

Connecting Interpreters and Image-Processors for Exploration

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Ellis GeoSpatial

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Remote Sensing Enterprises



Connecting Interpreters and Image-Processors for Exploration

The Opportunity

The Process

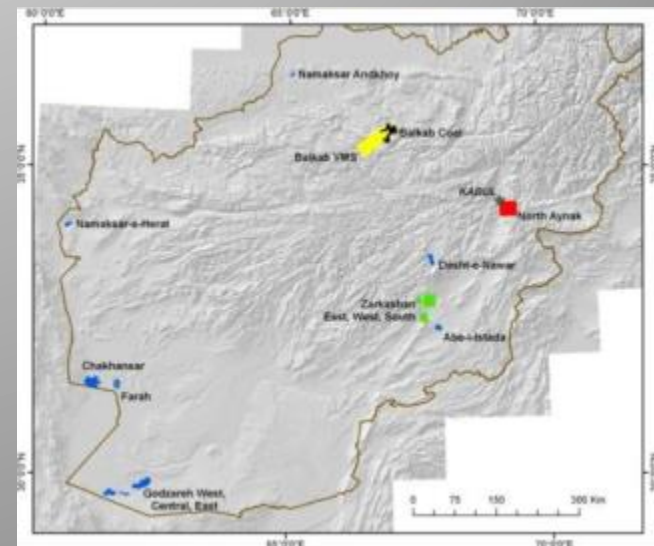


Image Processing & GIS

Internet-based Tools

Geologic Field Knowledge

Exploration Projects



The Opportunity

Experienced geologists have seen a lot of rocks, but often didn't have time to learn about image processing & GIS



Experienced image processors have seen a lot of imagery, but often didn't have time to walk outcrops in the field during their career



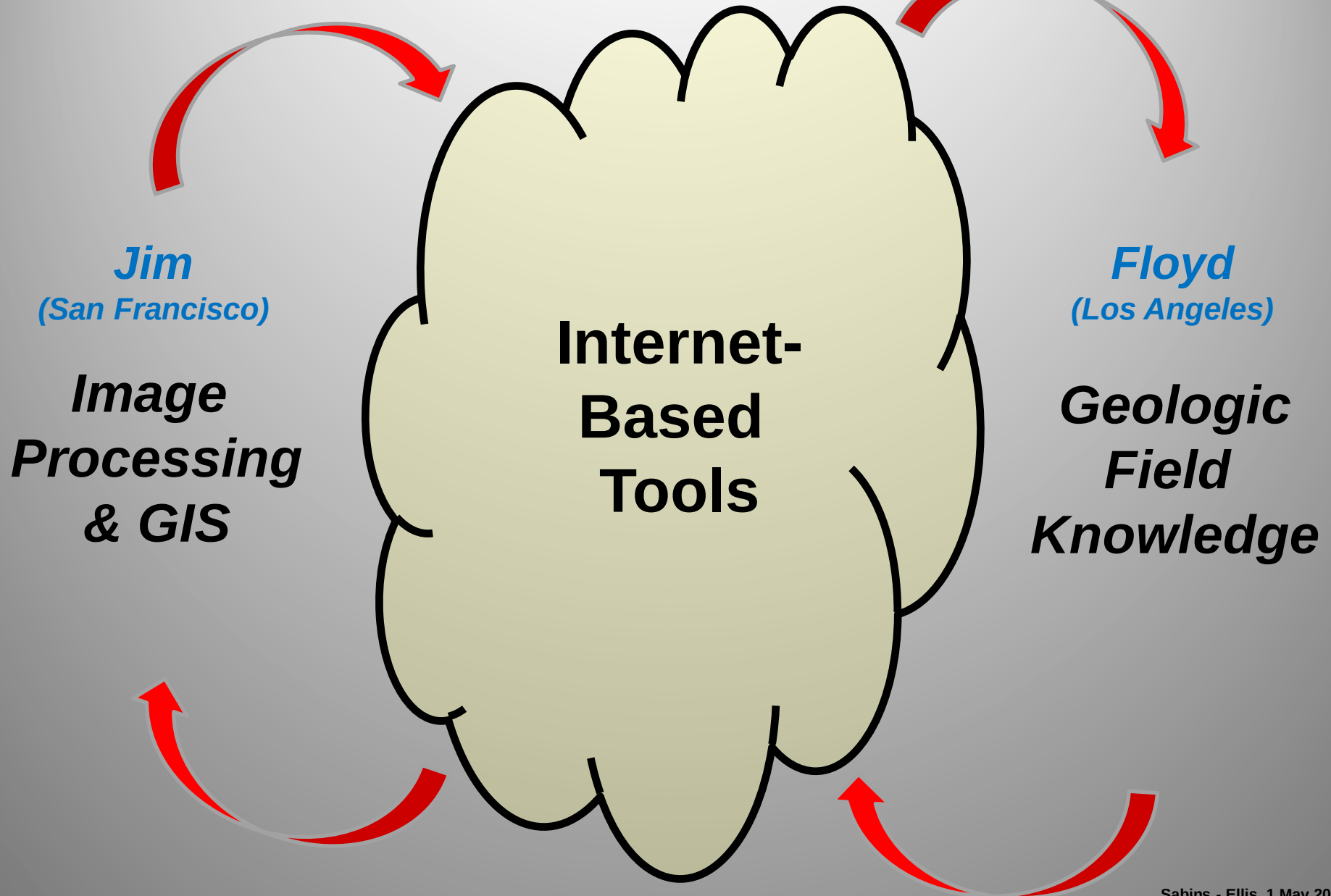
The Opportunity

These two skilled camps of geology often belong to different generations

Today's technology can bring them together from almost anywhere in the world to improve geologic mapping



The Process



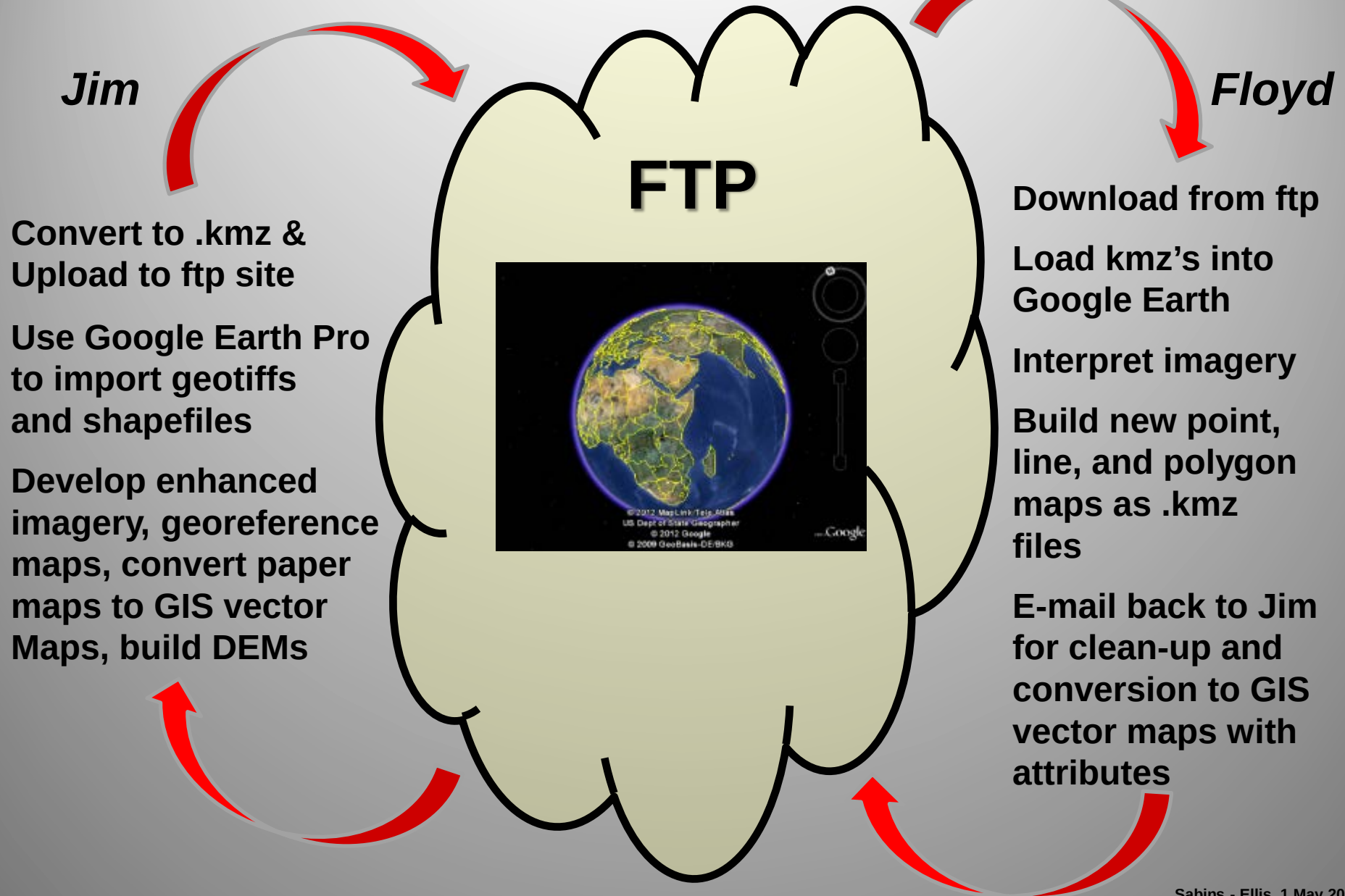


The Process





The Process - 1





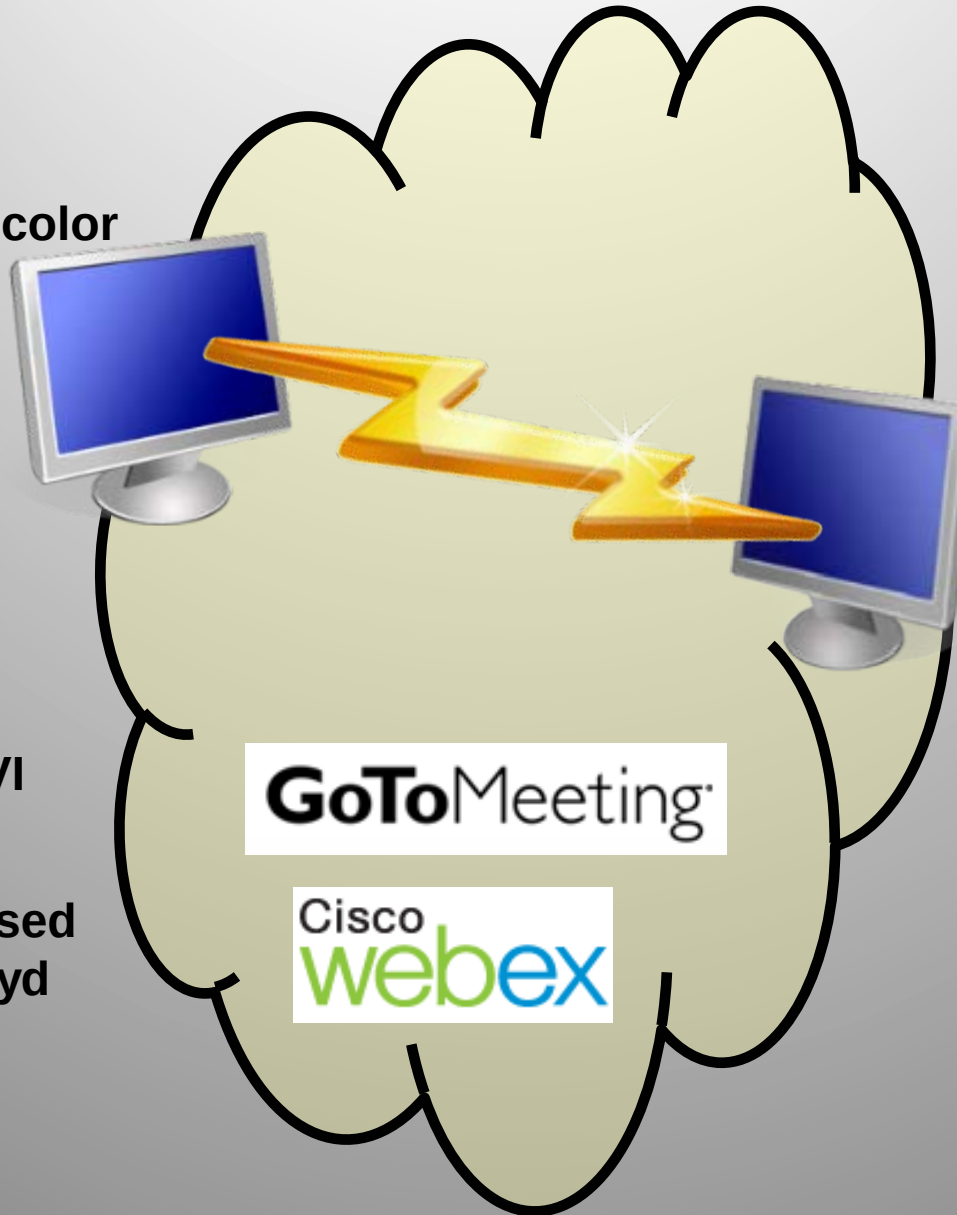
The Process - 2

Jim

Band ratios, PCs, color composites, DEM elevation ranges, GIS symbology, spectral profiles, displayed and made ready for changes by Floyd

Floyd views & Interacts with ENVI and ArcGIS tools

Jim hosts web-based meetings with Floyd



Floyd

Floyd views imagery on Jim's computer and *interactively* determines thresholds, symbology, classification groups, contrast-stretches

Jim interacts with images & maps displayed on Floyd's Google Earth



The Process - 3

Jim

Convert to .kmz &
upload to ftp site

Use Google Earth Pro
to import final images
and symbolized
shapefiles

Develop final images
& maps with grids,
graphs, spectral
library graphics
for report

FTP

**Final Reports
archived on
secure ftp
site for
DOD & USGS**

Floyd

Download from ftp

Load kmz's into
Google Earth

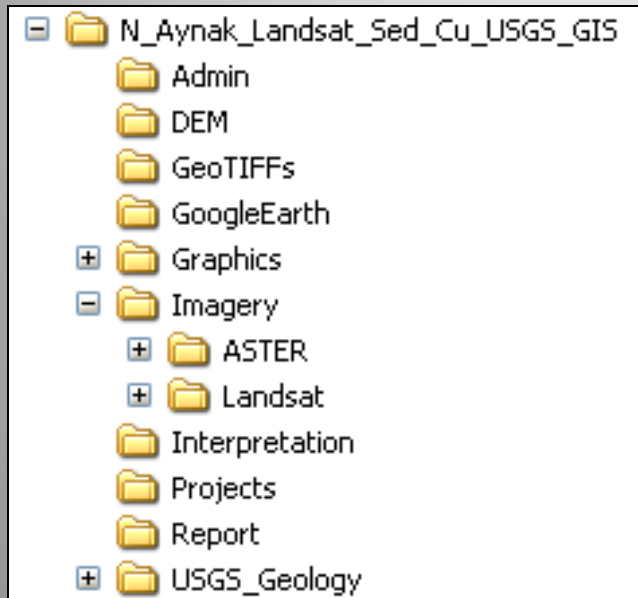
Write Report

Develop figures
from Google Earth

Upload final report
.docx for review &
conversion to pdf

Our Final Deliverables

GIS Database



+ Reports →

**Afghan
Geological
Survey
Bid Packages**

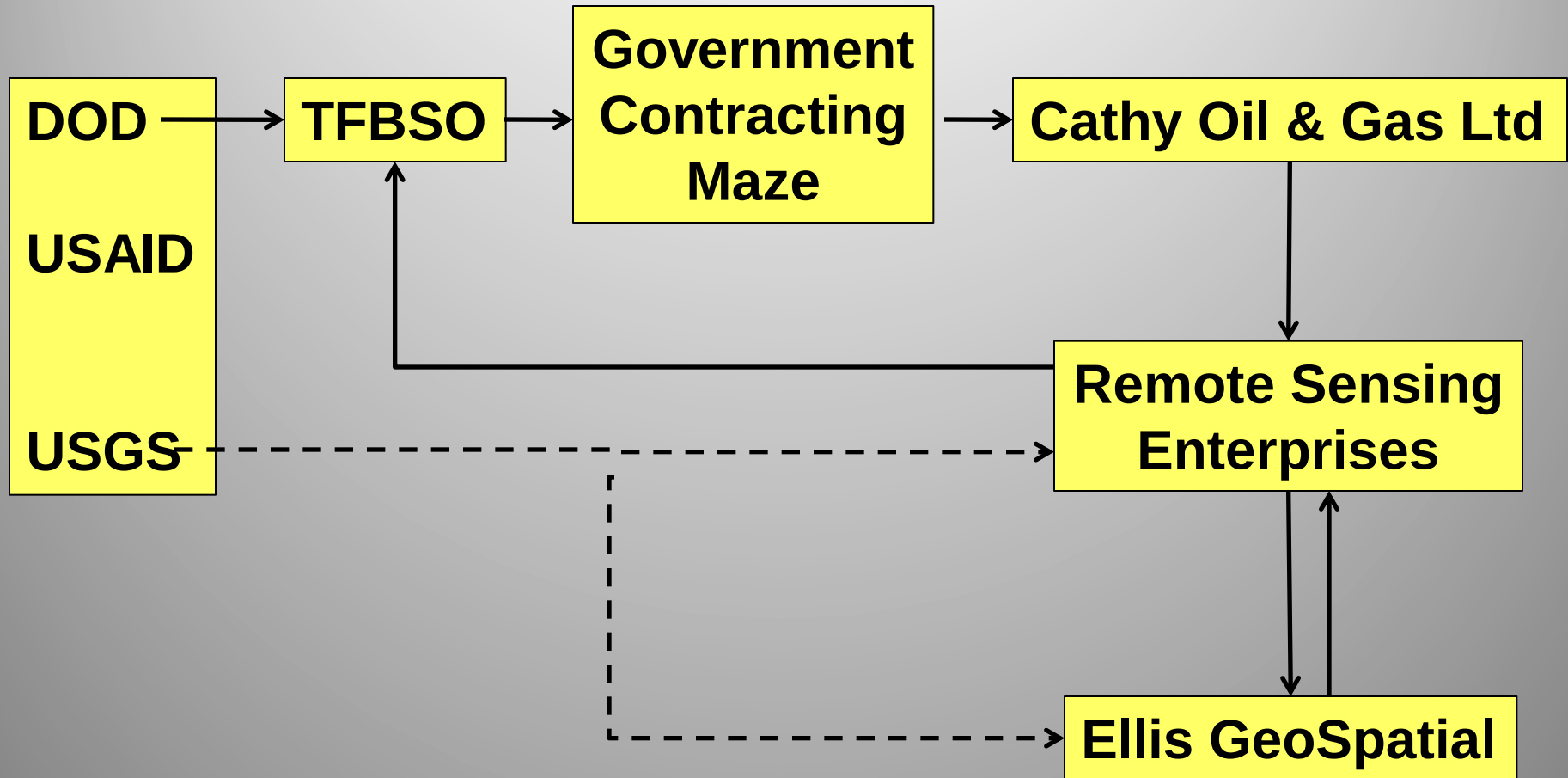
Public Domain

Examples of the imagery and maps are available at:

