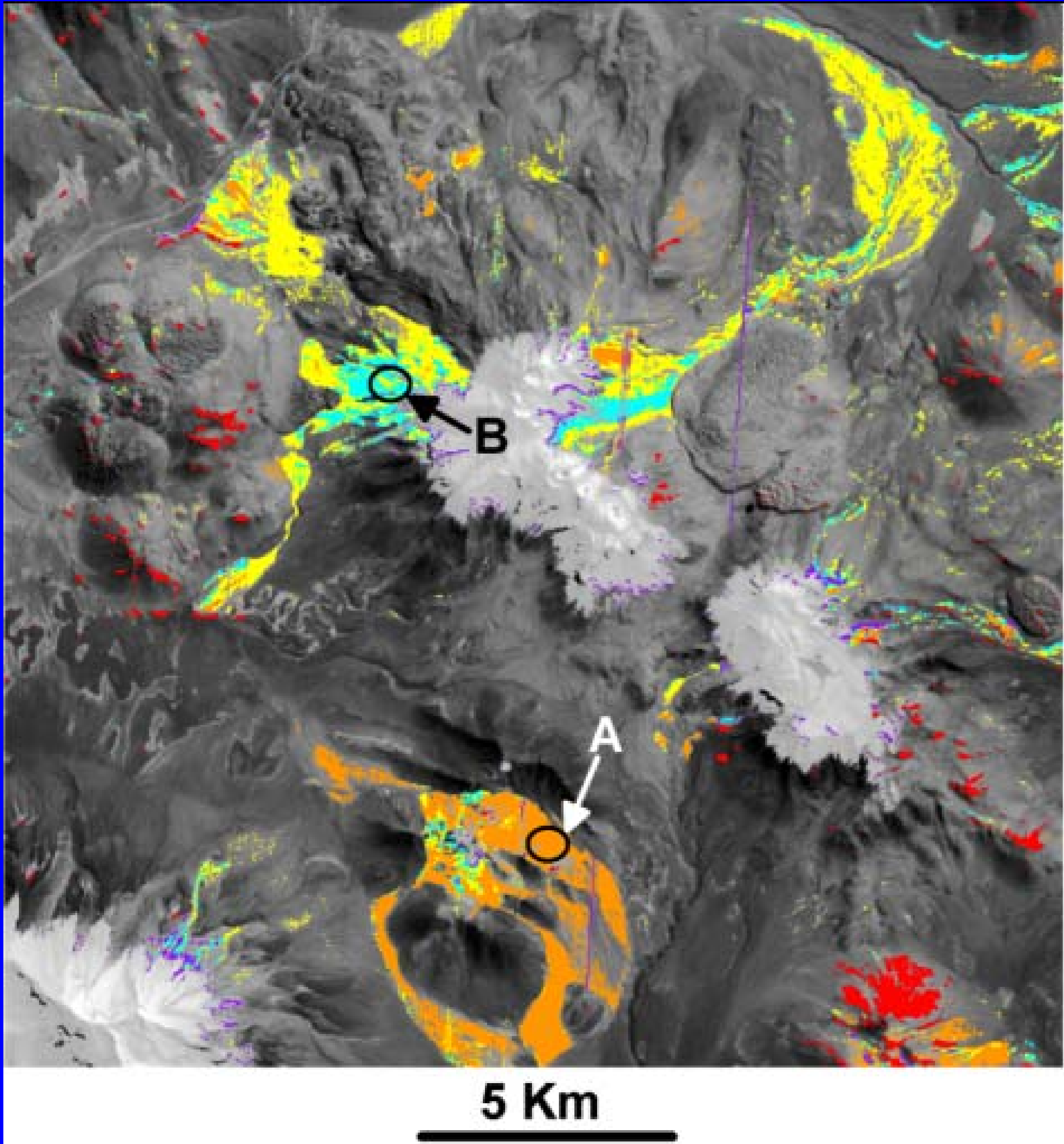


MNF-12

MNF-13

Cutoff = 11 ± 2 endmember classes*

*Note that Eigenchannels 12 & 13 still contain residual information in the salar

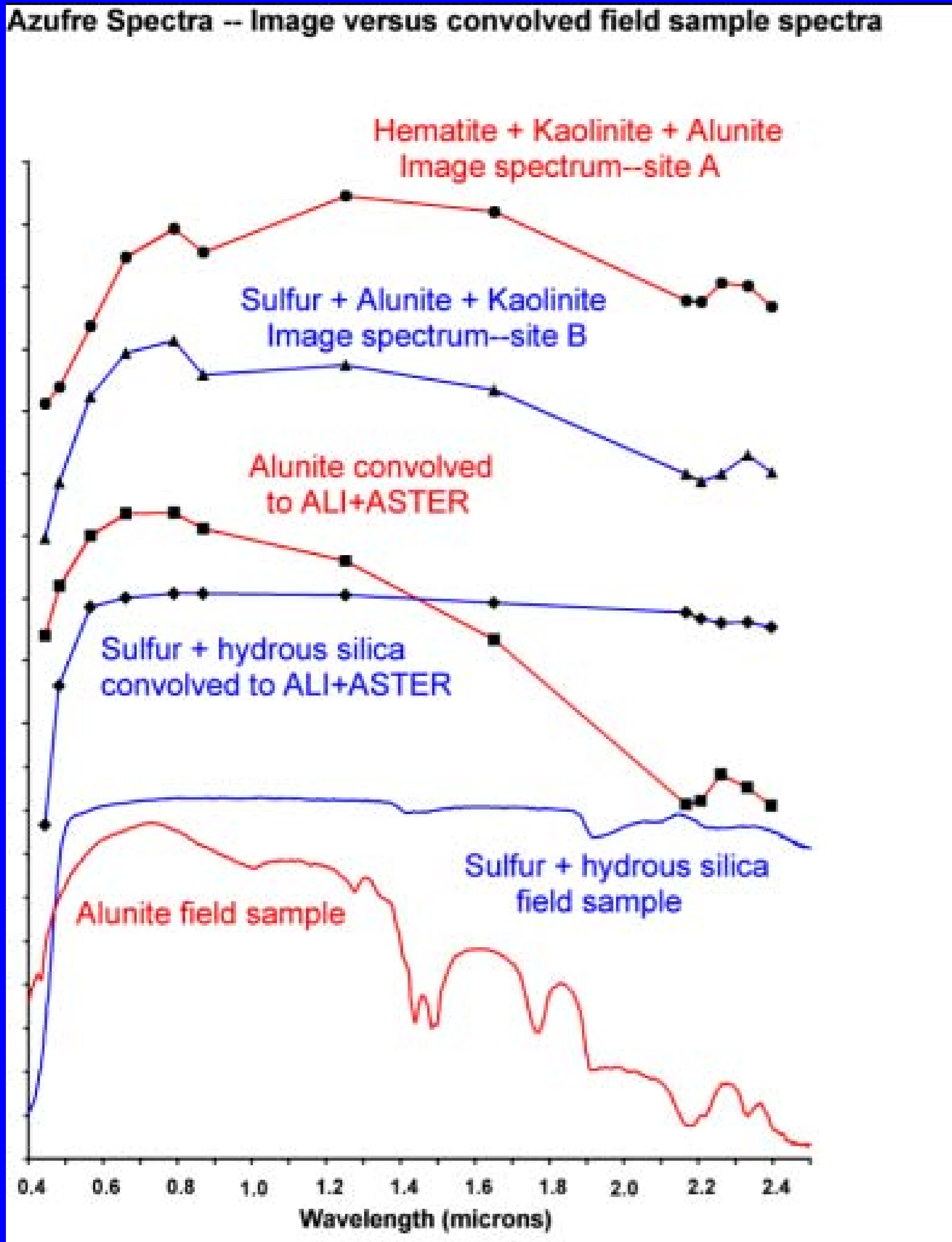


SAM and LSU* Results:

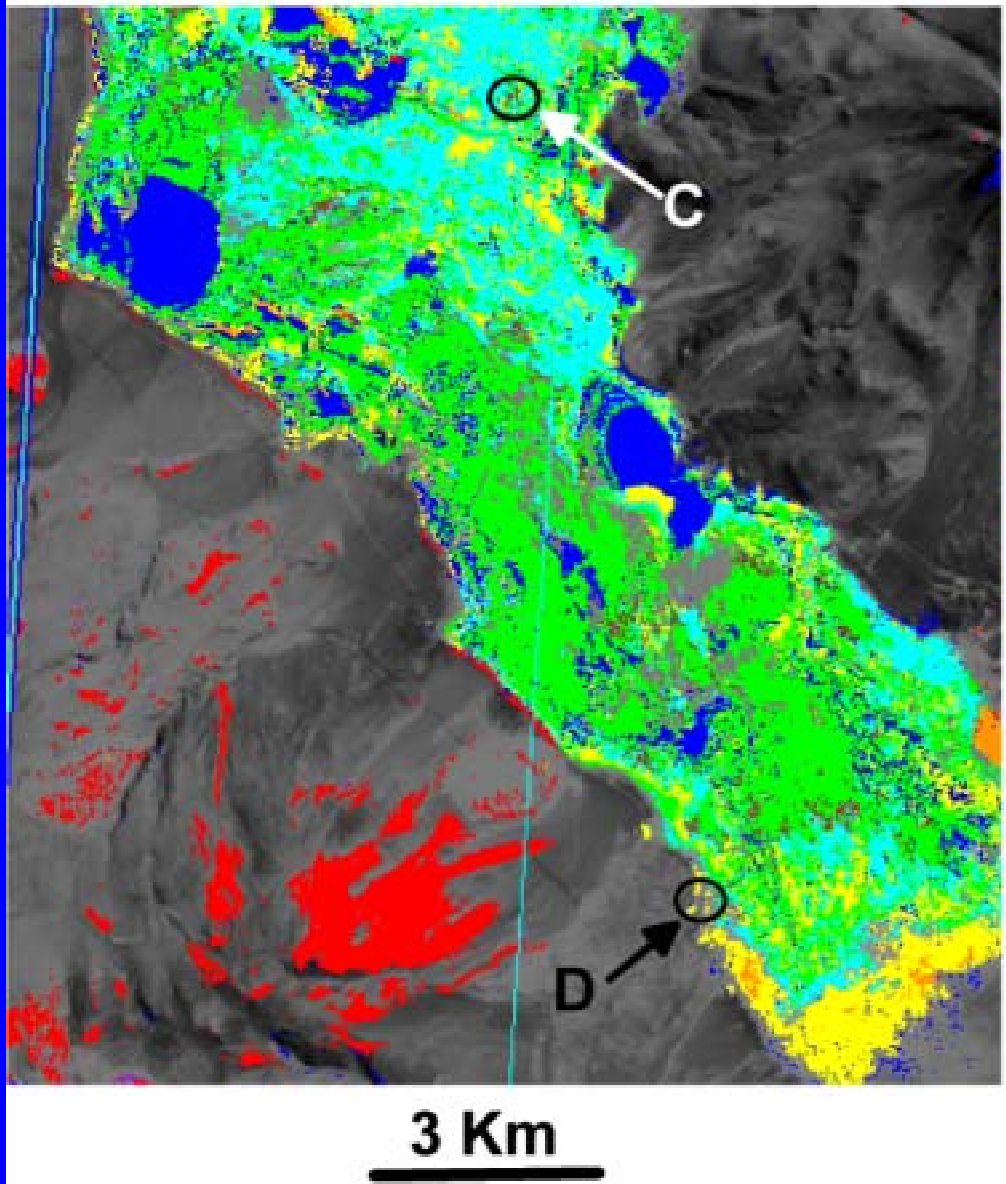
- Hematite
- Hem + Kao + Al
- Sulfur + Al + Kao
- Alunite
- *Snow + Al + Kao

*Constrained using 7 endmembers (incl. snow/ice & vegetation classes) + simulated shade/featureless class

AZUFRE SUBSET MAPPING RESULTS


Azufre Spectra -- Image versus convolved field sample spectra
Hematite + Kaolinite + Alunite
Image spectrum--site A
Sulfur + Alunite + Kaolinite
Image spectrum--site B
Alunite convolved
to ALI+ASTER
Sulfur + hydrous silica
convolved to ALI+ASTER
Sulfur + hydrous silica
field sample
Alunite field sample
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
Wavelength (microns)