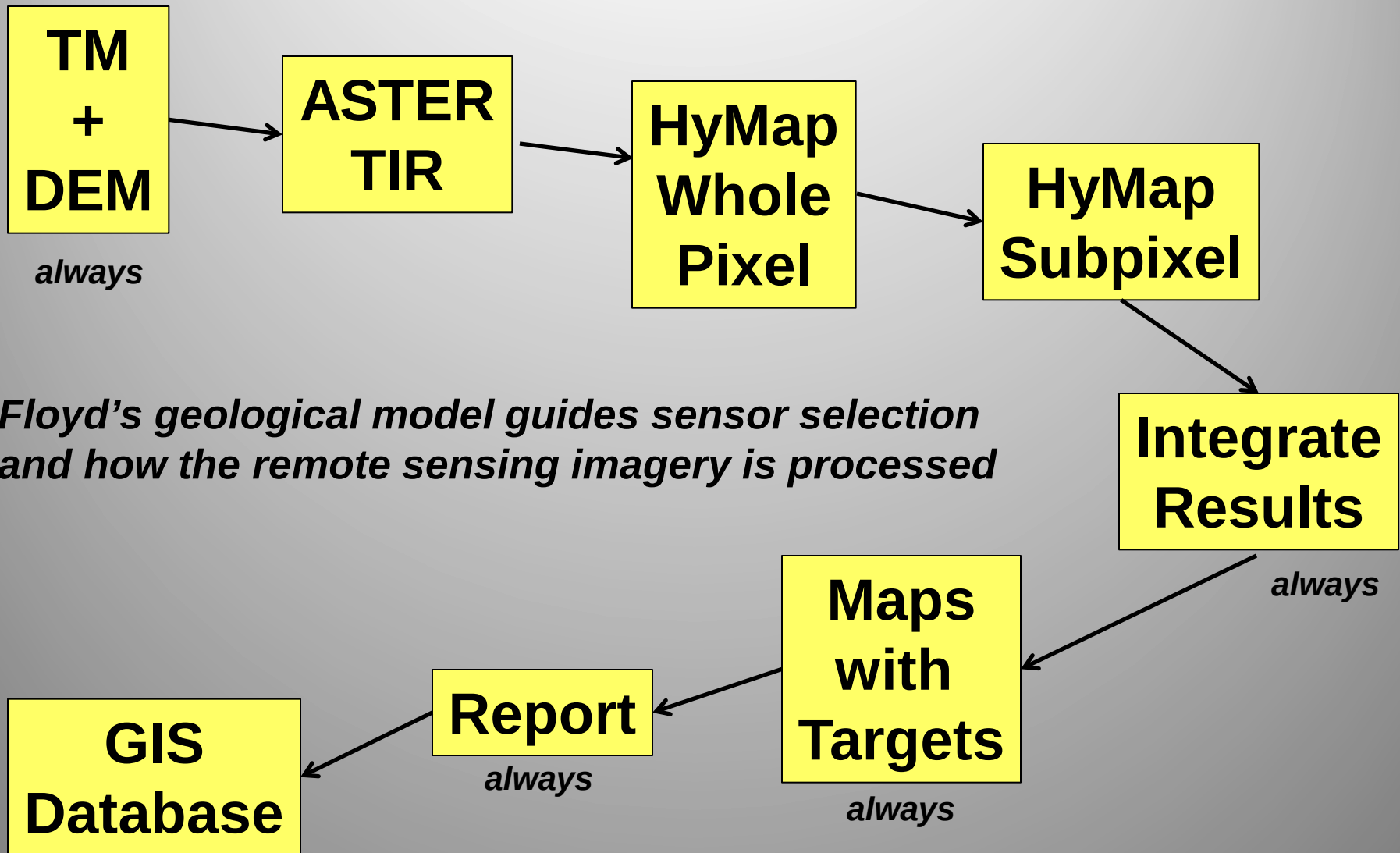
http://tfbso.defense.gov/www/attachments/TFBSO_AFGHAN_MINERALS.pdf
(start on page 25)

<http://pubs.usgs.gov/of/2011/1204/pdf/04A.pdf>
(start on page 11)

Overview of Work Process



Overview of Remote Sensing Process



Overview of Remote Sensing Process

Imagery

Landsat TM
ASTER
HyMap
Ikonos

Multispectral

Color Enhancement
Masking
Unsupervised Classification
Supervised Classification
Principal Components
Band Ratios
Thresholding

+

Hyperspectral

Whole Pixel
MNFs
SAM
Spectral Matching

Subpixel
Unmixing
MTMF





USGS Website for Afghanistan – TB's Data



USGS Projects in Afghanistan

- Home
- Background
- Projects
- Photo Gallery
- Map Viewer
- Documents
- Downloads
- Links
- Contacts

Minerals

Overview

Documents

Photo Gallery

Contacts

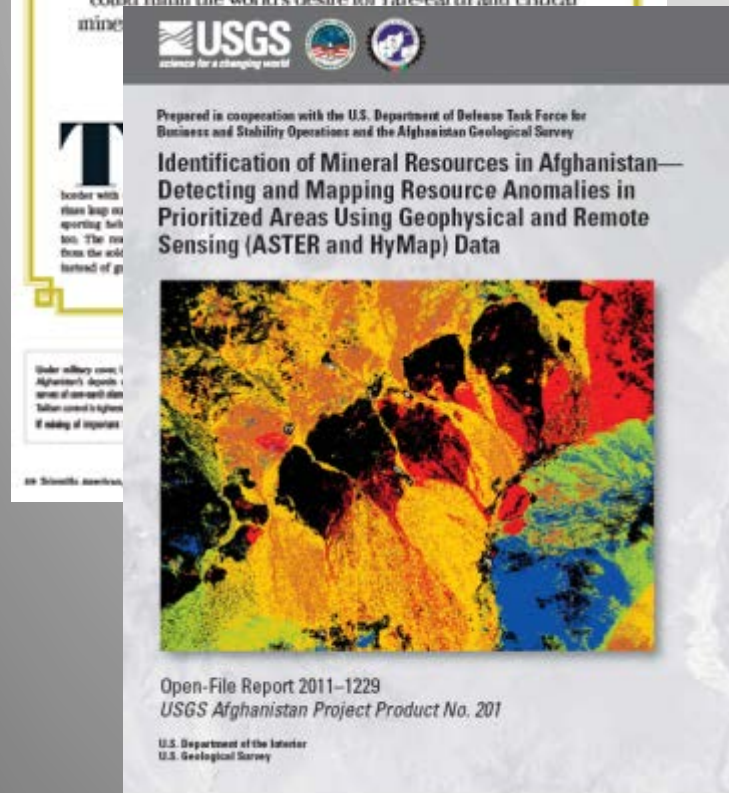
Mineral resources have great potential to support industrial growth and development in any country. Most of the existing information about Afghanistan's mineral resources was gathered between the early 1950s and the mid-1980s. Much of that data was hidden and protected by Afghan scientists during the subsequent two decades of intermittent conflict, and then returned to the Afghan government in 2001.

Between 2005 and 2007, scientists with the USGS' Mineral Resources Program worked closely with colleagues at the Afghanistan Geological Survey (AGS) to bring together all the various types of existing information about known mineral deposits in Afghanistan. They also collected new data throughout the country in order to assess the possible occurrence of undiscovered deposits of non-fuel mineral resources. The product of this cooperative effort was the 2007 Preliminary Assessment of Non-Fuel Mineral Resources of Afghanistan.



The assessment revealed that Afghanistan has abundant mineral resources, including known deposits of copper, iron, barite, sulfur, talc, chromium, magnesium, salt, mica, marble, rubies, emeralds, lapis lazuli, asbestos, nickel, mercury, gold and silver, lead, zinc, fluor spar, bauxite, beryllium, and lithium. Based on quantitative probabilistic estimates, the country also appears to have significant undiscovered deposits (at depths less than 1 kilometer) of copper, mercury, rare-earth elements, sulfur, chromite, asbestos, potash, graphite, and sand and gravel. About two dozen mineralized areas merit further study and may contain resources amenable to rapid development.

Publications on Mineral Potential



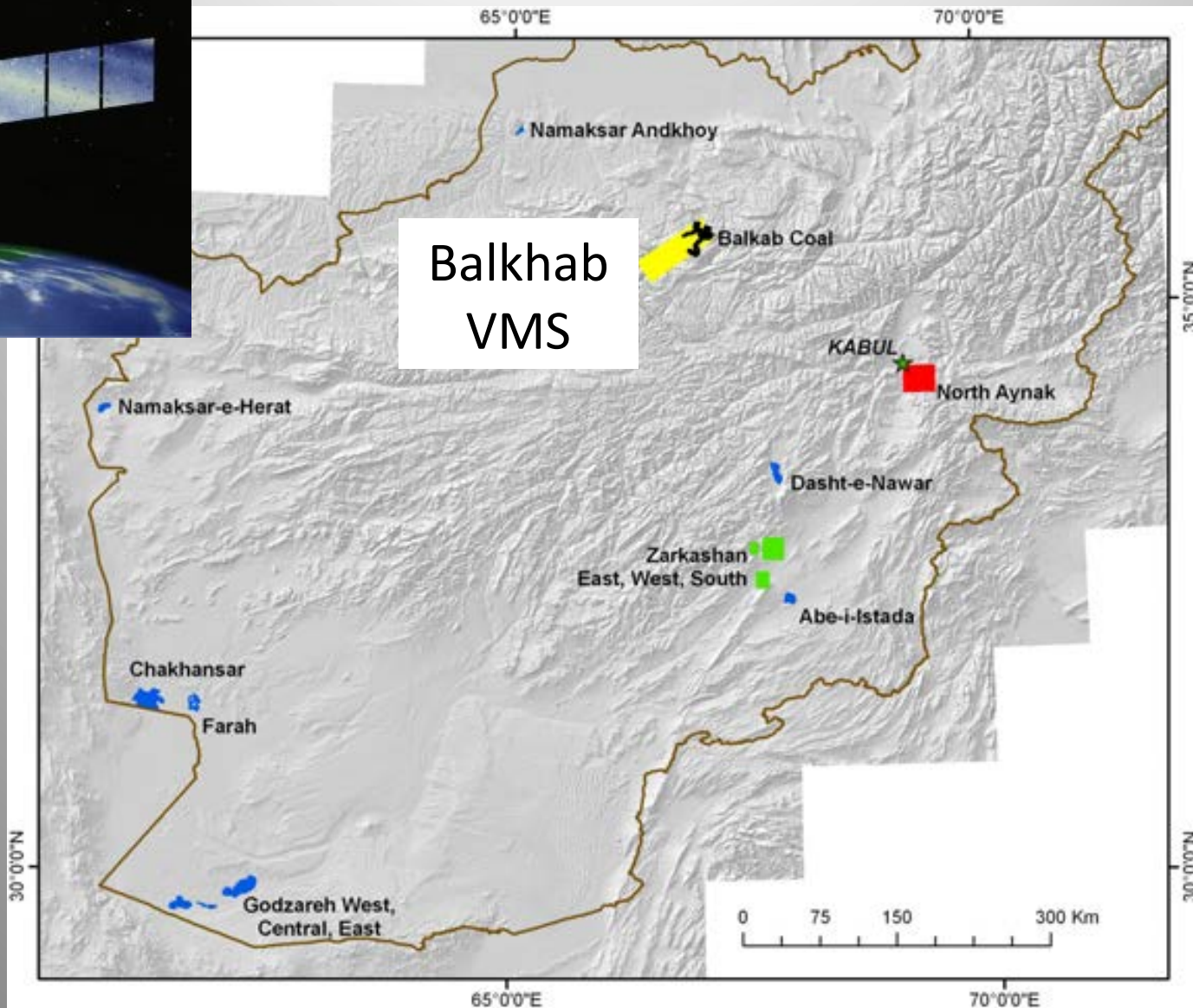
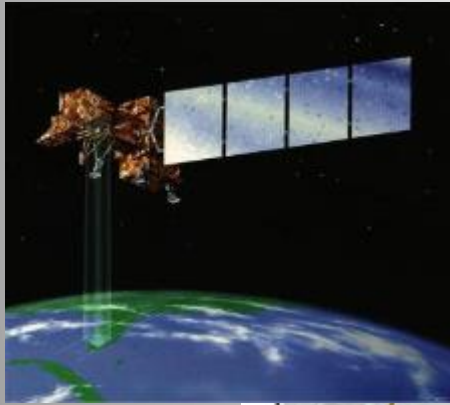


Overview of Some Projects

Goal: Use Remote Sensing to refine terrabytes of data into mineral exploration targets

- 1) Mineral Alteration Zones in Volcanic Massive Sulfide (VMS)**
- 2) Copper in Sedimentary Rocks**
- 3) Gold in Quartz Veins**
- 4) Chromite in Ultramafic Rocks**
- 5) Coal**

1) Mineral Alteration Zones in VMS

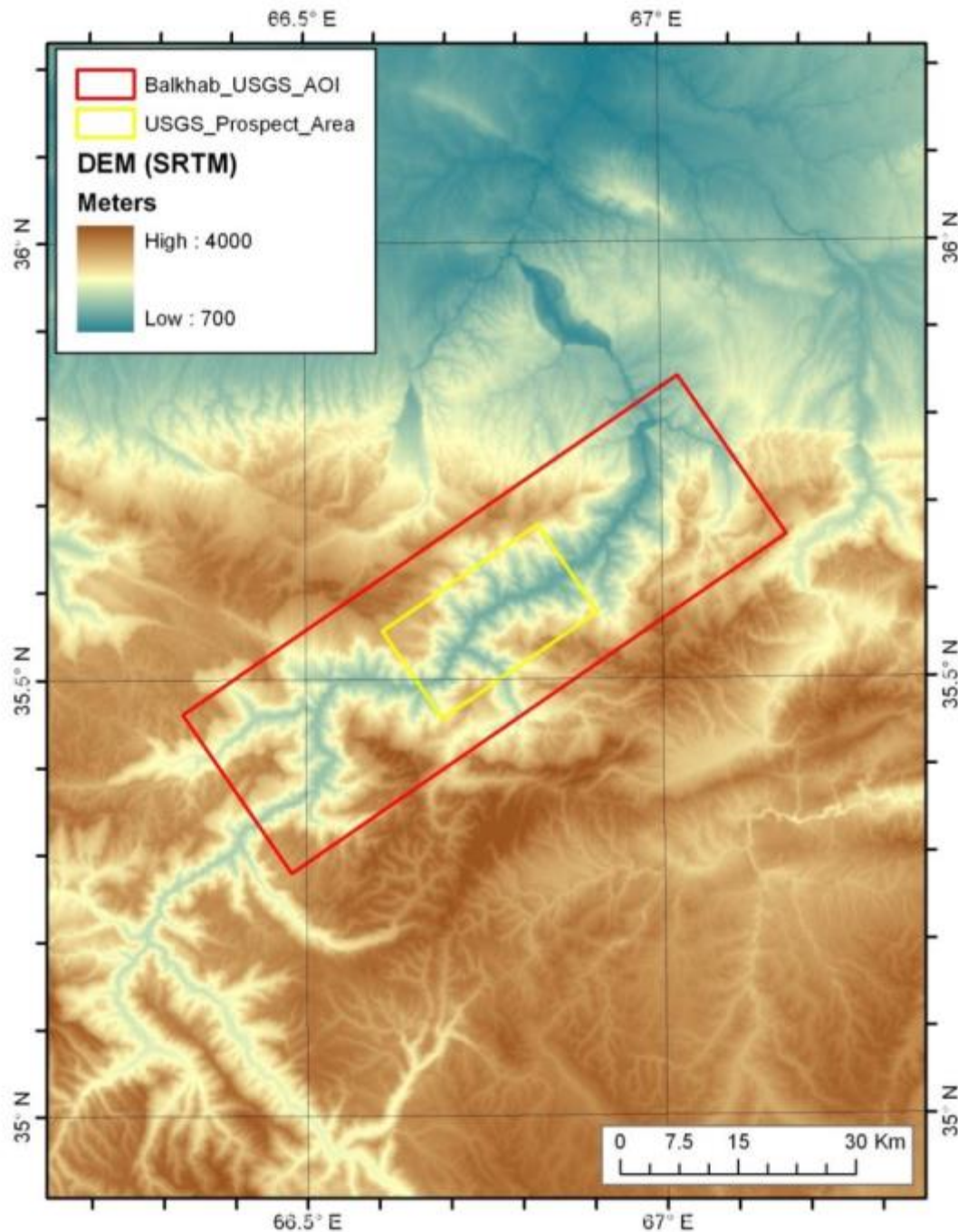


Satellite Imagery on Google Earth

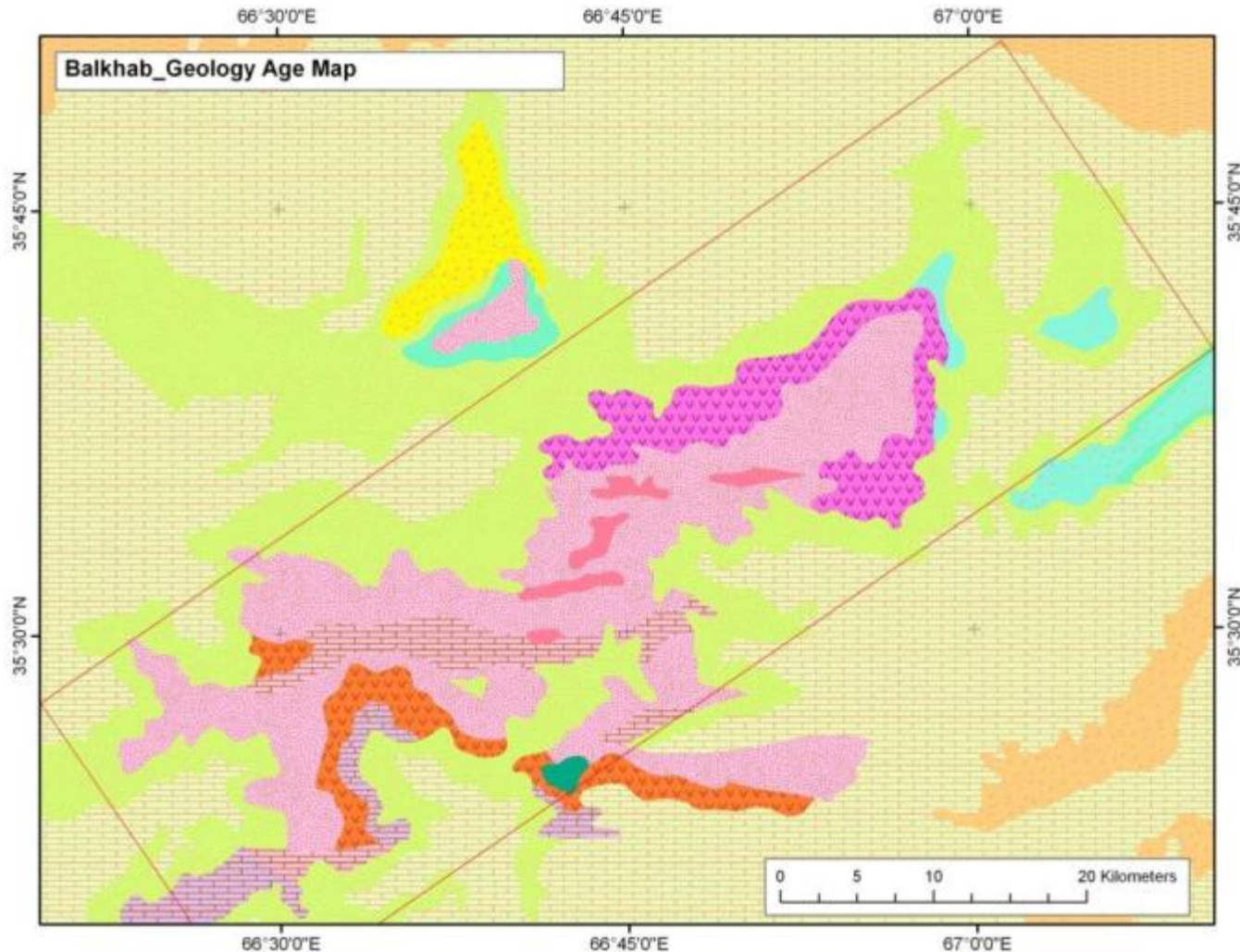




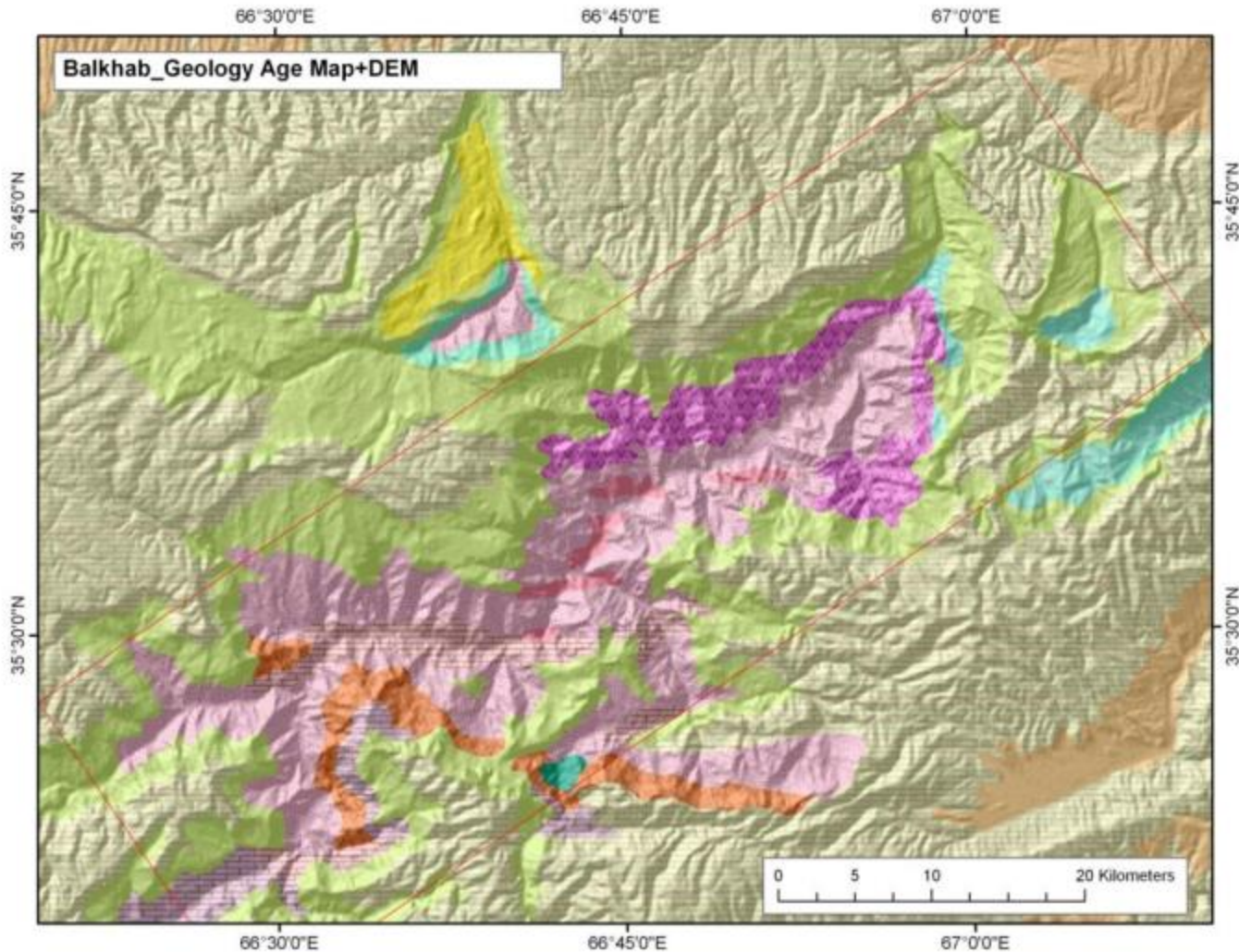
DEM with USGS AOIs



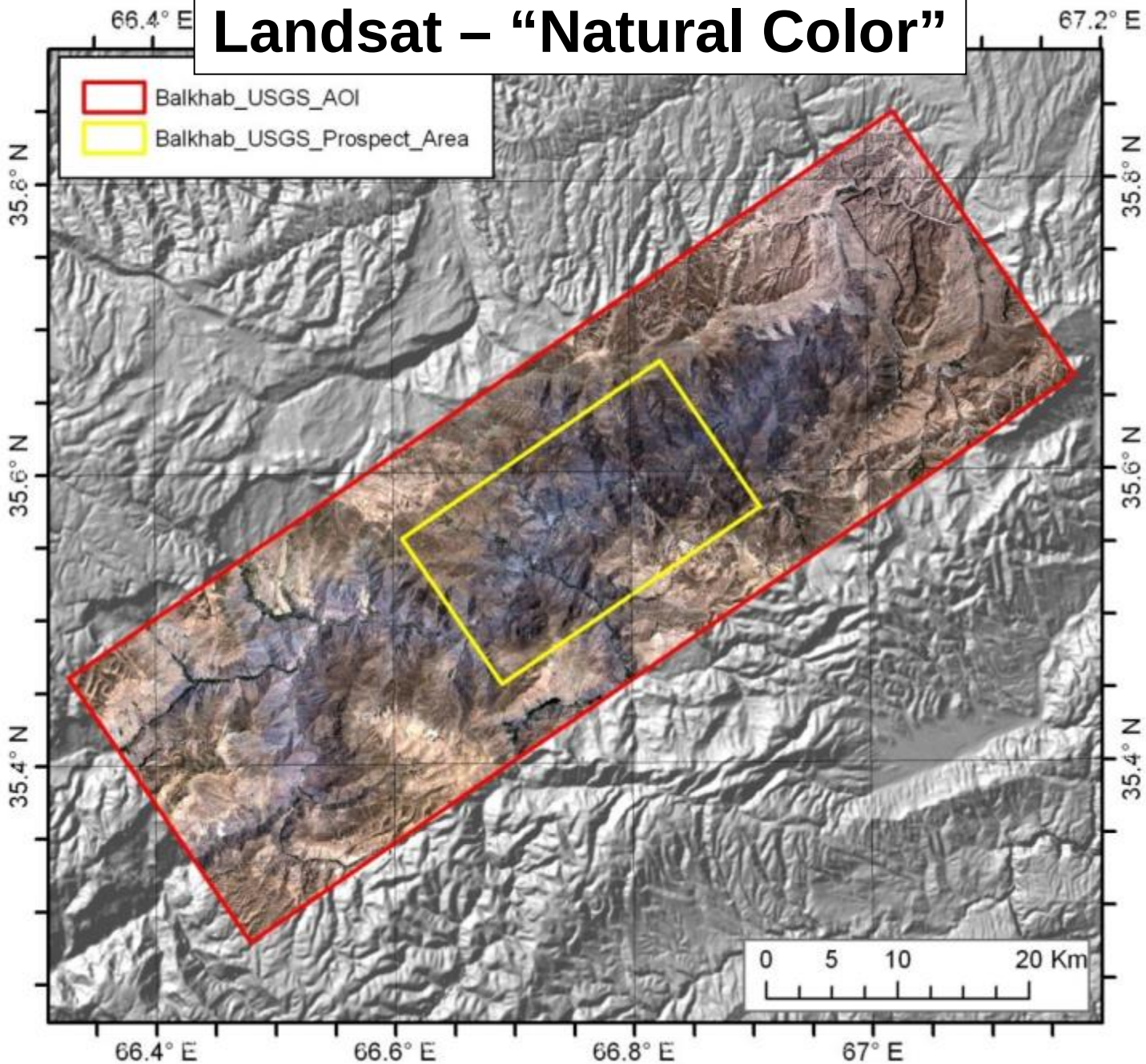
Published Geologic Map



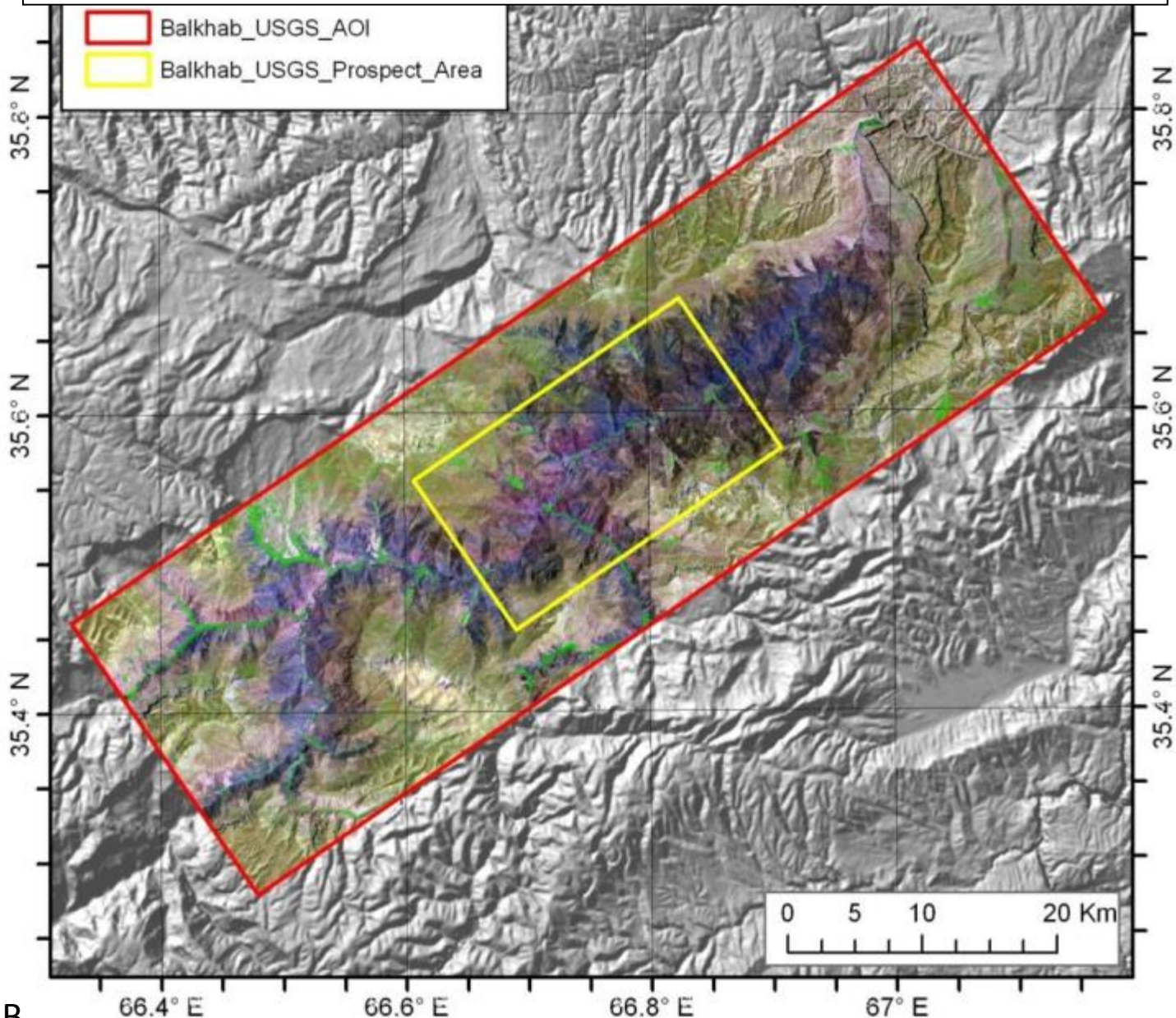
Published Geologic Map with DEM



Landsat – “Natural Color”