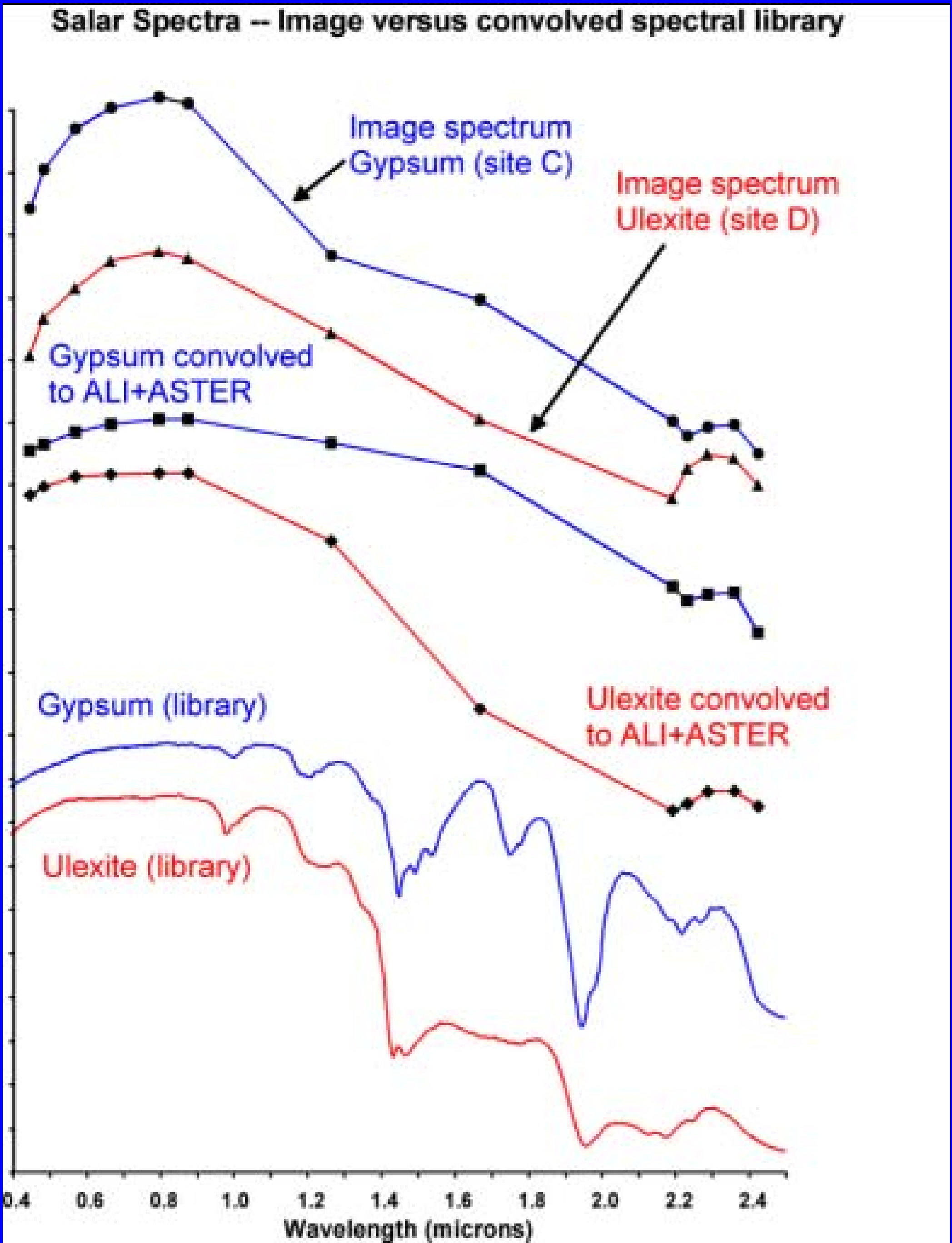
Salar de Ascotan--ALI/ASTER Data Subset



LSU* Results:

- Hematite
- Sulfur + Alunite + Kaolinite
- Ulexite
- Gypsum
- Gypsum + Smectite
- Smectite
- Wet Brines (3 classes)
- Hematite +Kaolinite + Alunite

*Constrained using 11 endmembers (incl. vegetation class) + simulated shade/featureless class



Salar Spectra -- Image versus convolved spectral library
Image spectrum
Gypsum (site C)
Image spectrum
Ulexite (site D)
Gypsum convolved
to ALI+ASTER
Gypsum (library)
Ulexite convolved
to ALI+ASTER
Ulexite (library)
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
Wavelength (microns)