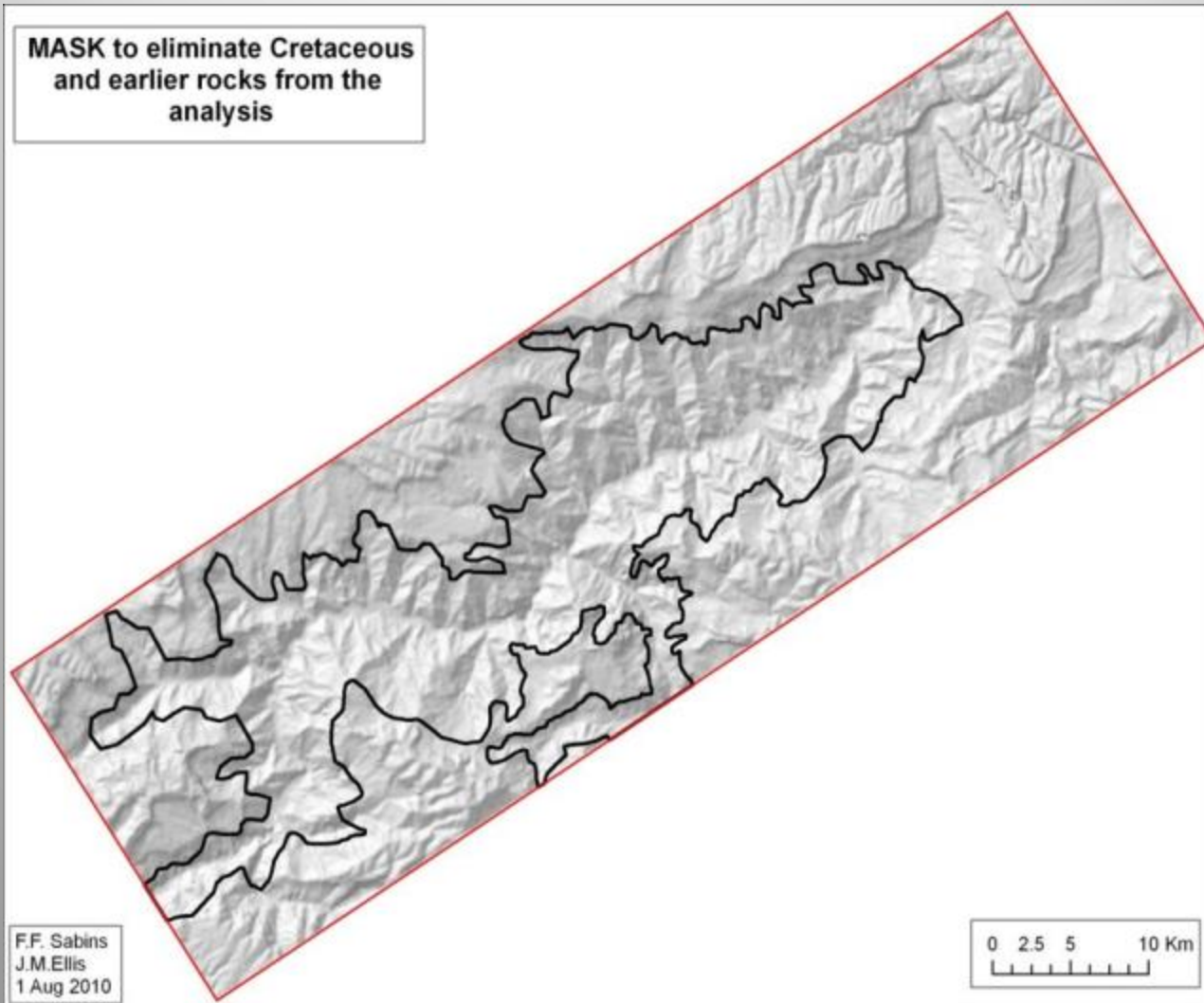


Landsat – 2-Infrared + 1-visible bands

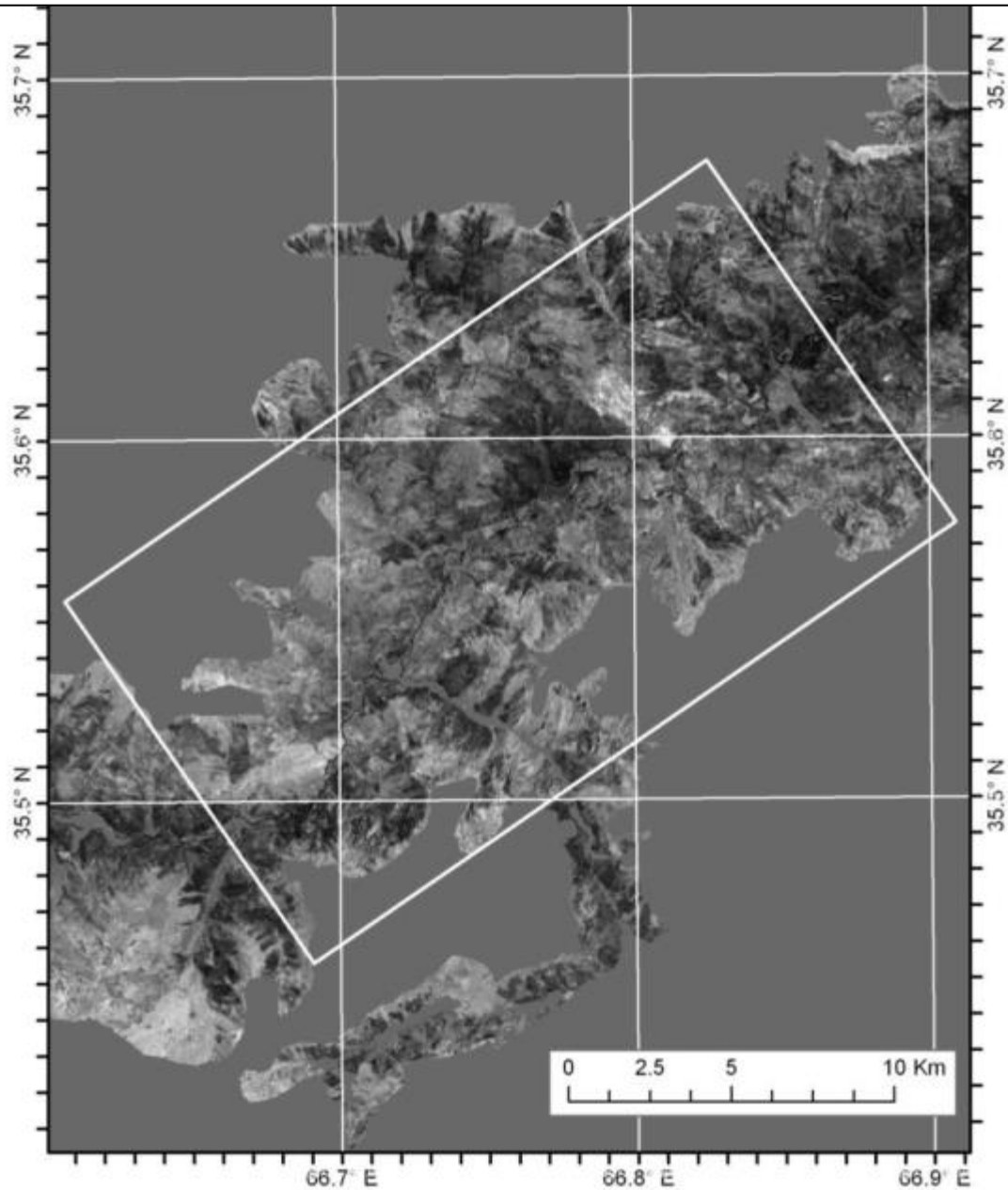


742 as RGB

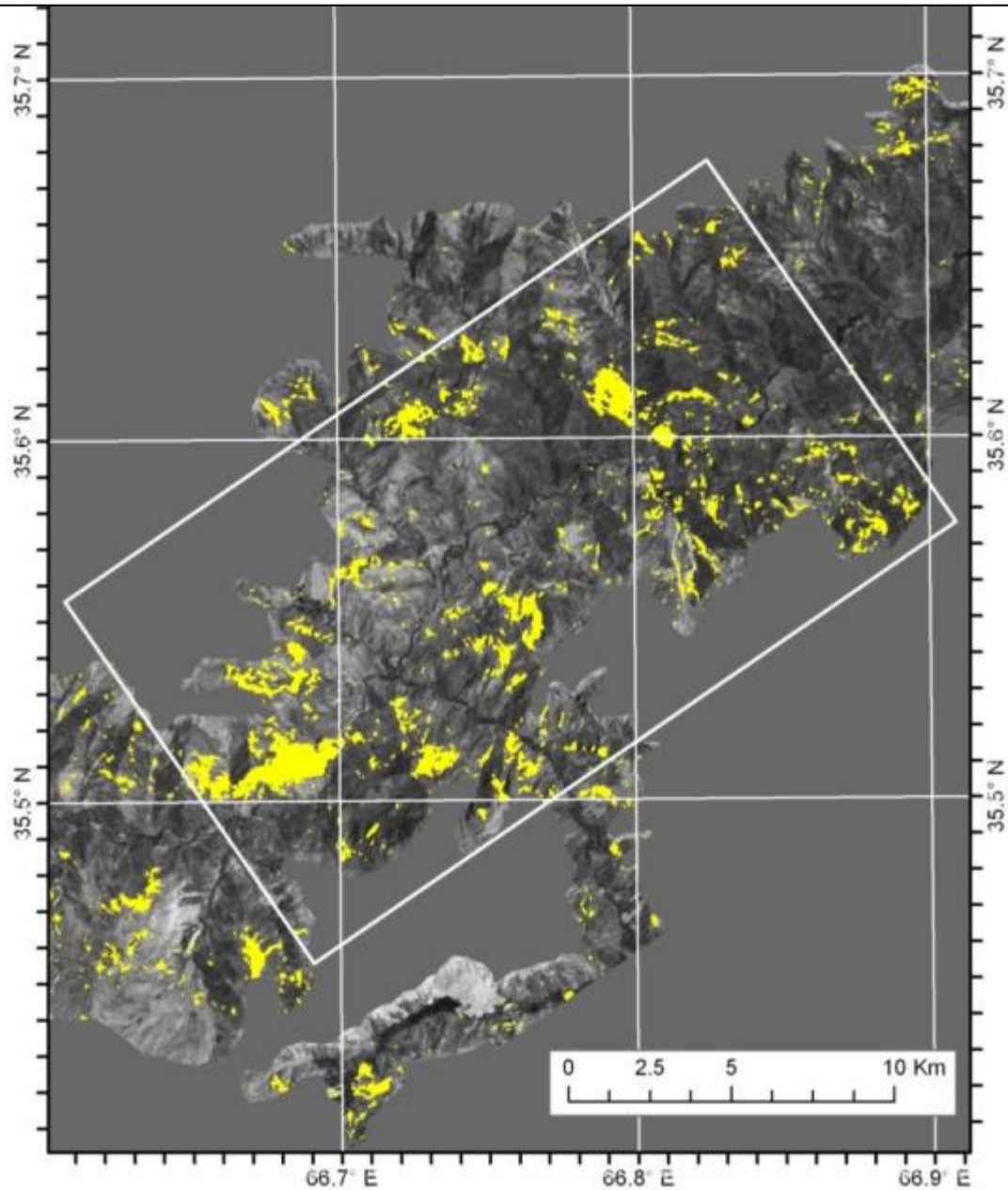
Mask geology younger than Cretaceous



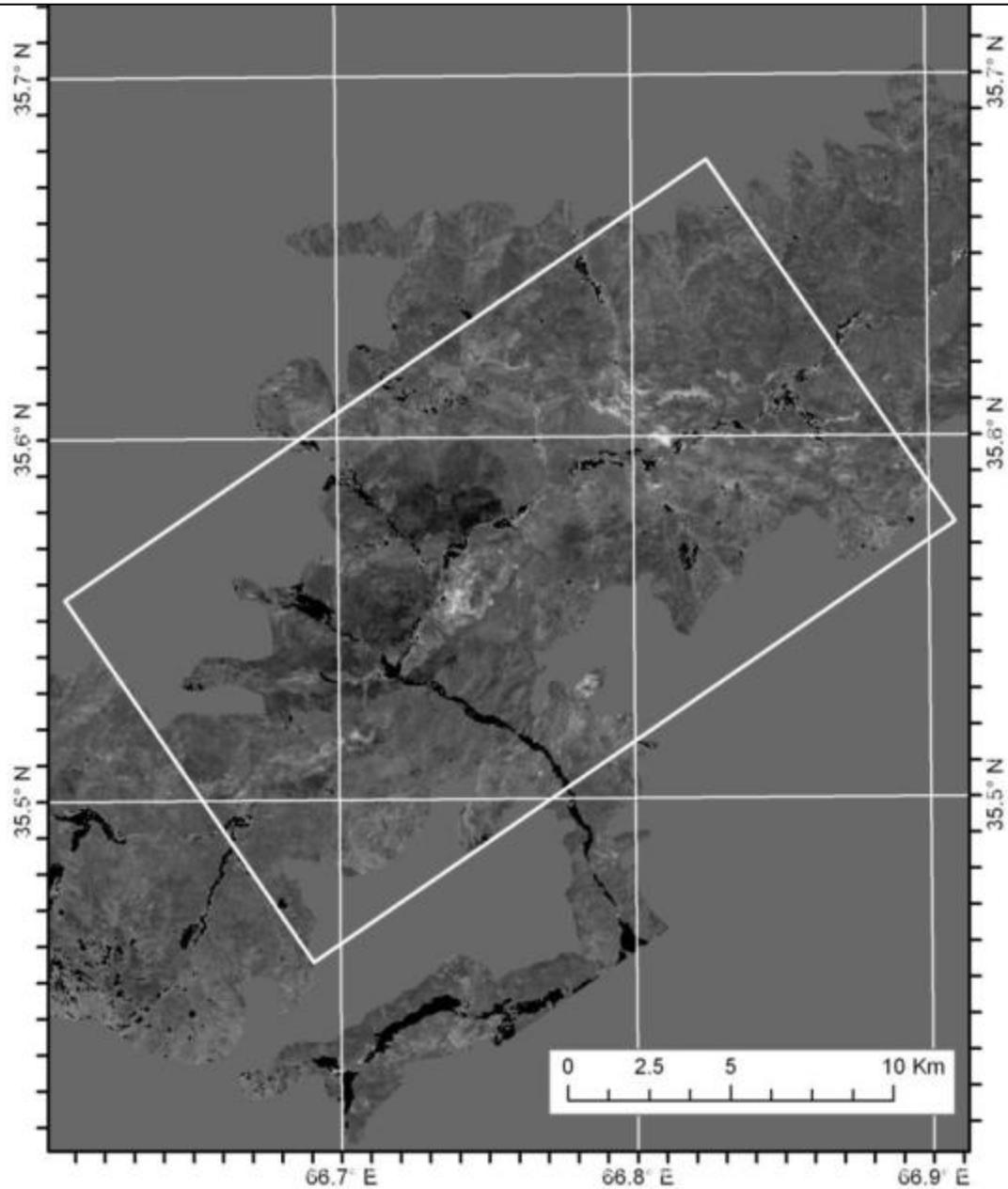
Landsat – “Iron” Bands 3/1 Ratio (Red/Blue)



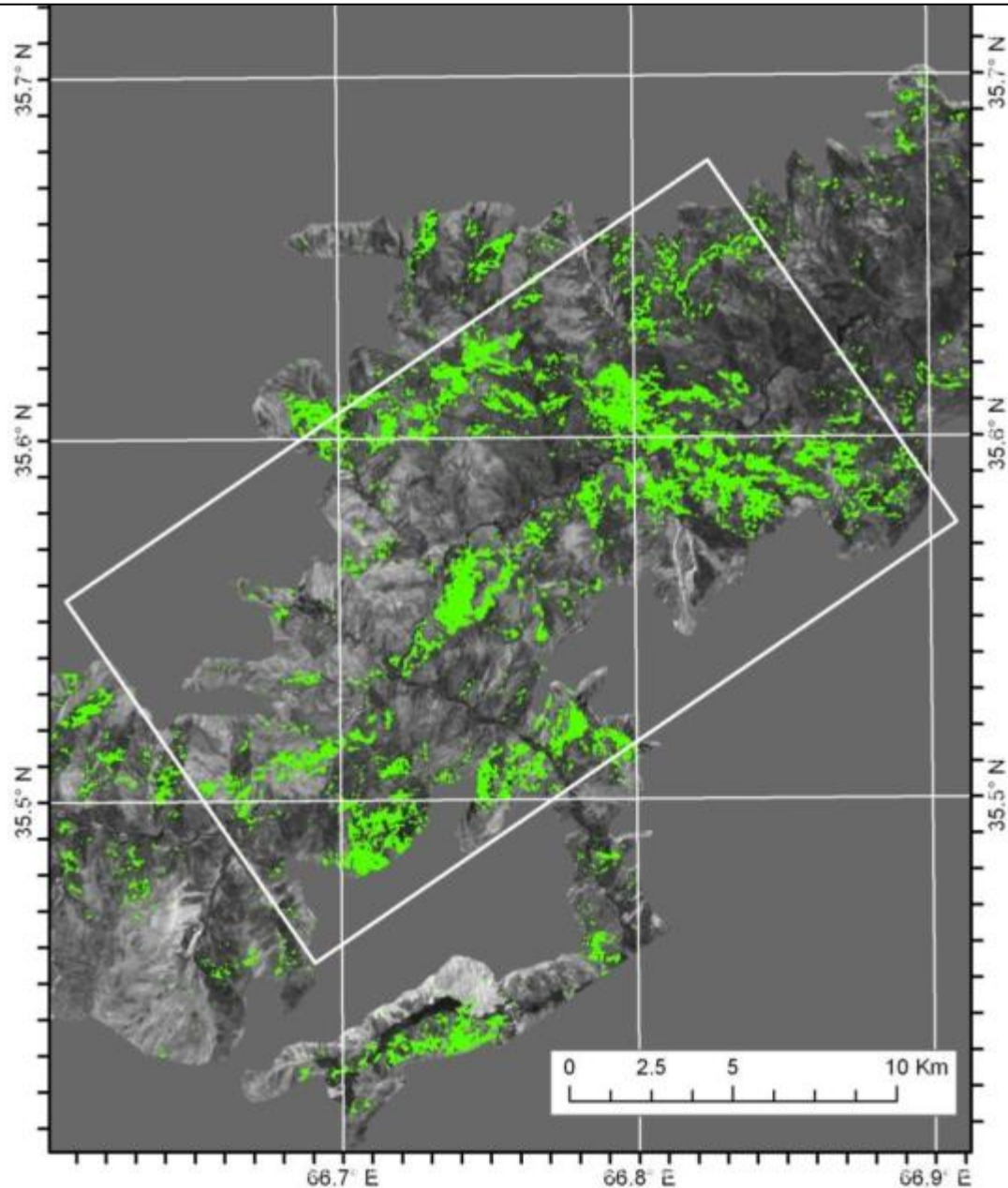
Landsat – “Iron” Bands 3/1 Ratio (Red/Blue)



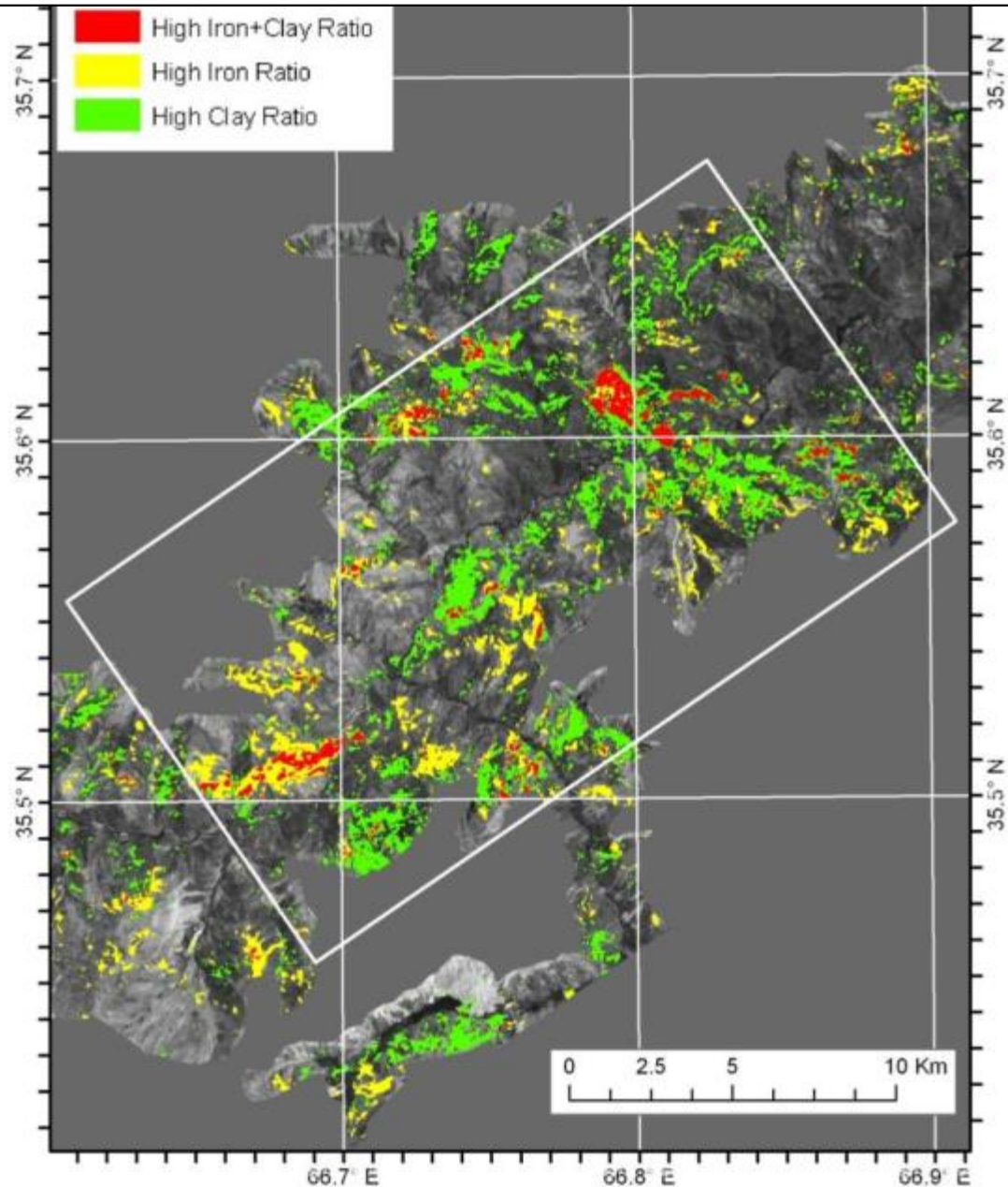
Landsat – “Clay” Bands 5/7 Ratio (Shortwave IR)



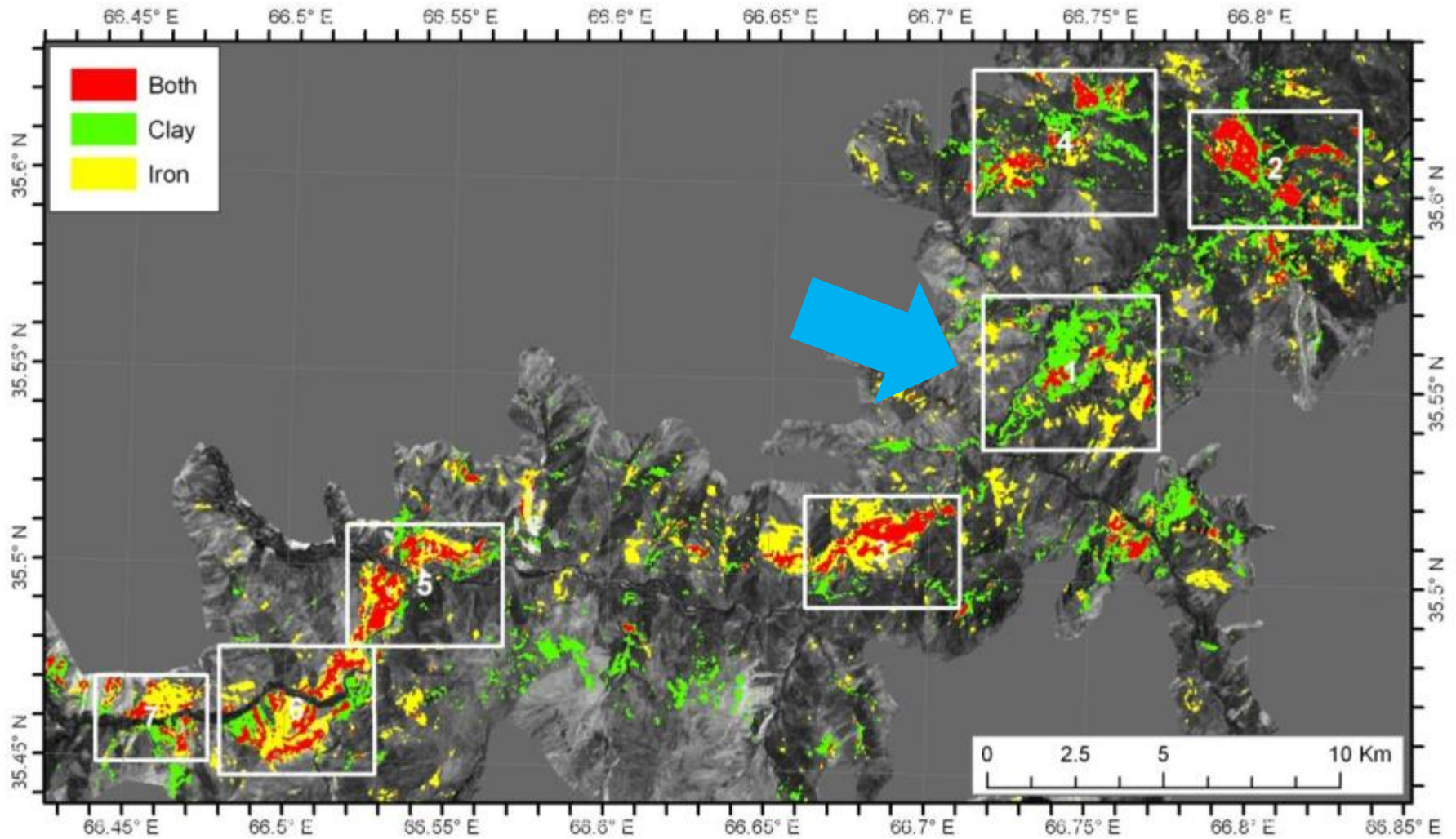
Landsat – “Clay” Bands 5/7 Ratio (Shortwave IR)



Landsat – “Clay” Bands 5/7 Ratio (Shortwave IR)

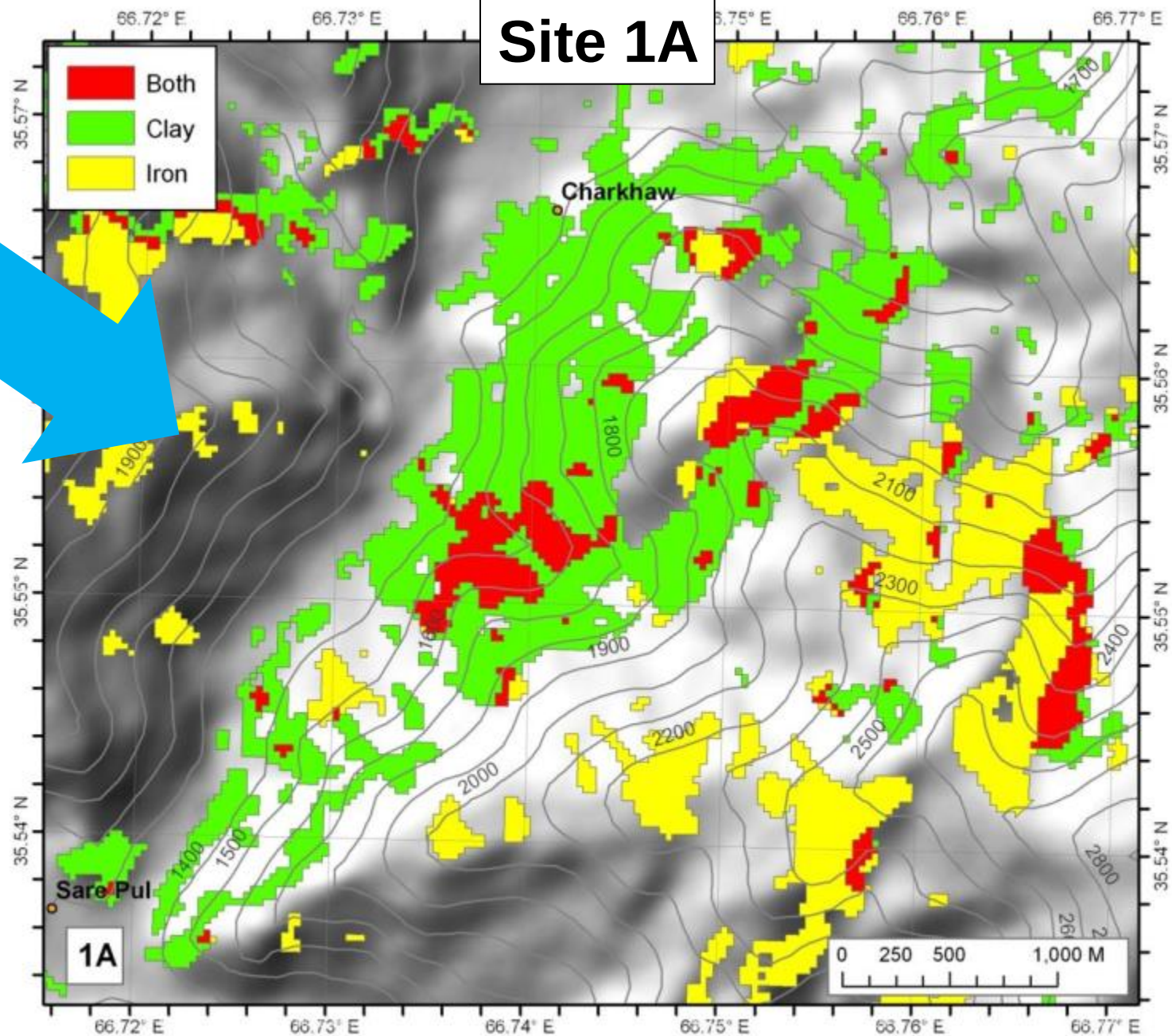


Landsat – Mineral Exploration Target Map

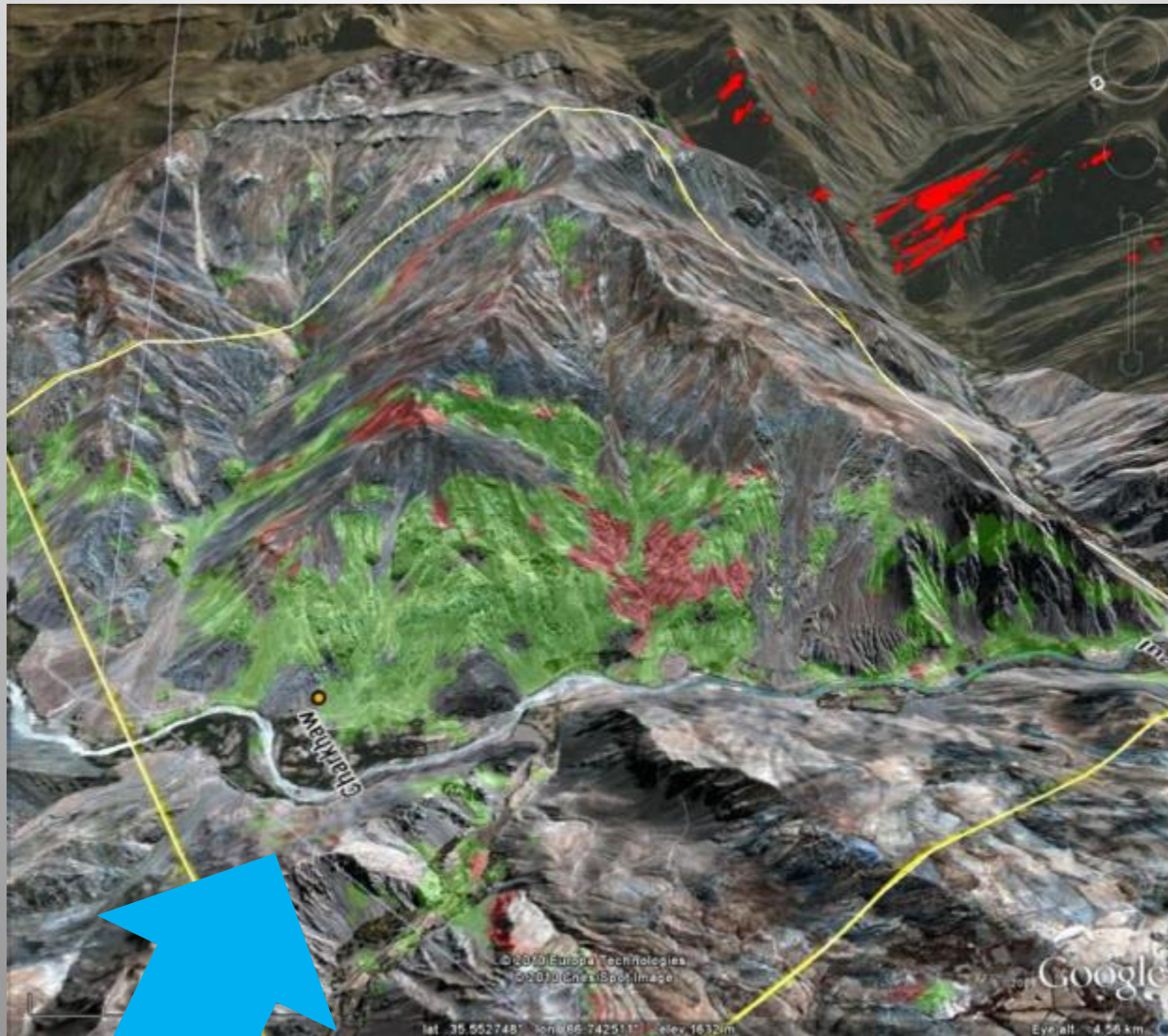




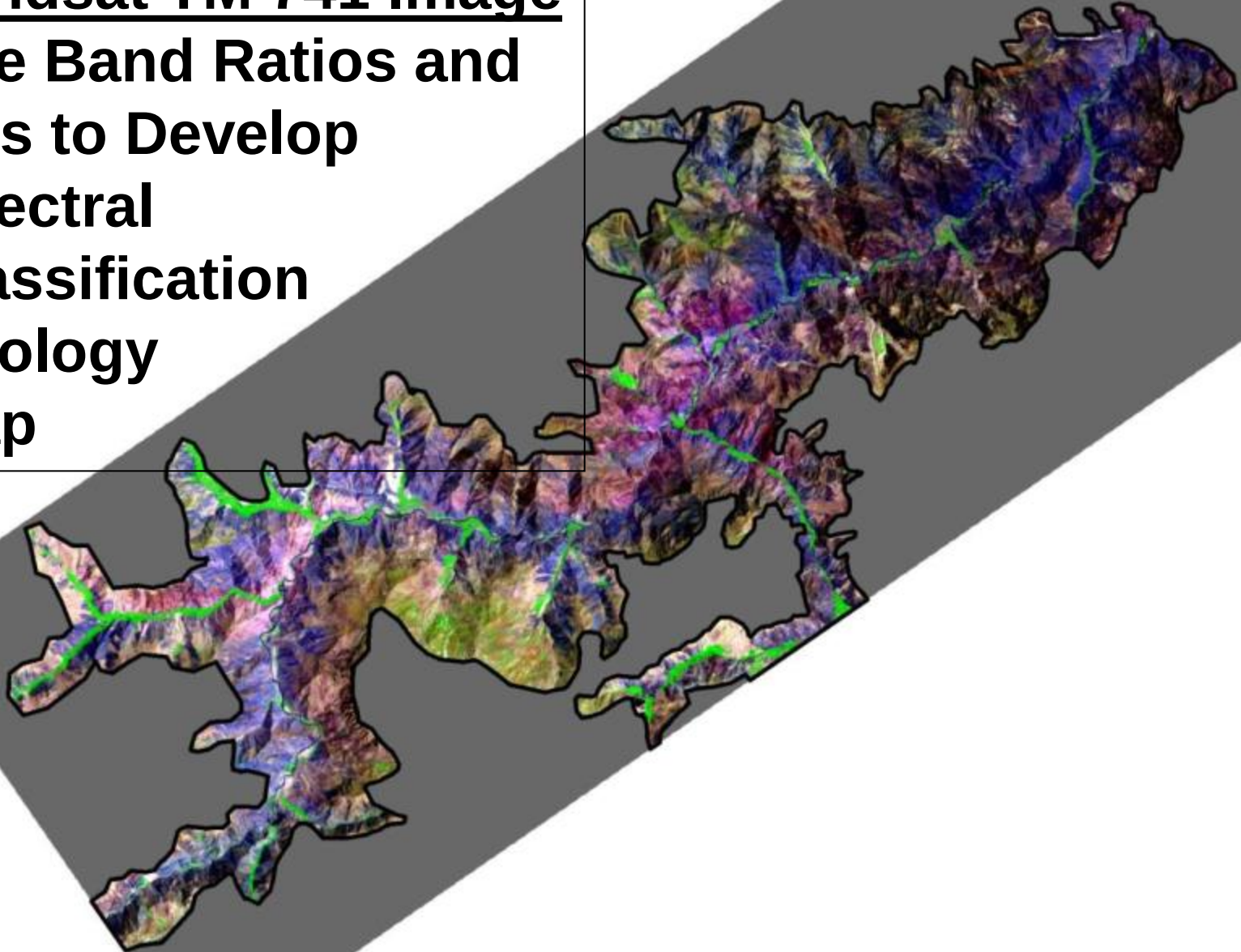
Site 1A



Site 1A in Google Earth

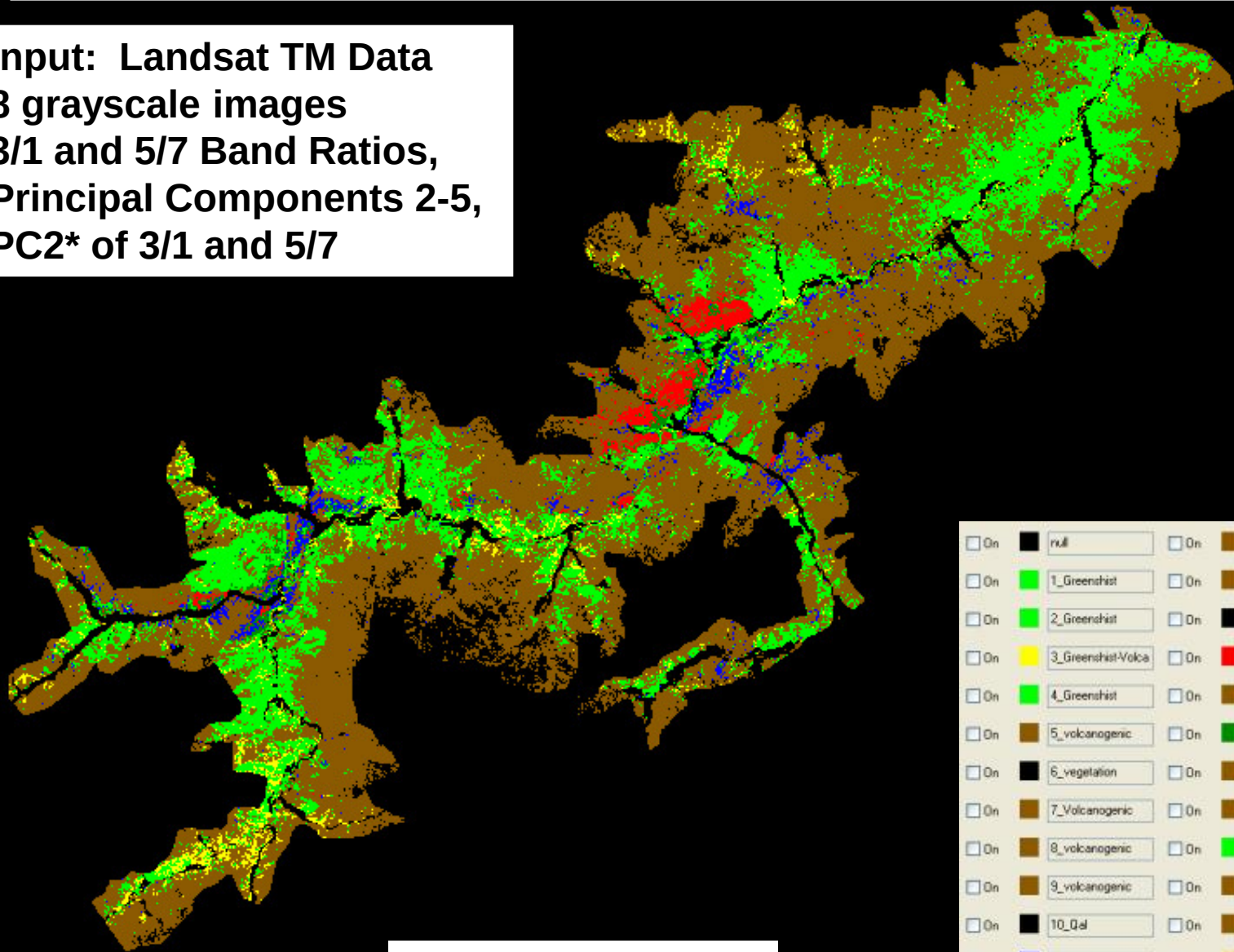


Landsat TM 741 Image
Use Band Ratios and
PCs to Develop
Spectral
Classification
Geology
Map



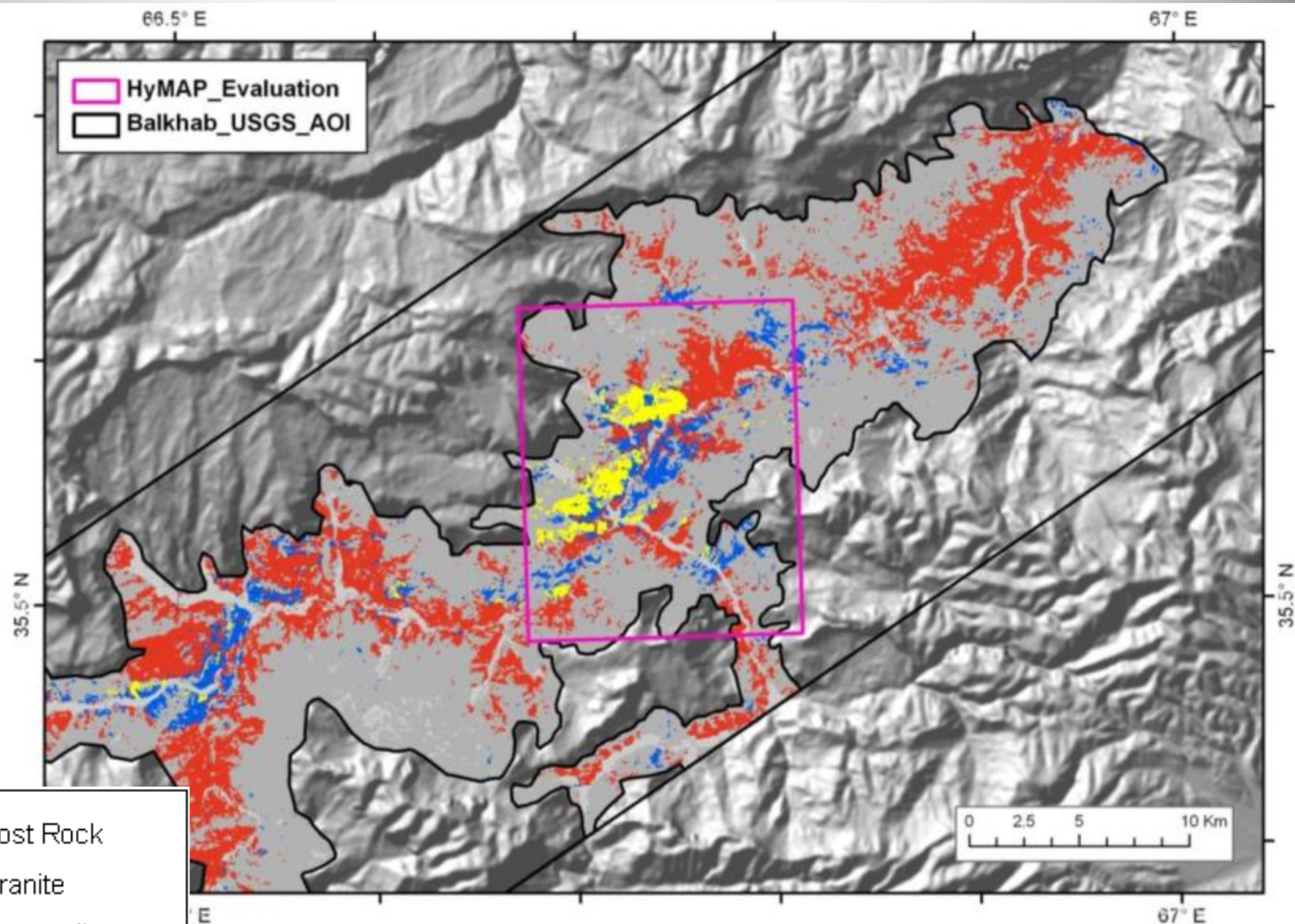
Unsupervised Classification – 25 classes

Input: Landsat TM Data
8 grayscale images
3/1 and 5/7 Band Ratios,
Principal Components 2-5,
PC2* of 3/1 and 5/7



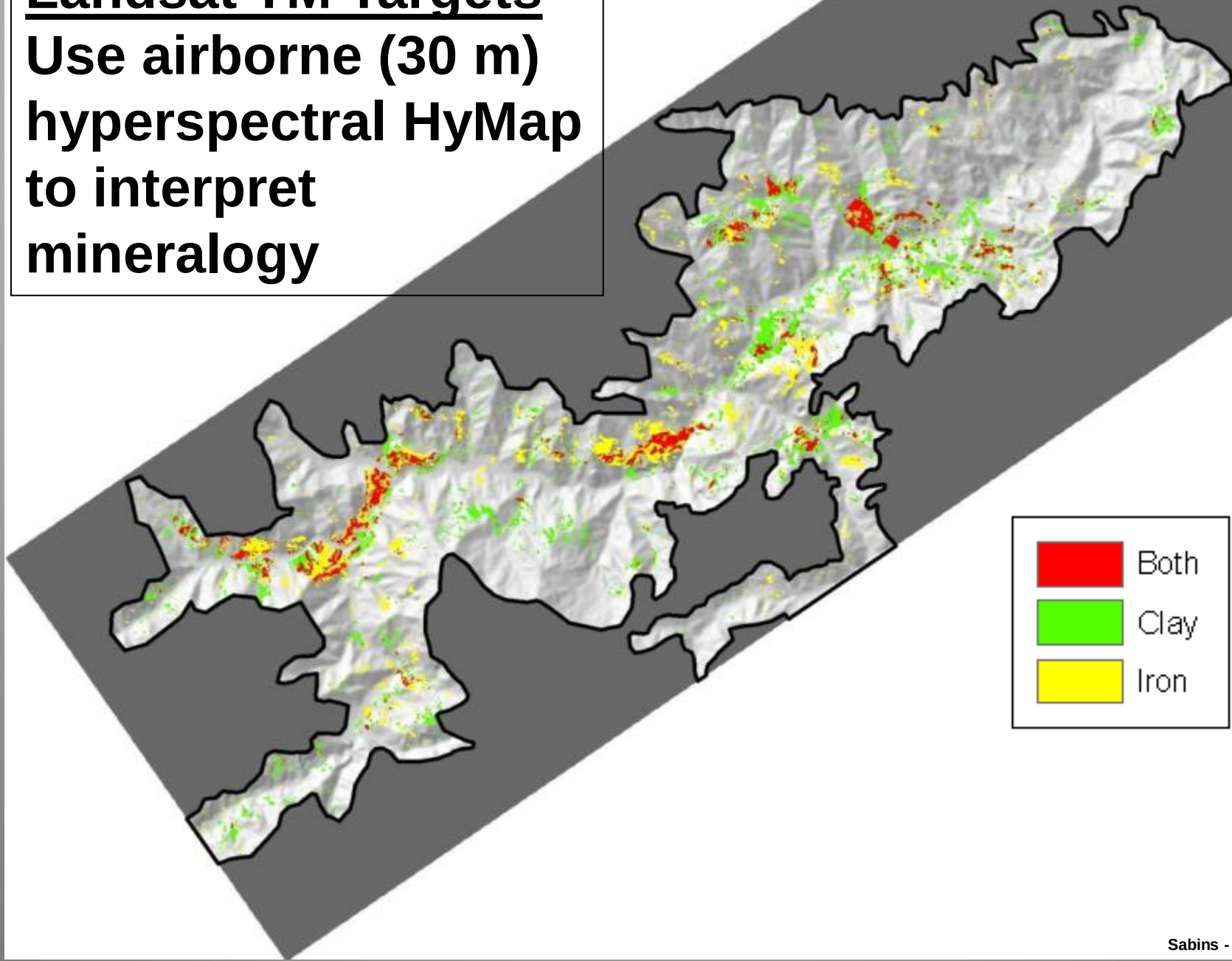
*Bedell and Crosta, 2009

☐ On		11 null	☐ On		13_volcanogenic
☐ On		1_Greenschist	☐ On		14_volcanogenic
☐ On		2_Greenschist	☐ On		15_vegetation
☐ On		3_Greenschist-Volca	☐ On		16_granitic
☐ On		4_Greenschist	☐ On		17_volcanogenic
☐ On		5_volcanogenic	☐ On		18_igneous?
☐ On		6_vegetation	☐ On		19_volcanogenic
☐ On		7_Volcanogenic	☐ On		20_volcanogenic
☐ On		8_volcanogenic	☐ On		21_Greenschist
☐ On		9_volcanogenic	☐ On		22_volcanogenic?
☐ On		10_Qal	☐ On		23_volcanogenic
☐ On		11_Anomaly1	☐ On		24_volcanogenic
☐ On		12_volcanogenic	☐ On		25_Greenschist

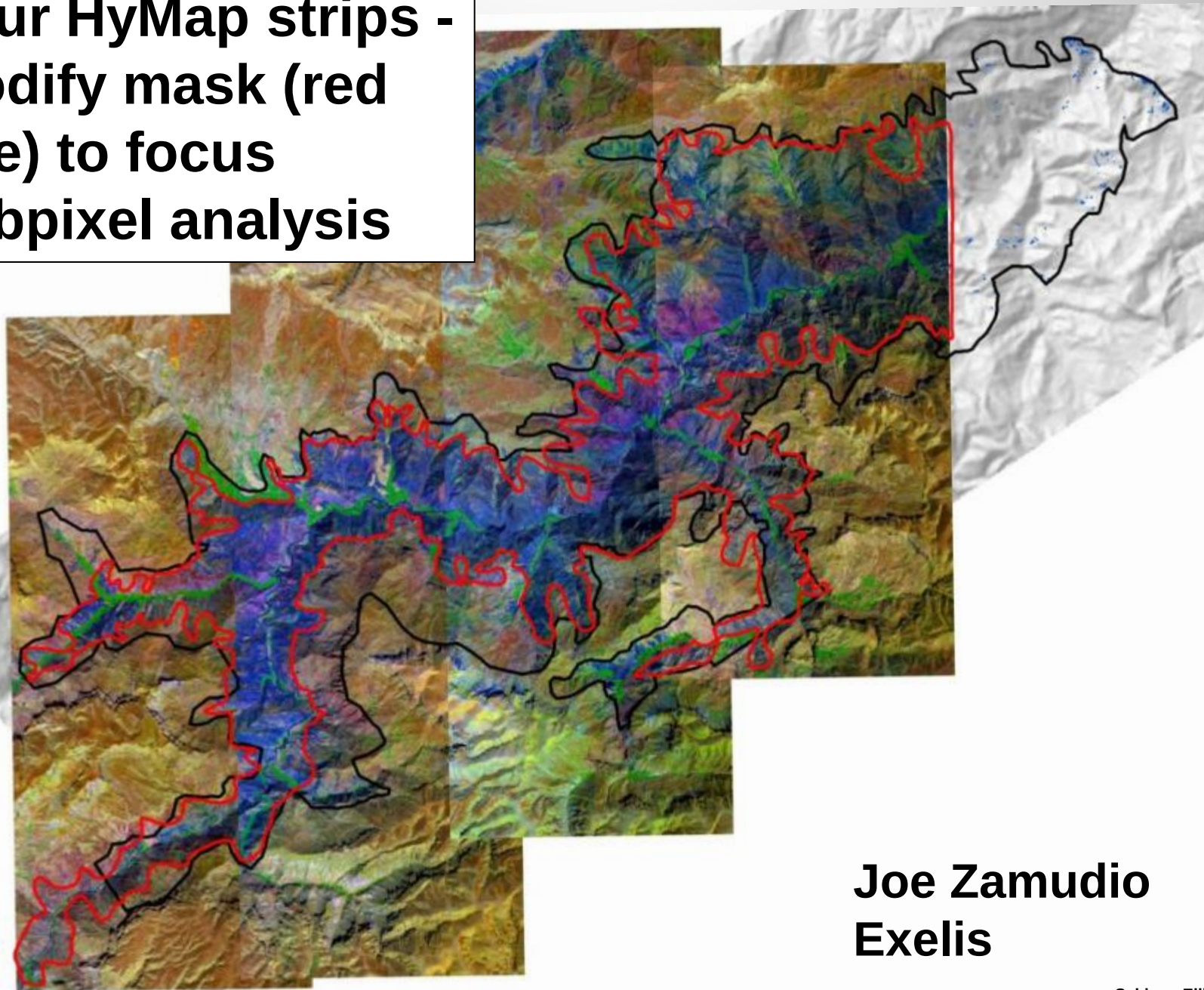


Geology Map - Roll-up 25 Classes into 4 Classes

Landsat TM Targets
**Use airborne (30 m)
hyperspectral HyMap
to interpret
mineralogy**