Dimensionality Comparison (HYPERION versus ALI+ASTER) Part One

<u>High Signal-to-Noise; Low Spectral Resolution (ALI+ASTER)</u>

MNF-1

MNF-2

MNF-3

MNF-4

MNF-5

MNF-6

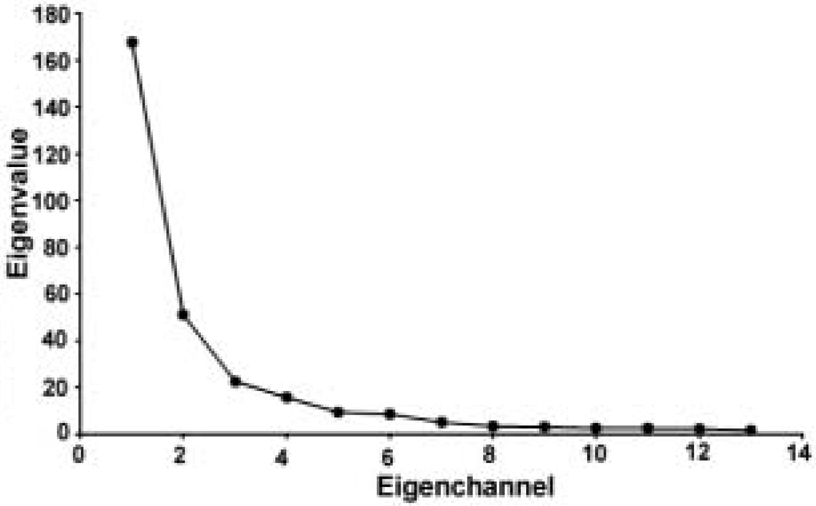
MNF-7

MNF-8

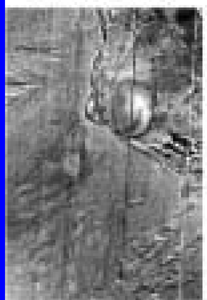
MNF-9

MNF-10

MNF-11



MNF-12

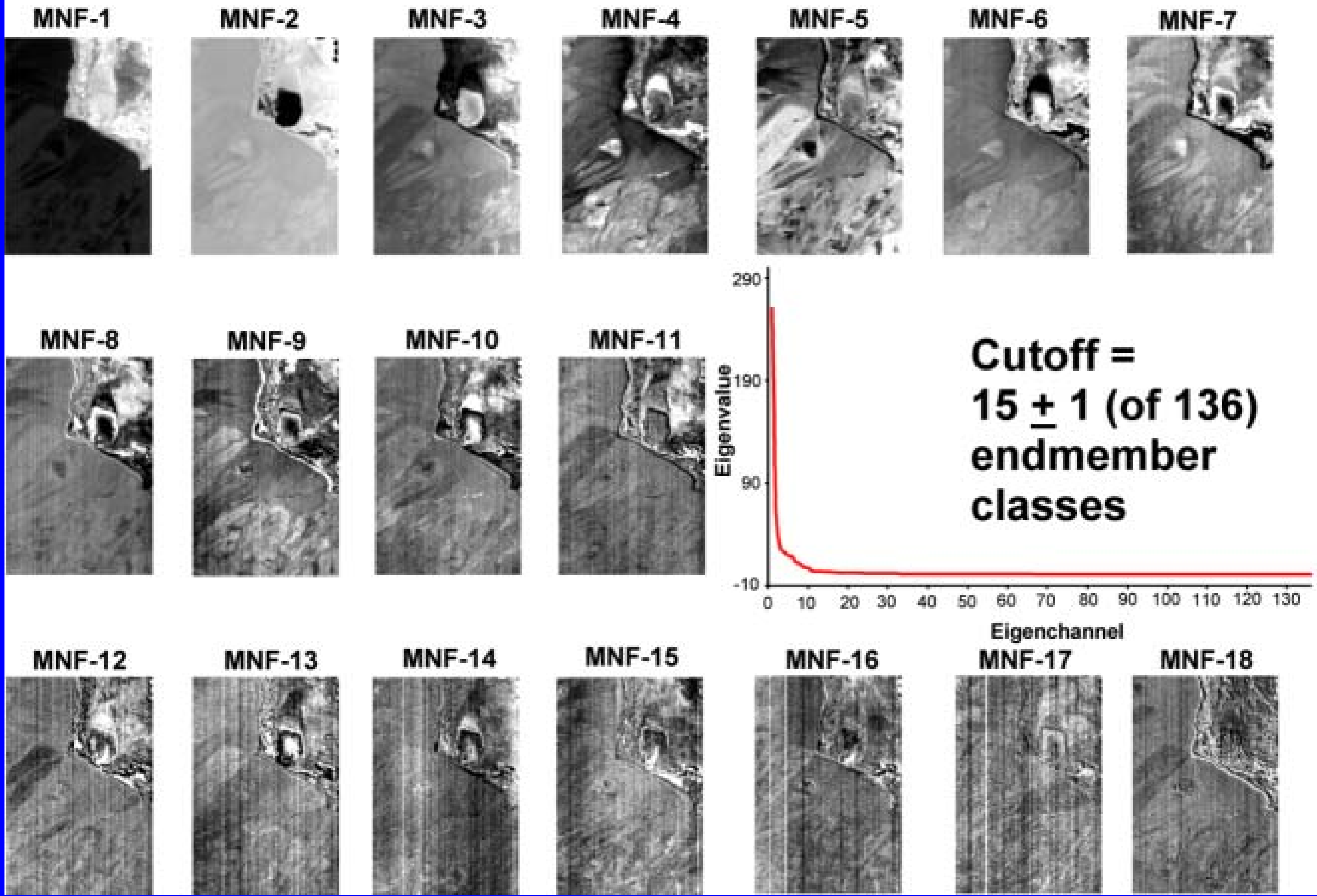


MNF-13

Cutoff = 12 endmember classes

Dimensionality Comparison (HYPERION versus ALI+ASTER) Part Two

High Spectral Resolution; Low Signal-to-Noise (HYPERION)



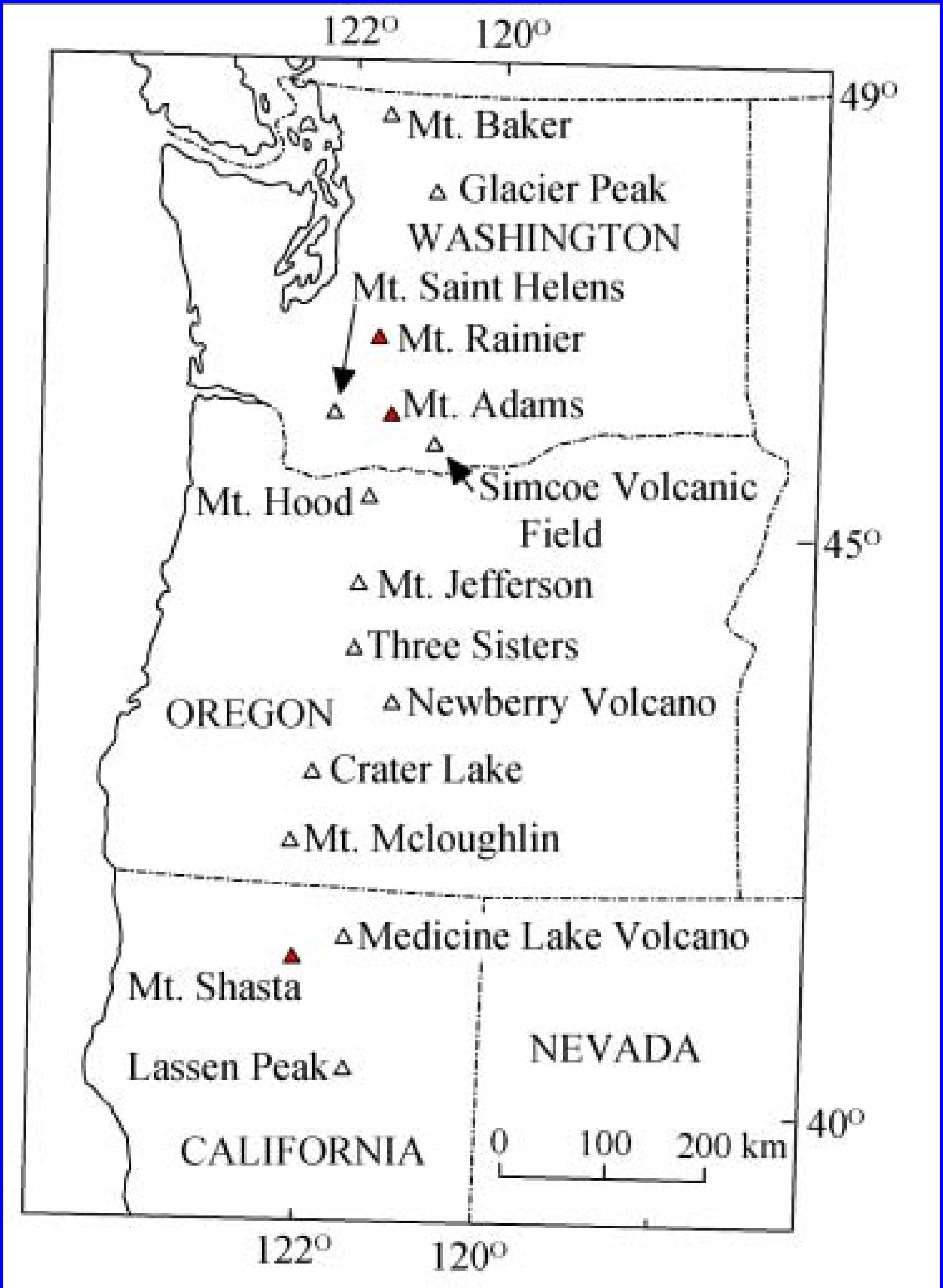
CONCLUSIONS—Azufre, Chile

1. Hyperspectral to multispectral calibration is effective for extending mapping confidence over broad MS image swaths

2. Aspects of data dimensionality

   --Scene complexity may require dimensionality greater than provided by multispectral sensors

   --Hyperspectral data S/N critical to gaining full dimensionality advantages



Cascade volcanoes regional setting

OBJECTIVES– Mount Shasta, California

- Hyperion vs. AVIRIS mineral mapping and S/N comparisons

- Satellite and Airborne DEM data

- Development of GIS techniques

    - Slope analysis

    - Volume modeling

<u>METHODS—Mount Shasta</u>

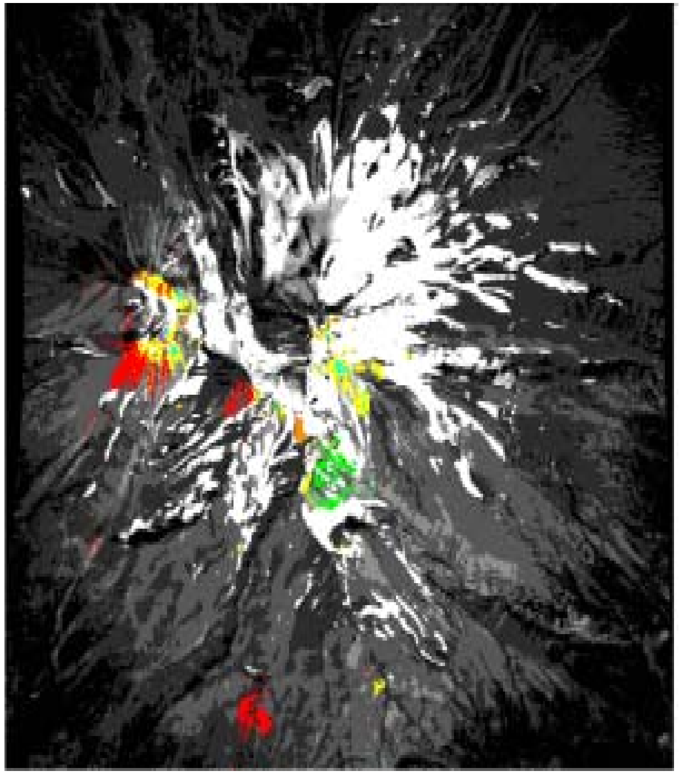
• Calibration to reflectance: ATREM + Field sample spectra