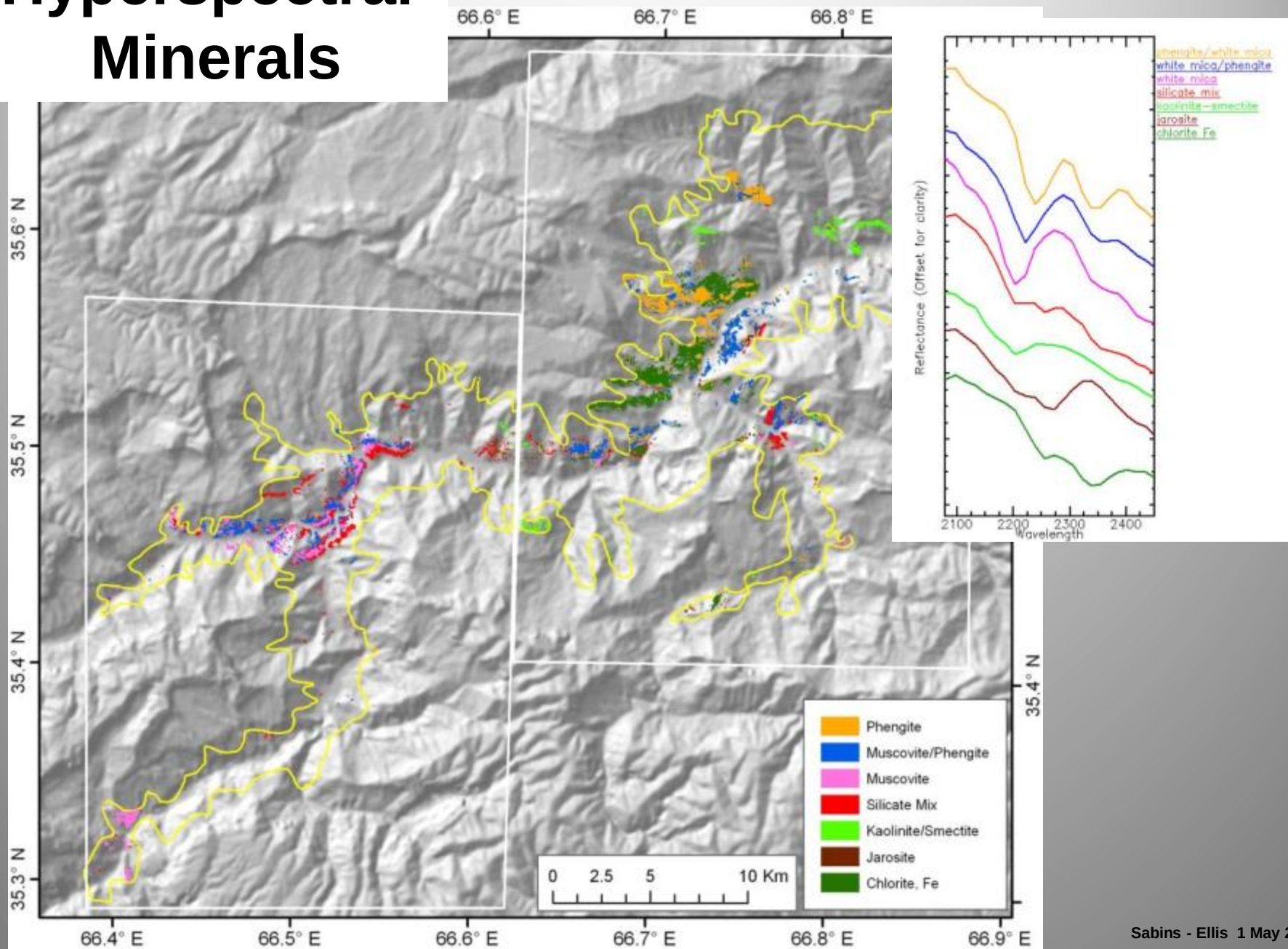


**Four HyMap strips -
Modify mask (red
line) to focus
subpixel analysis**



**Joe Zamudio
Exelis**

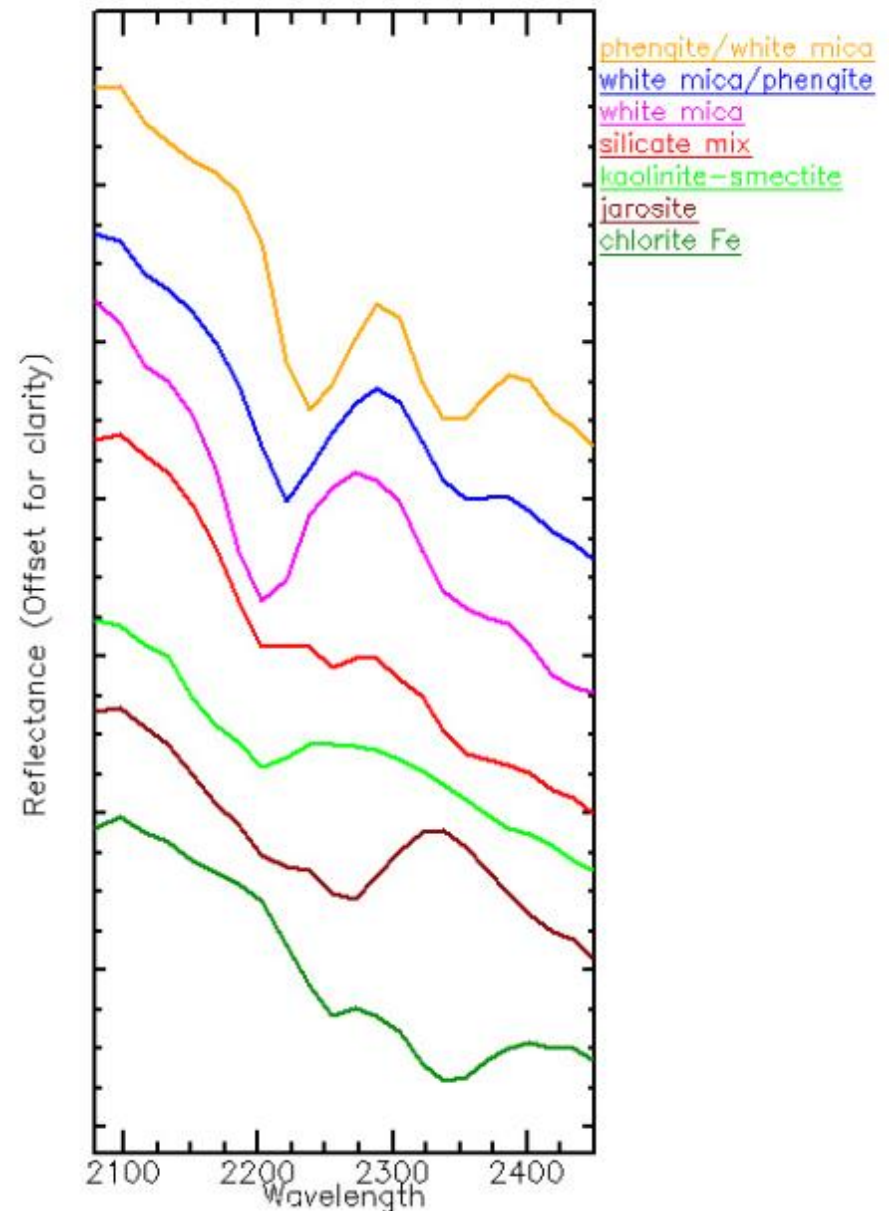
Hyperspectral Minerals



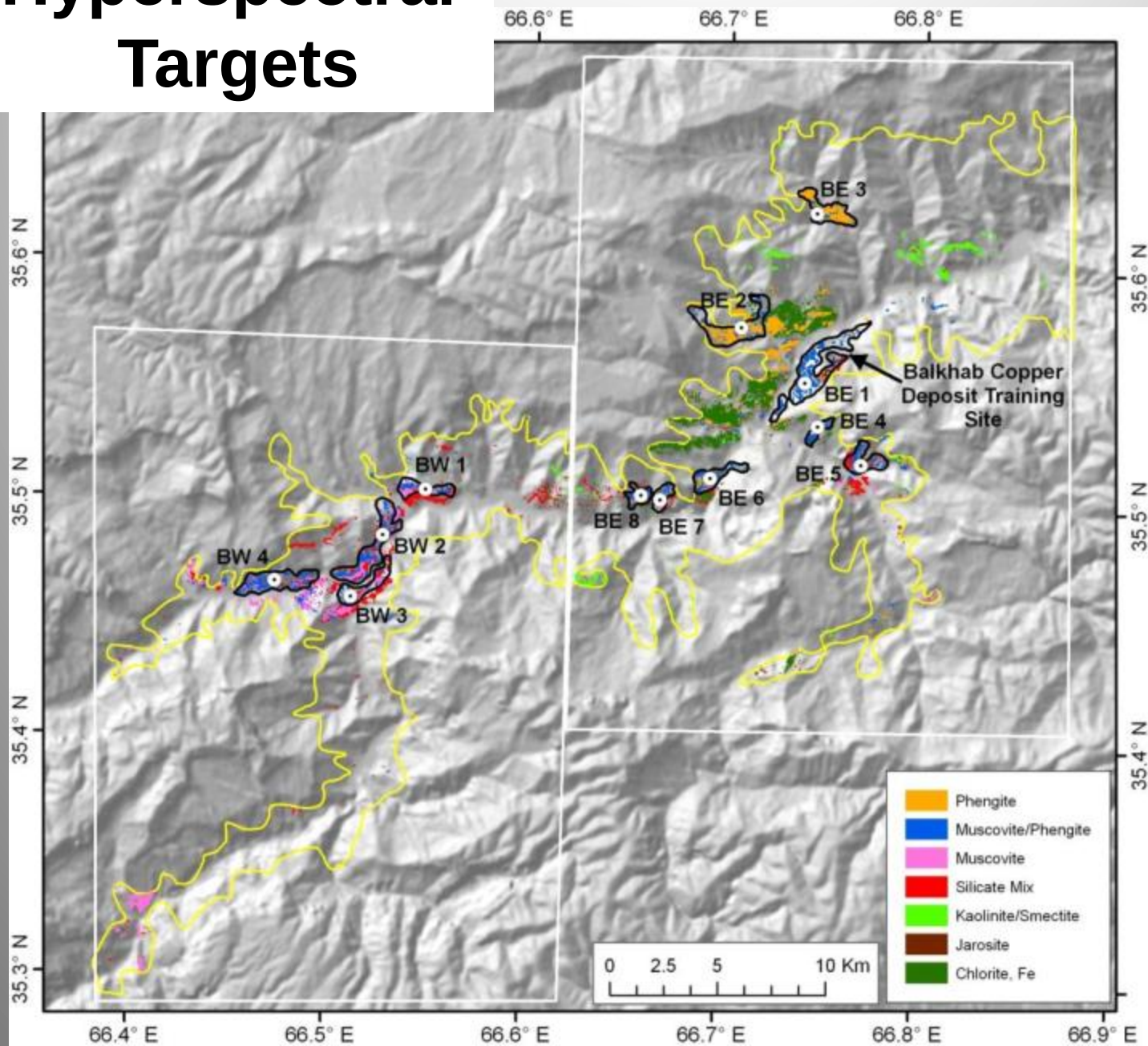


Muscovite (white mica) has the characteristic absorption feature at 2200 nm. For phengite the absorption feature has shifted to 2240 nm. A third mineral has an intermediate absorption minimum at 2225 nm, which indicates an Mg/Fe²⁺ composition intermediate between muscovite (white mica) and phengite.

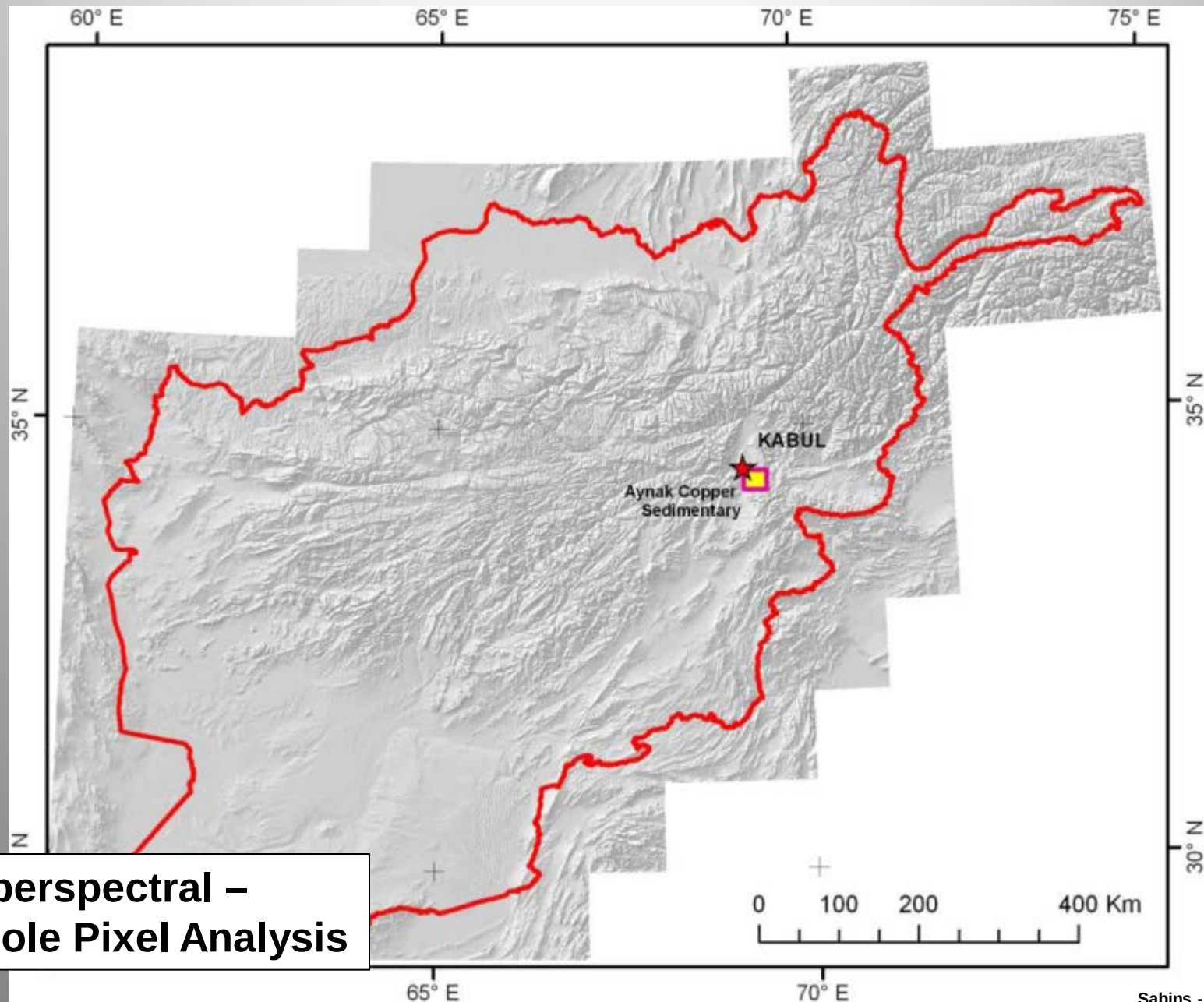
Mapping the mineral transition between muscovite and phengite is important for exploration because various workers (Yang and others, 2001, Prendergast, 2007) have recognized that VMS mineral deposits are located at the change from muscovite to phengite.



Hyperspectral Targets



2) Copper in Sedimentary Rocks

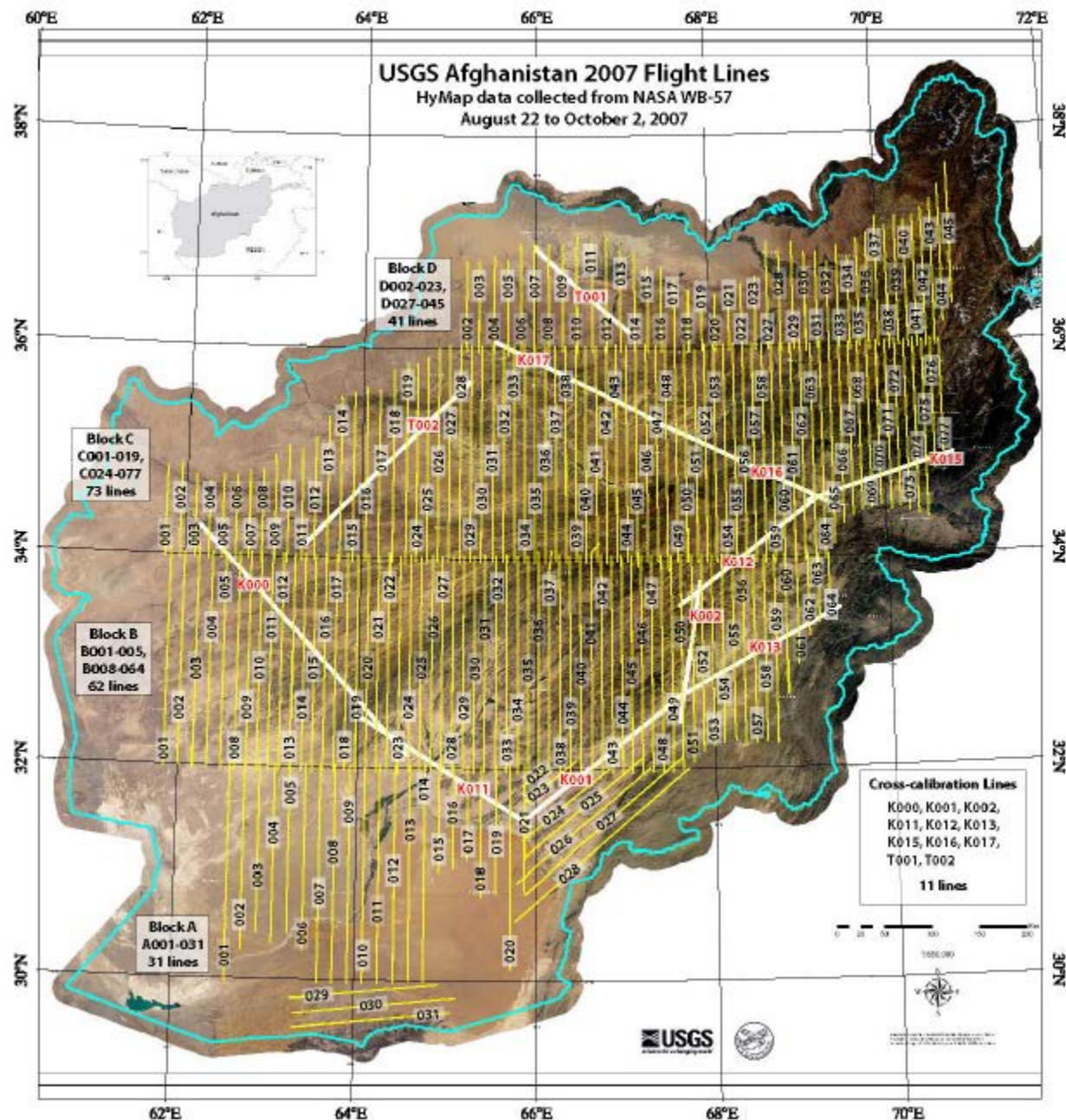


Hyperspectral –
Whole Pixel Analysis

Airborne HyMap Hyperspectral Survey



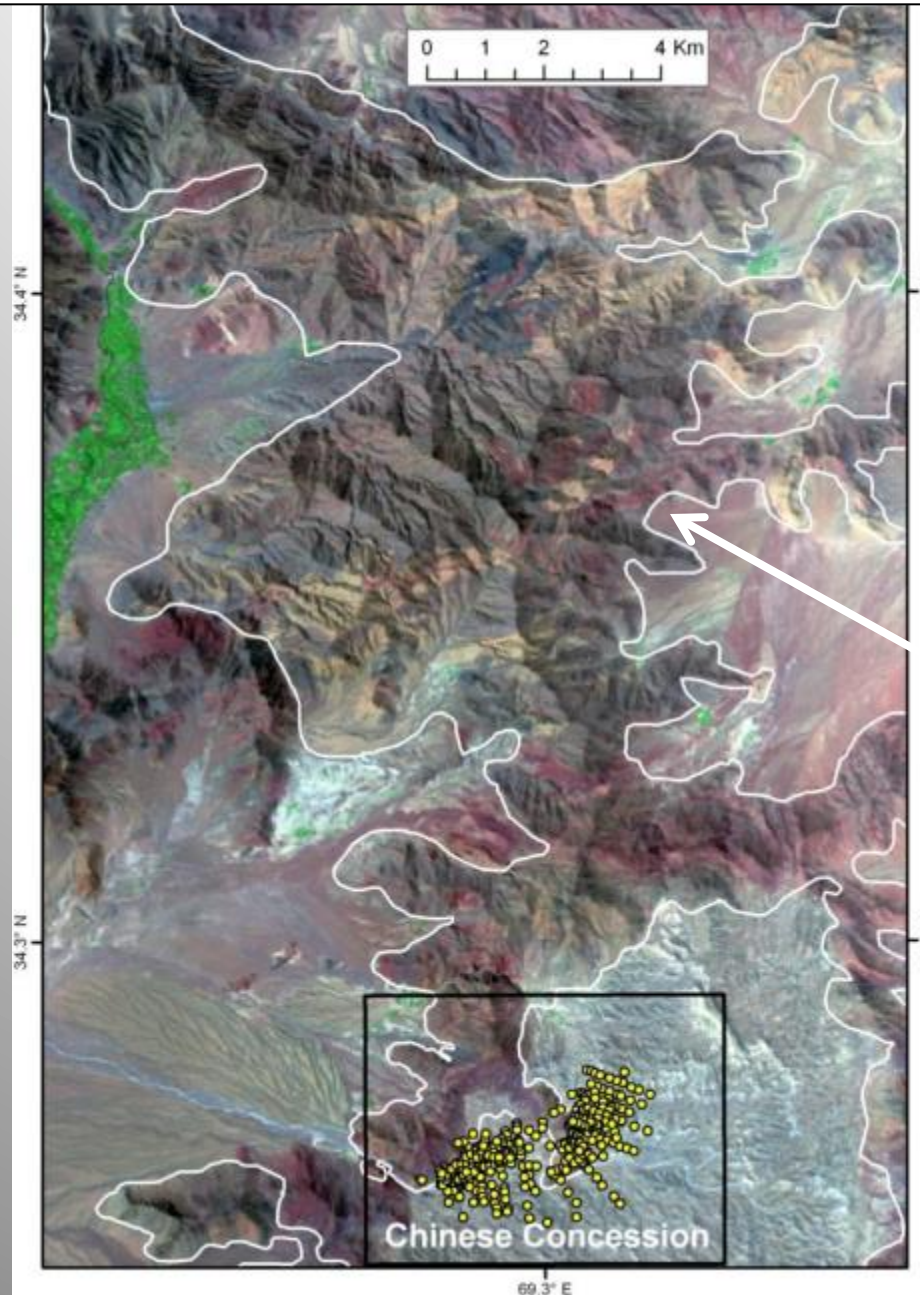
Airborne HyMap Hyperspectral Flight Lines



Chinese \$3B Mining Concession

Original work
in North with
only Landsat
TM imagery

Extended to
south with
hyperspectral
HyMap



Loy Khwar +
Mask

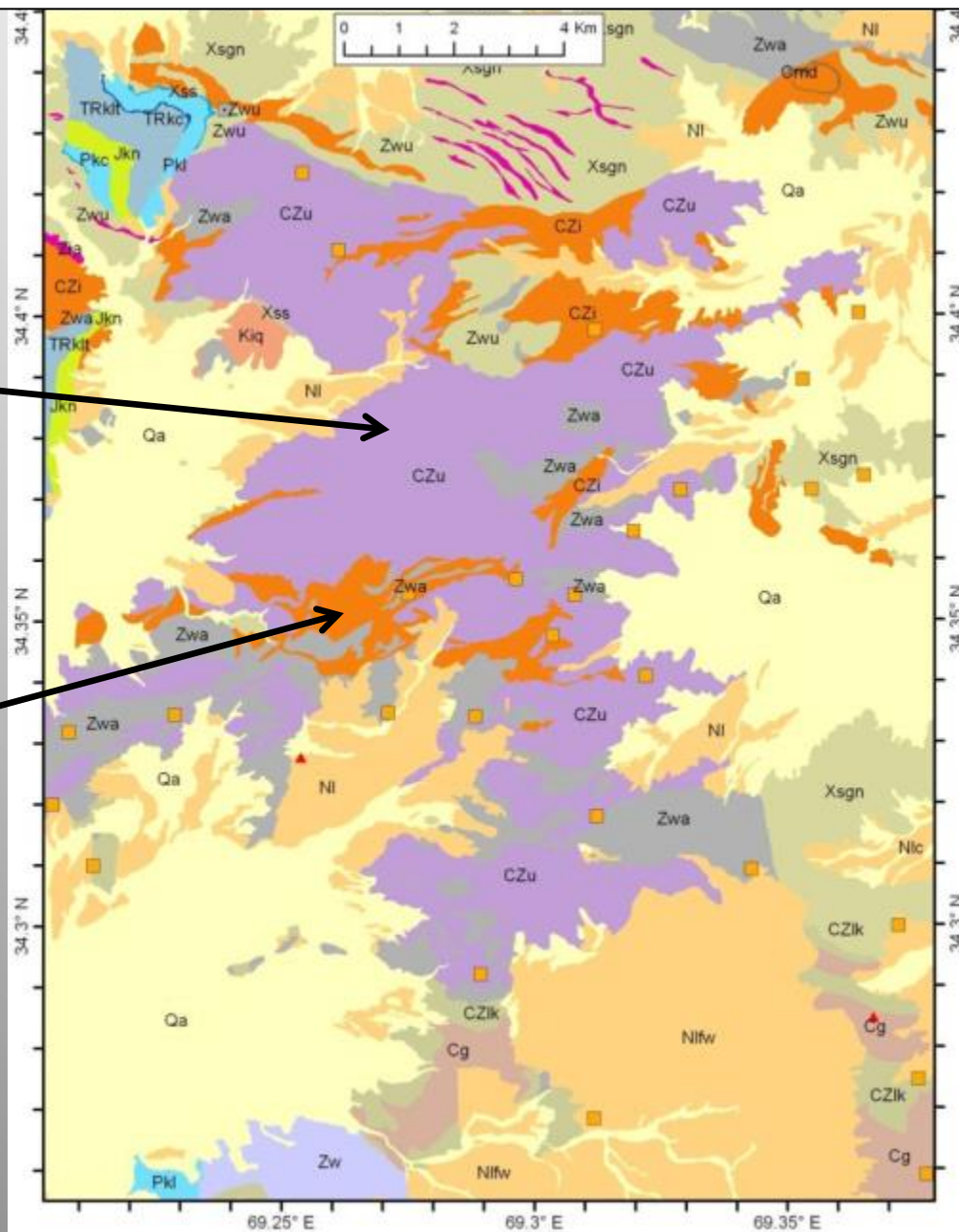
Host rock for
sedimentary
copper

USGS Geologic Map (Bohannon, 2010, Sheet 1)

Loy Khwar

Shist
Member

Dolomitic
Member
*Most
Interest*



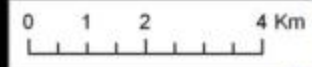
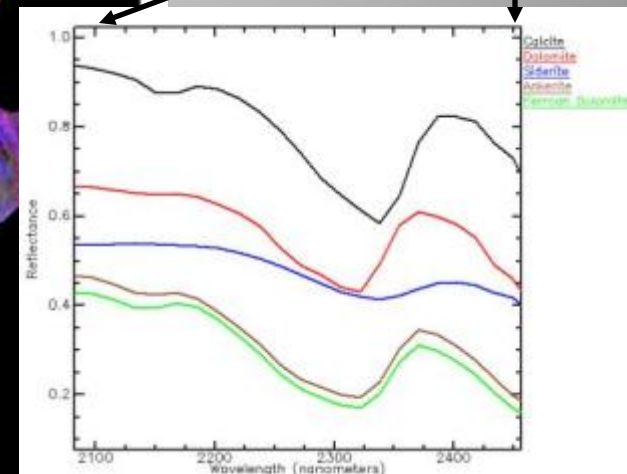
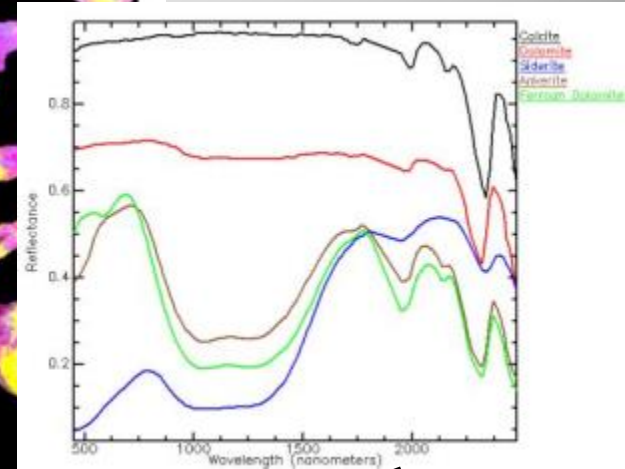
MNF 489 with Lab Spectral Profiles

?
Understood
as Dolomitic
outcrops

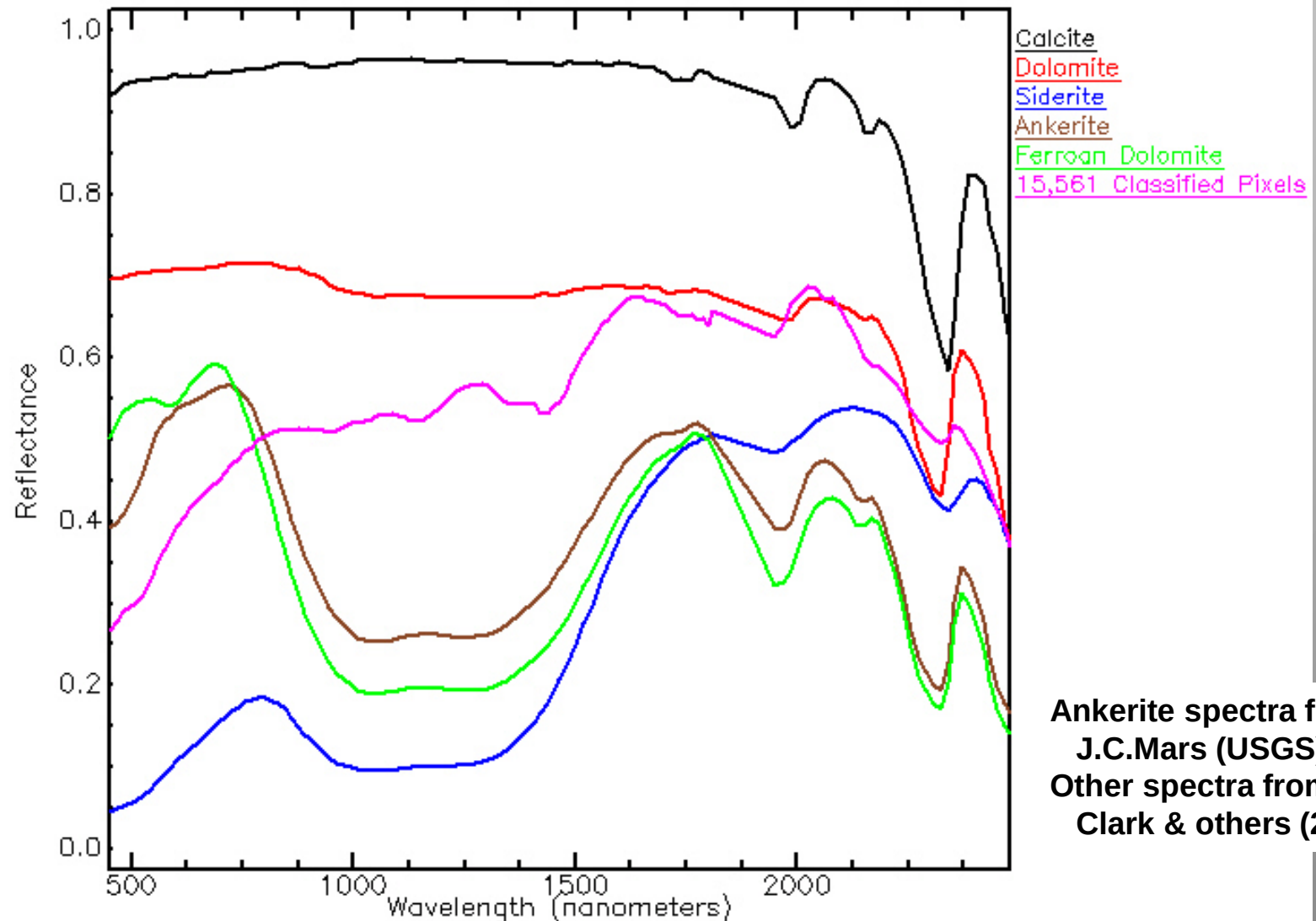
?

Ankerite spectra from
J.C.Mars (USGS)
Other spectra from
Clark & others (2007)