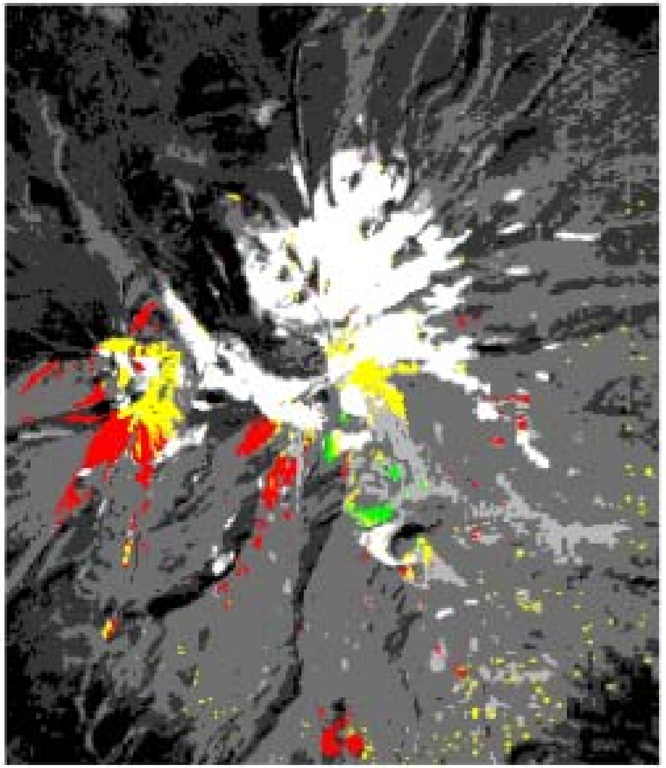
• Noise reduction—MNF transform applied to Hyperion data

• Linear spectral unmixing using image spectra

• Slope analysis—Location of steeply sloping altered rocks

• Volume analysis—Volume estimation of altered rock masses using GIS methods





AVIRIS Mineral Map:

- Strong Oxide
- Kaolinite
- Alunite +- Kaolinite +- Gypsum
- Red Banks Oxide
- Hydrous Silica
- Amphibole-rich Flows

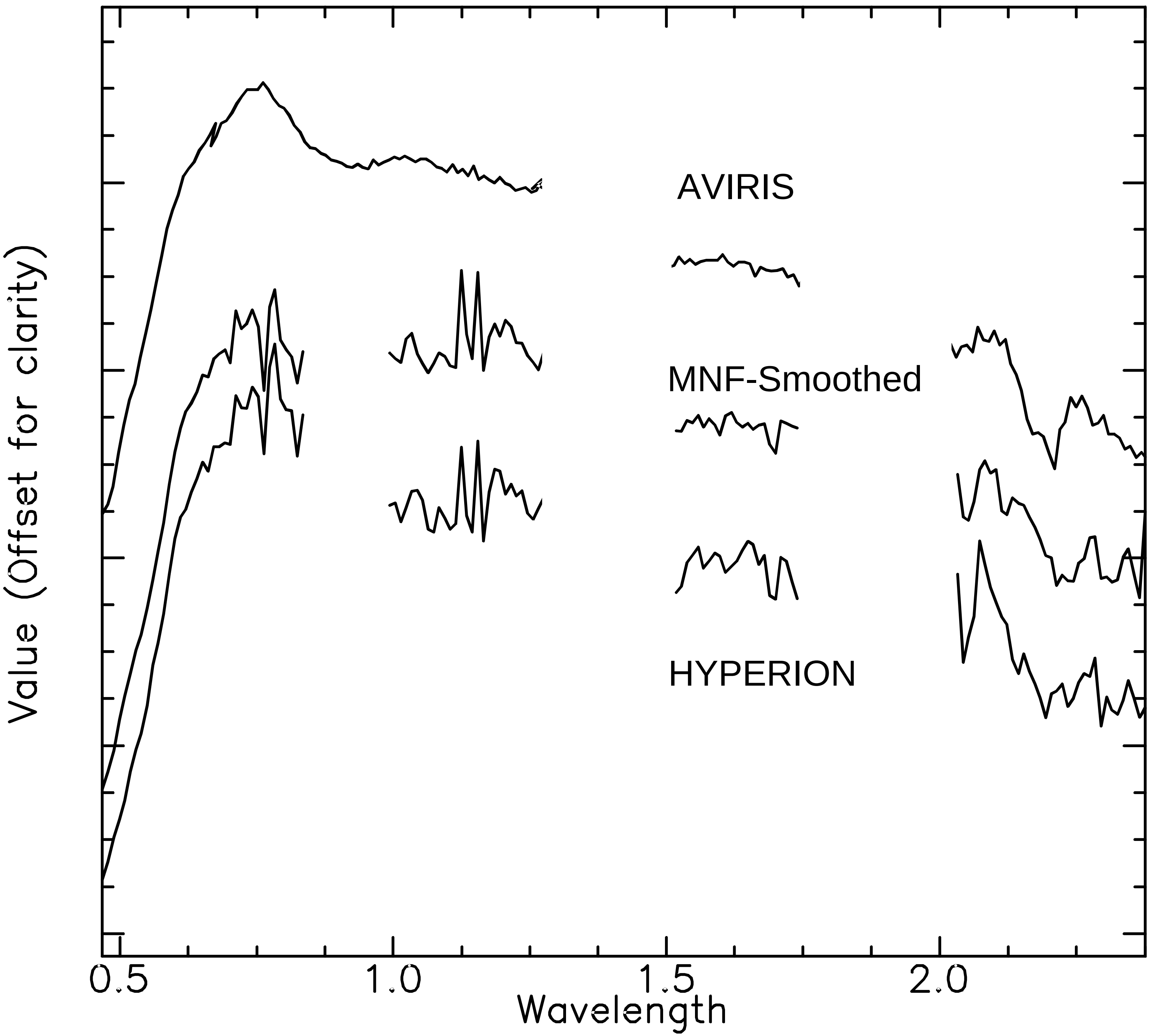
Hyperion Mineral Map:

- Strong Oxide
- Kaolinite
- Amphibole-rich Flows

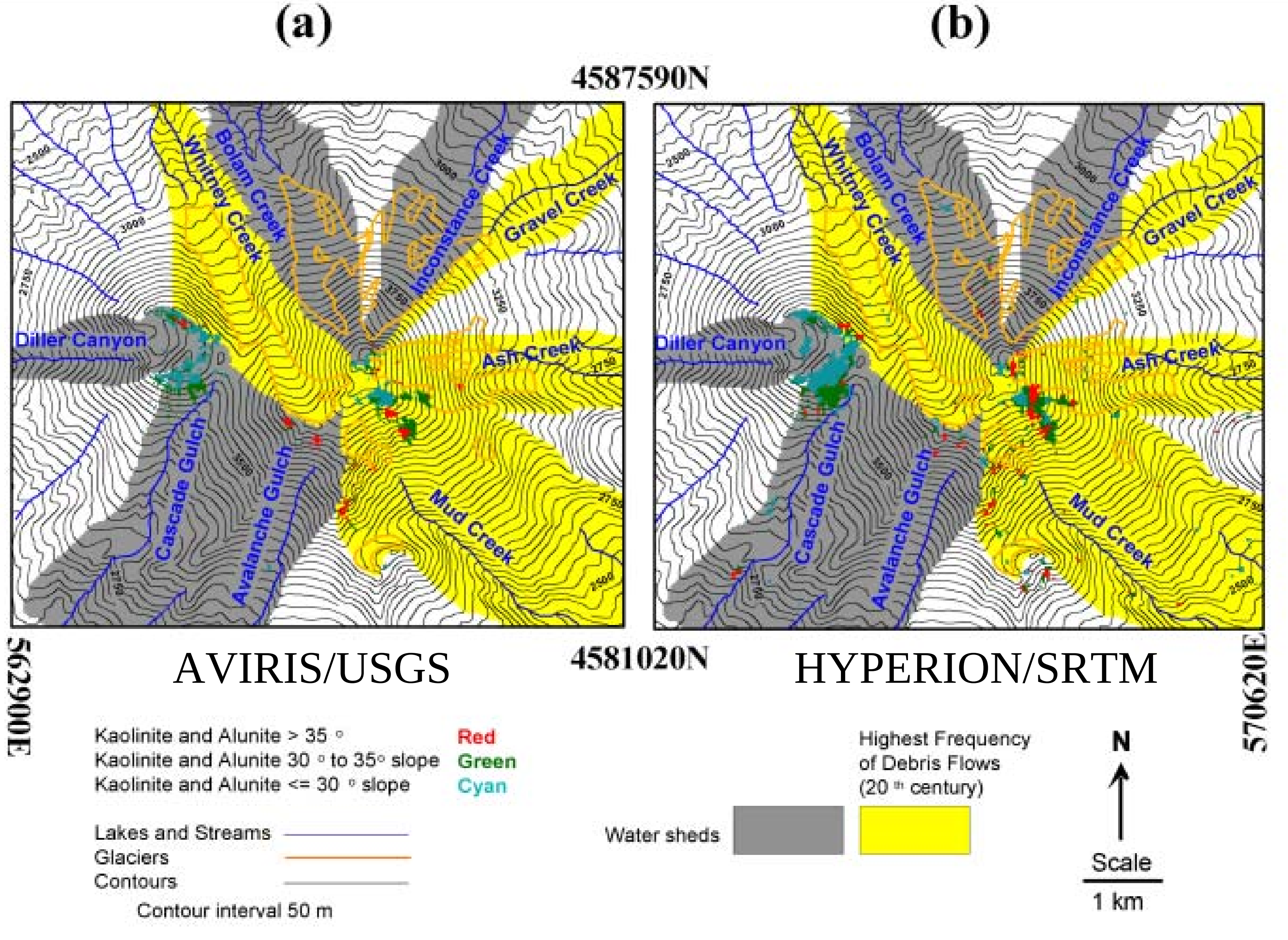
N

Scale
2 km

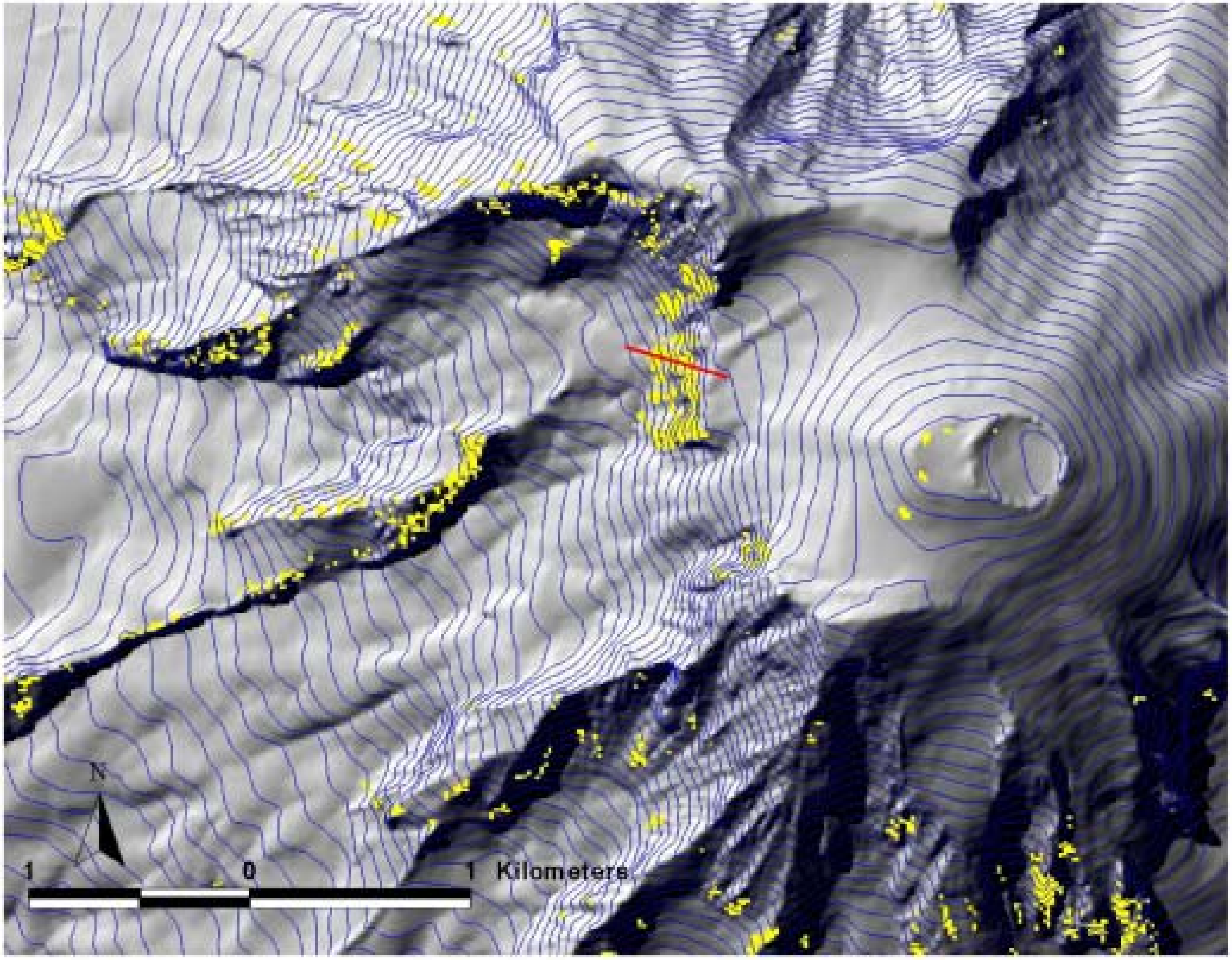
MOUNT SHASTA, CALIFORNIA

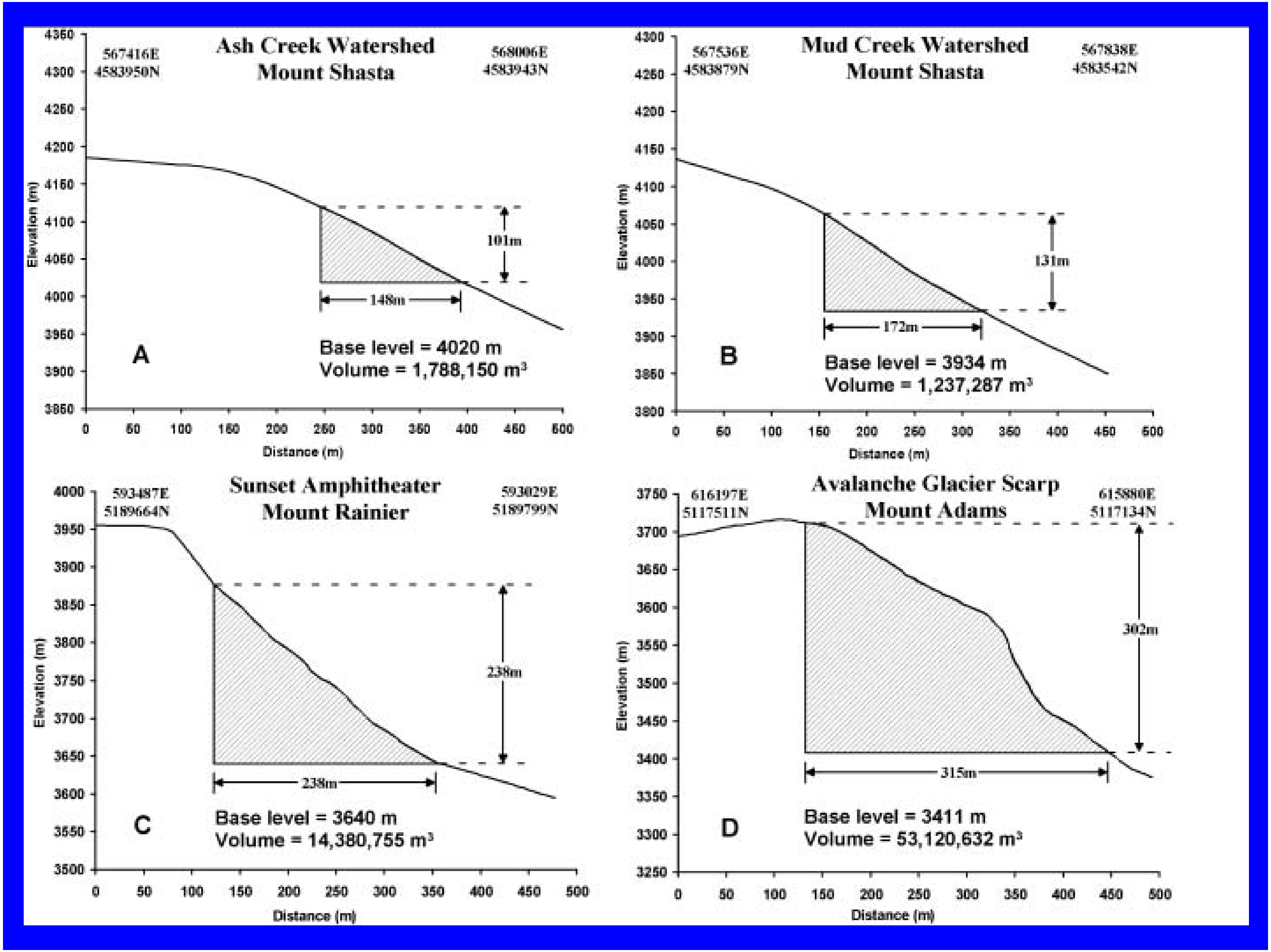


AVIRIS
MNF-Smoothed
HYPERION
Value (Offset for clarity)
0.5
1.0
1.5
2.0
Wavelength


(a)
(b)
4587590N
4581020N
562900E
570620E
AVIRIS/USGS
HYPERION/SRTM
Bolam Creek
Whitney Creek
Inconstance Creek
Gravel Creek
Diller Canyon
Ash Creek
Cascade Gulch
Avalanche Gulch
Mud Creek
Kaolinite and Alunite > 35 ° Red
Kaolinite and Alunite 30 ° to 35° slope Green
Kaolinite and Alunite <= 30 ° slope Cyan
Lakes and Streams
Glaciers
Contours
Contour interval 50 m
Highest Frequency of Debris Flows (20 th century)
Water sheds
N
Scale
1 km

Sunset Amphitheater
Mount Rainier, WA



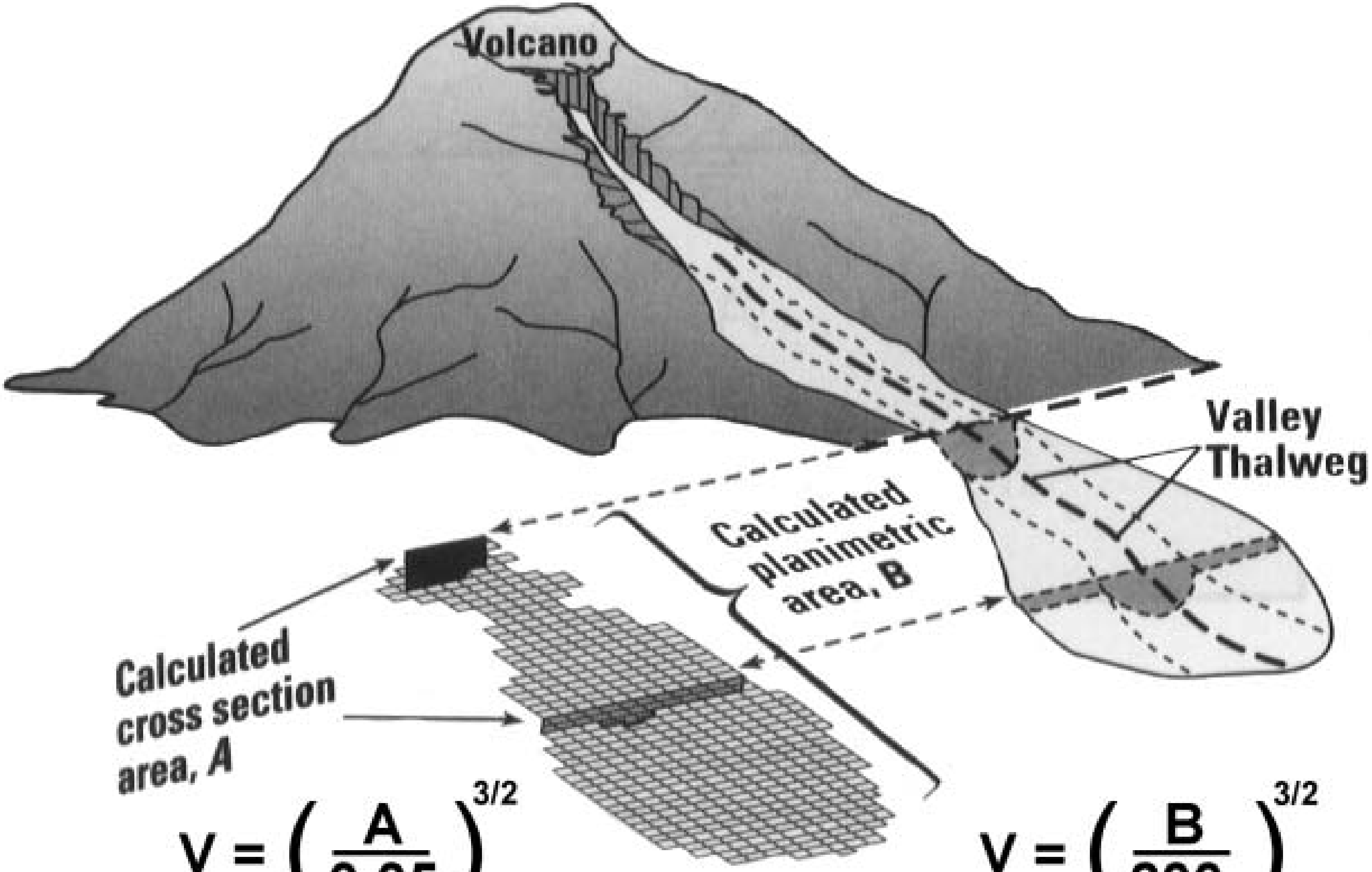


Ash Creek Watershed
Mount Shasta
567416E
4583950N
568006E
4583943N
101m
148m
A
Base level = 4020 m
Volume = 1,788,150 m³
Elevation (m)
Distance (m)
Mud Creek Watershed
Mount Shasta
567536E
4583879N
567838E
4583542N
131m
172m
B
Base level = 3934 m
Volume = 1,237,287 m³
Sunset Amphitheater
Mount Rainier
593487E
5189664N
593029E
5189799N
238m
238m
C
Base level = 3640 m
Volume = 14,380,755 m³
Avalanche Glacier Scarp
Mount Adams
616197E
5117511N
615880E
5117134N
302m
315m
D
Base level = 3411 m
Volume = 53,120,632 m³

Table 2. Volume estimates for selected altered rock masses at Mount Shasta, Mount Rainier, and Mount Adams.

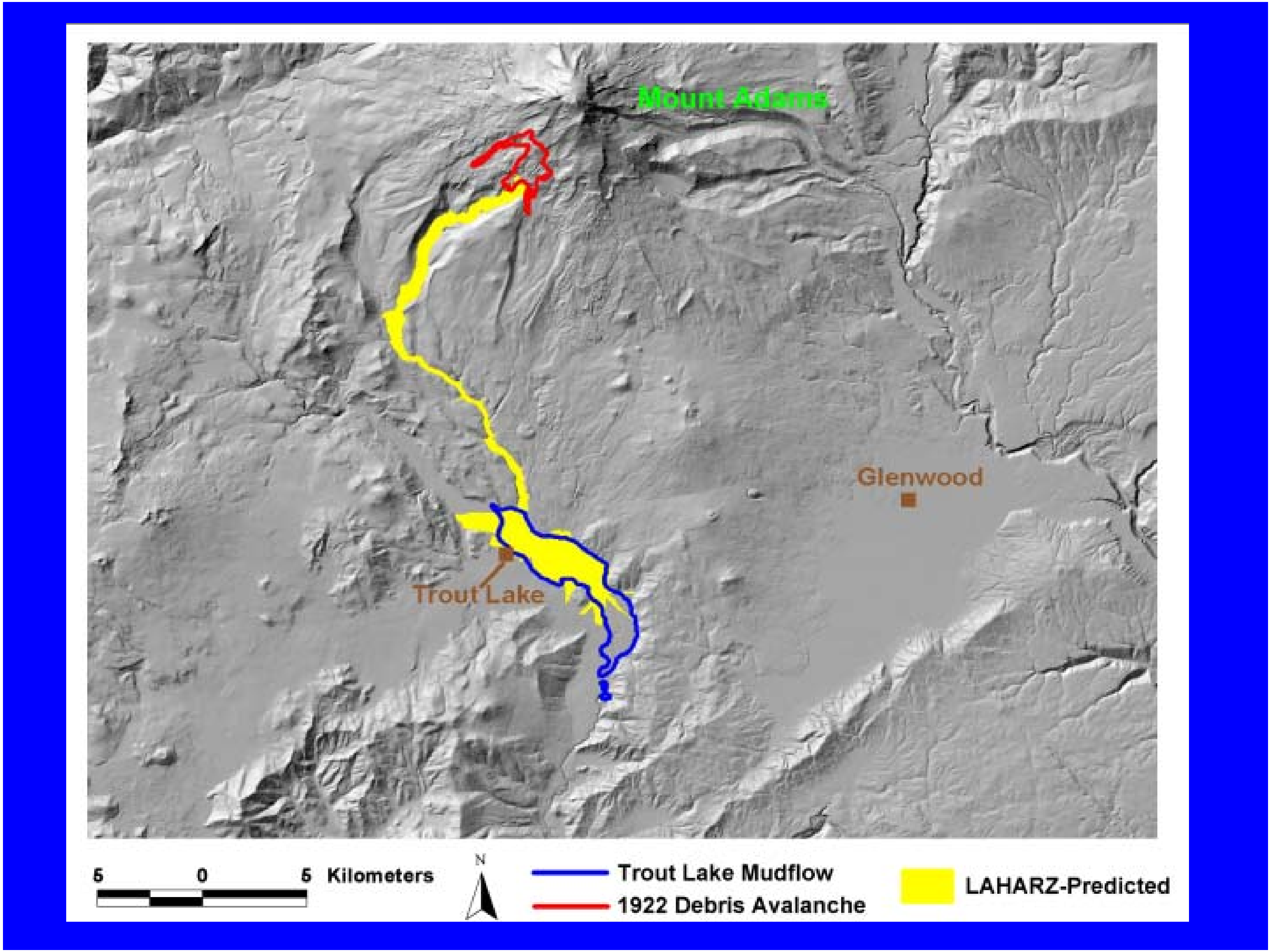
Site	Volume	Debris Flow Comparisons
Mount Shasta, Ash Creek	1.8×10^6 m^3	Ash Creek 1937-39 5.0×10^6 m^3
Mount Shasta, Mud Creek	1.2×10^6 m^3	Mud Creek 1924-1931 23.0×10^6 m^3
Mount Rainier, Sunset Amphitheater	1.4×10^7 m^3	Electron Mudflow 2.5×10^8 m^3
Mount Adams, Avalanche Glacier	5.3×10^7 m^3	Trout Lake Mudflow 6.6×10^7 m^3

LAHARZ-Inundation Model
After Iverson et al. (1998)



$$V = \left(\frac{A}{0.05} \right)^{3/2}$$

$$V = \left(\frac{B}{200} \right)^{3/2}$$


Mount Adams
Glenwood
Trout Lake
5 0 5 Kilometers
N
Trout Lake Mudflow
1922 Debris Avalanche
LAHARZ-Predicted

CONCLUSIONS—Mount Shasta

- Hyperion has sufficient S/N and spatial resolution to observe key aspects of alteration mineralogy

- USGS and SRTM digital elevation data give similar slope and volume analysis results

- Importance of accurate image registration to DEMs

- Volume analysis based on alteration vertical and lateral extent can help to constrain debris flow source characteristics

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