Lab Spectra

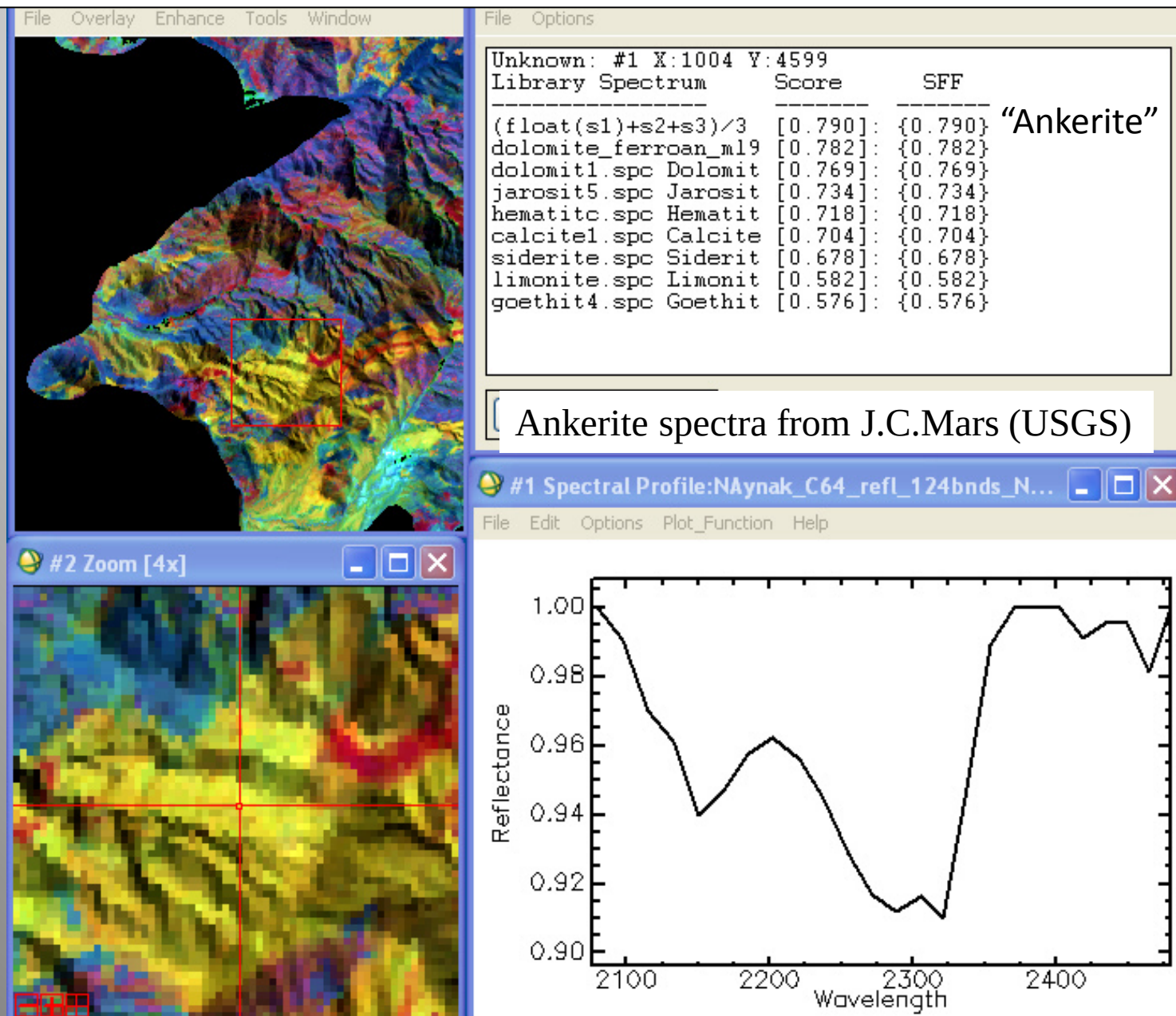


Dolomitic Host Rock - Solid Solution

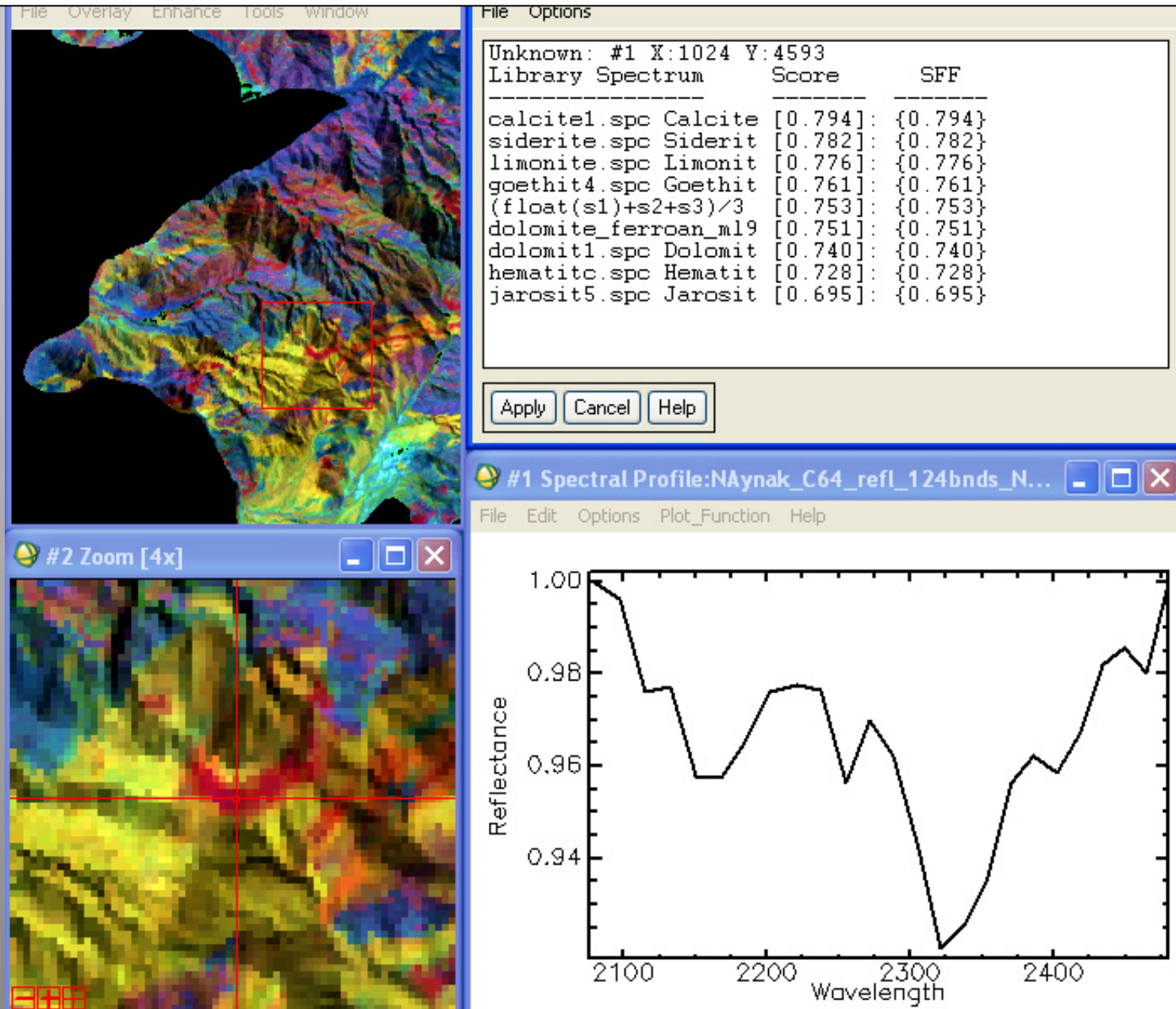


Dolomite (Mg) - Ferroan Dolomite – Ankerite (Fe) & Siderite

HyMap Pixel ~“Ankerite” iron-rich dolomite



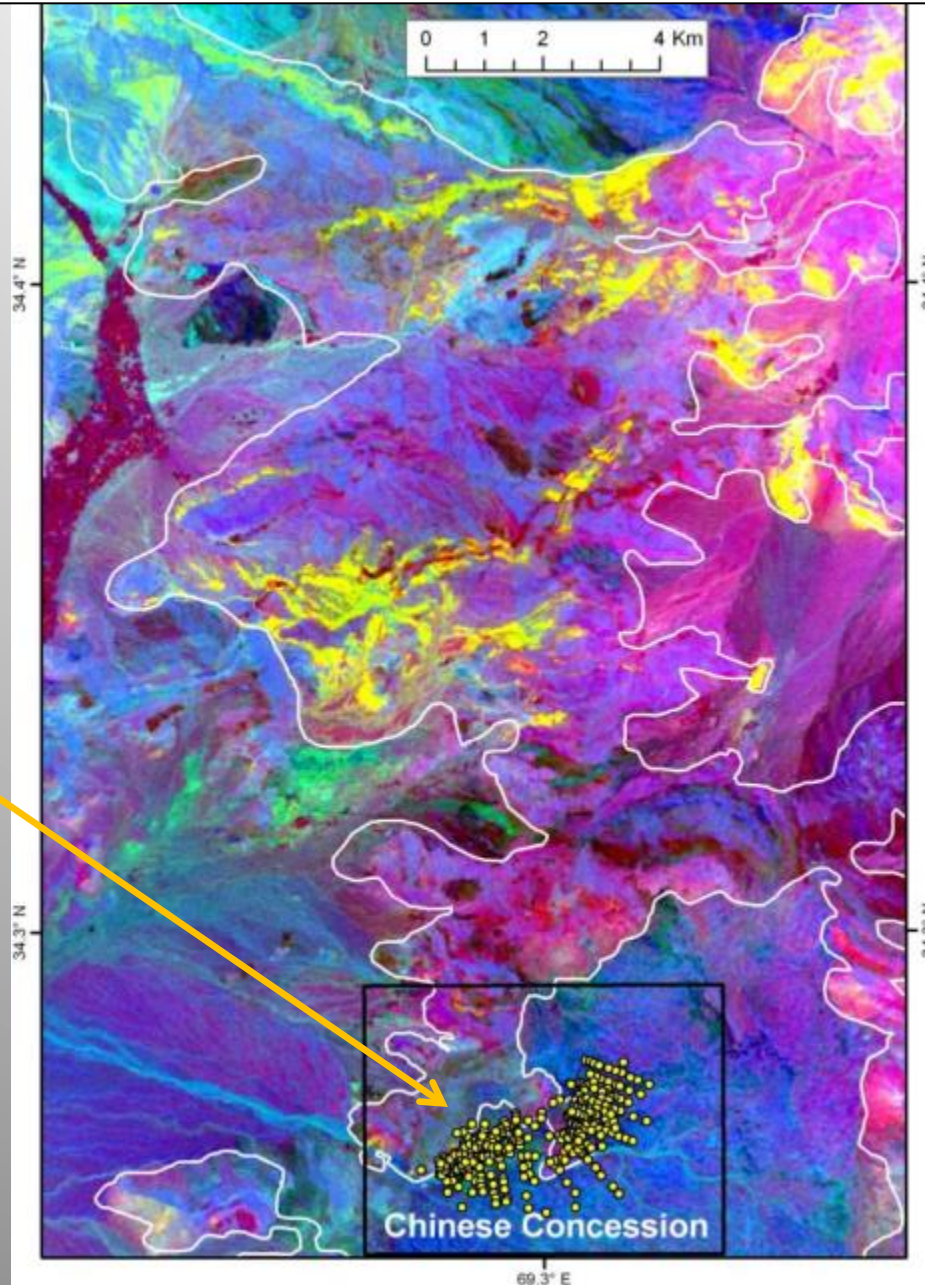
HyMap Pixel Most Closely Matches “Calcite”



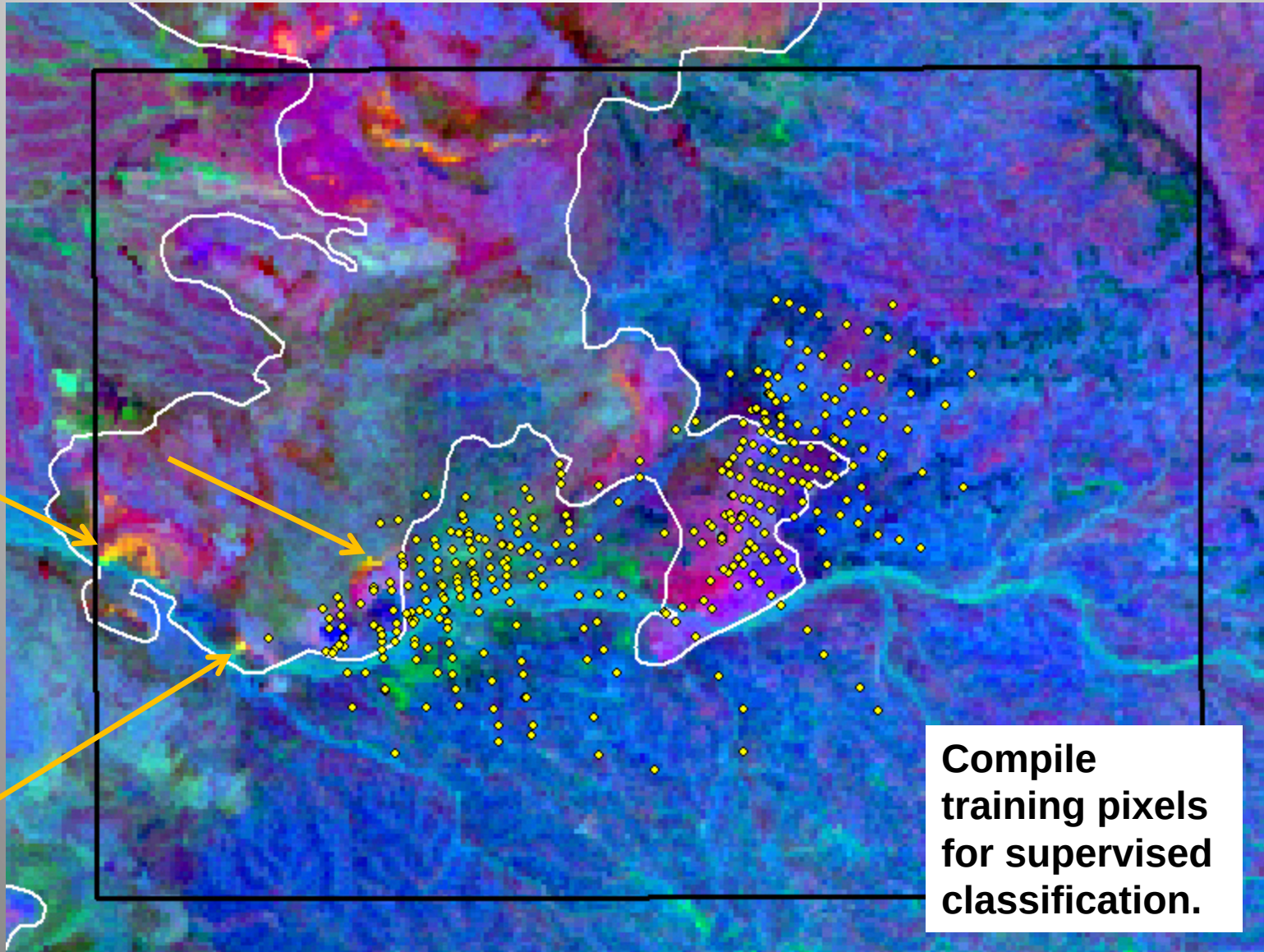
Build Training Site Around Known Copper Deposit

Golden pixels
seen around
Chinese Mine

Compile
training pixels
for supervised
classification.

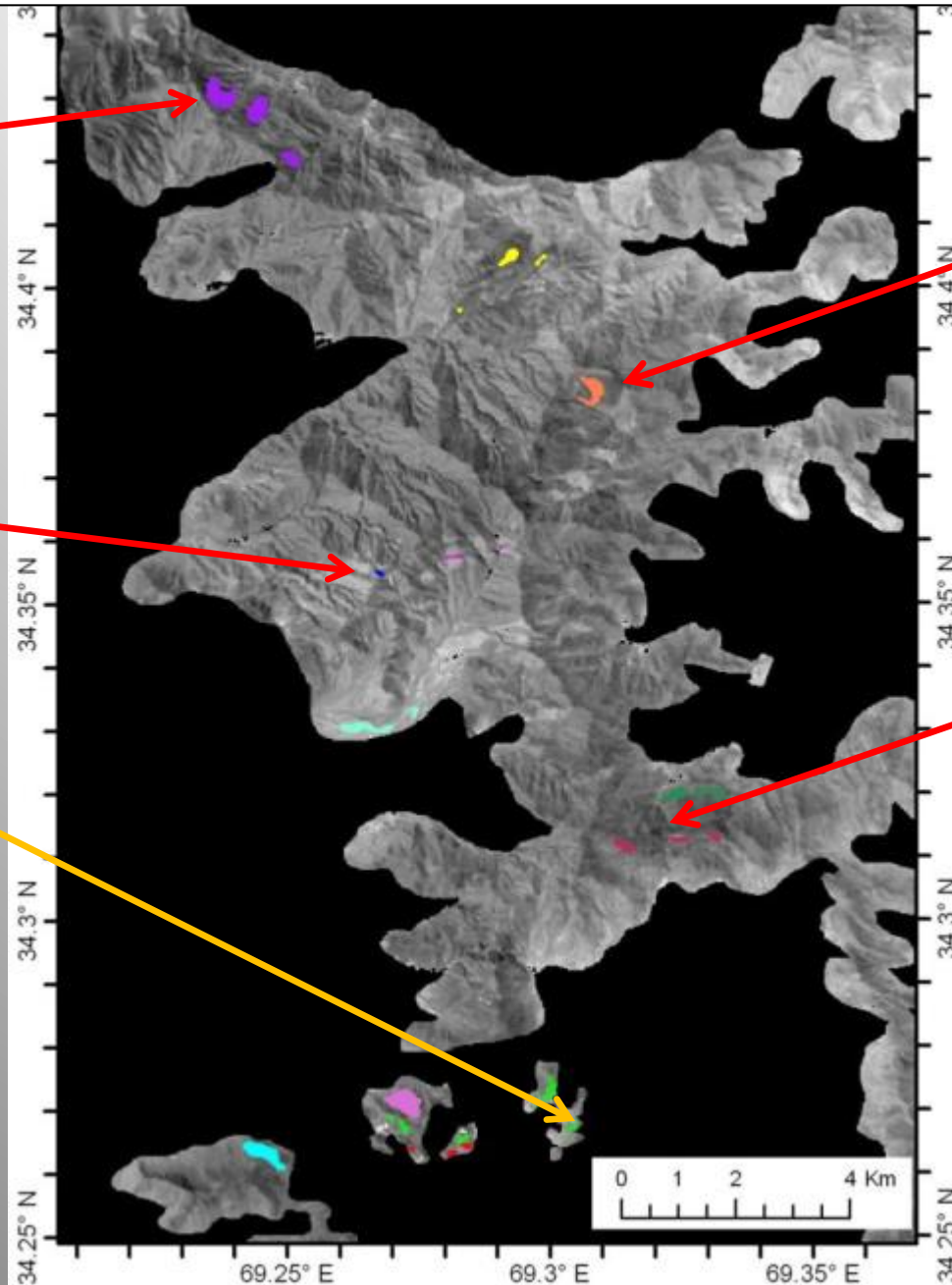


Pixels with Same Color as in the North

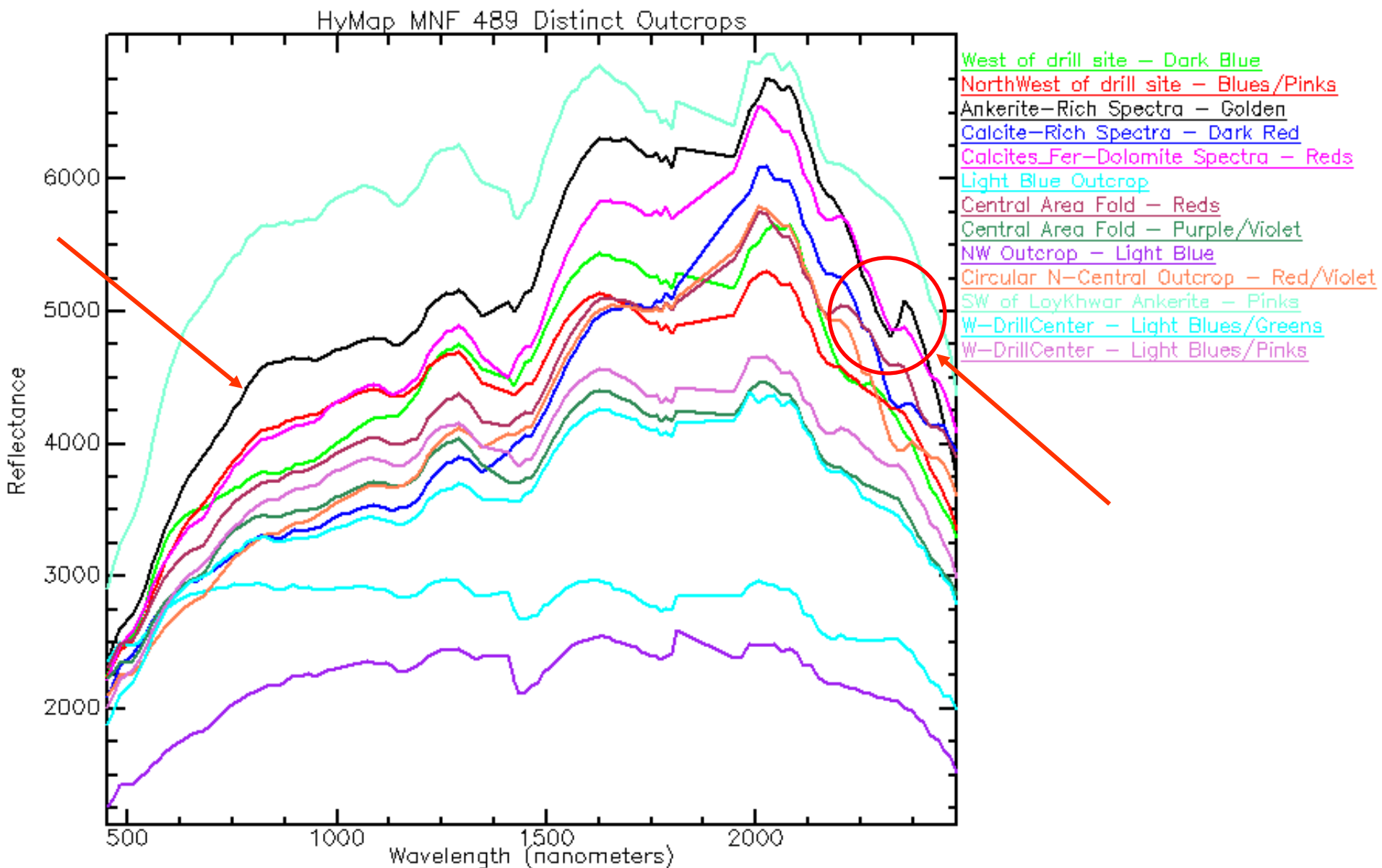


Collect Training Pixels from 13 Different Outcrops

Compile more training sites for Supervised Classification



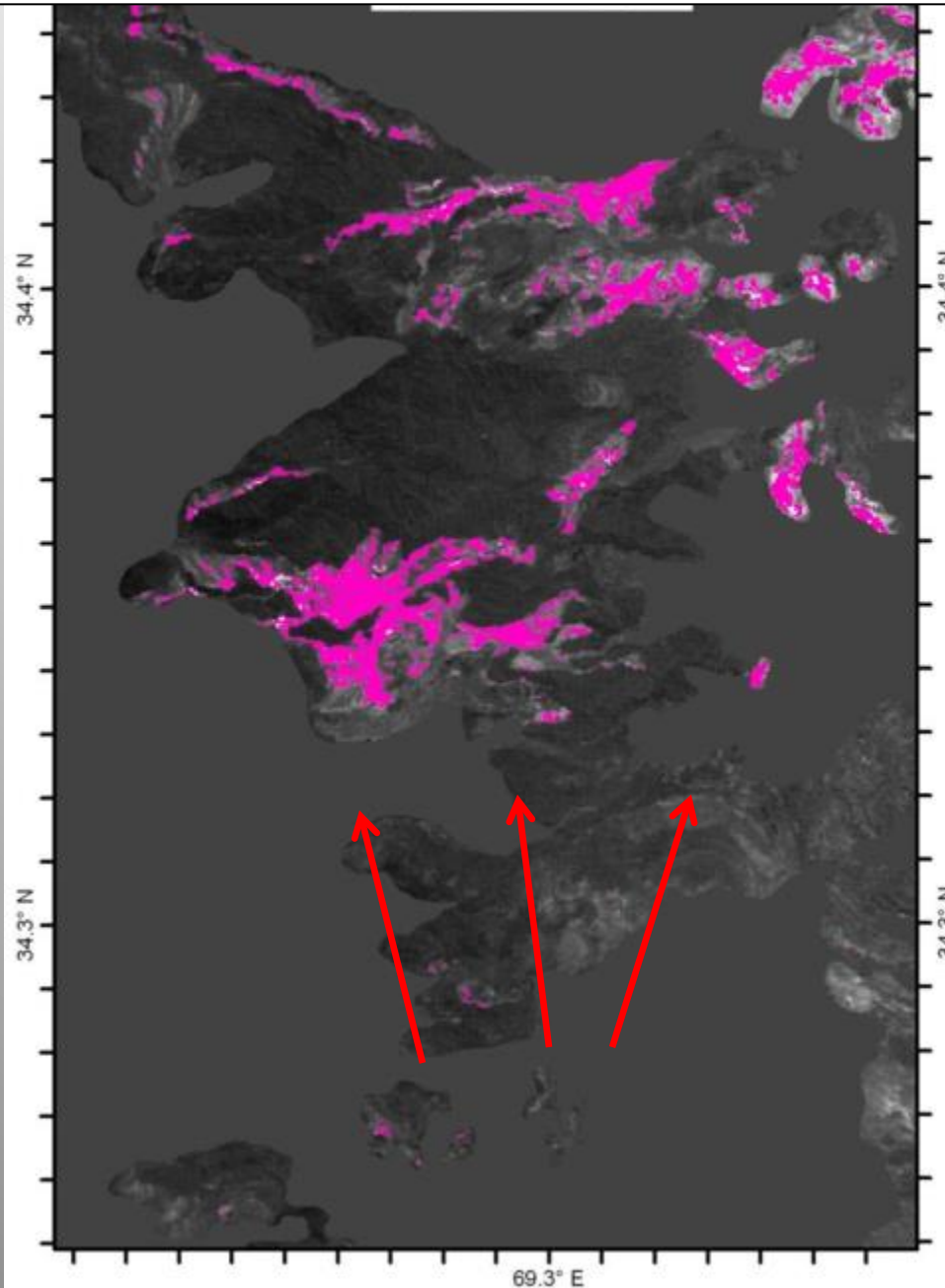
Spectra of Supervised Classification Training Sites



“Ankerite” Outcrops Extrapolated from China Mine

Supervised
classification
done with
MNFs 2-12

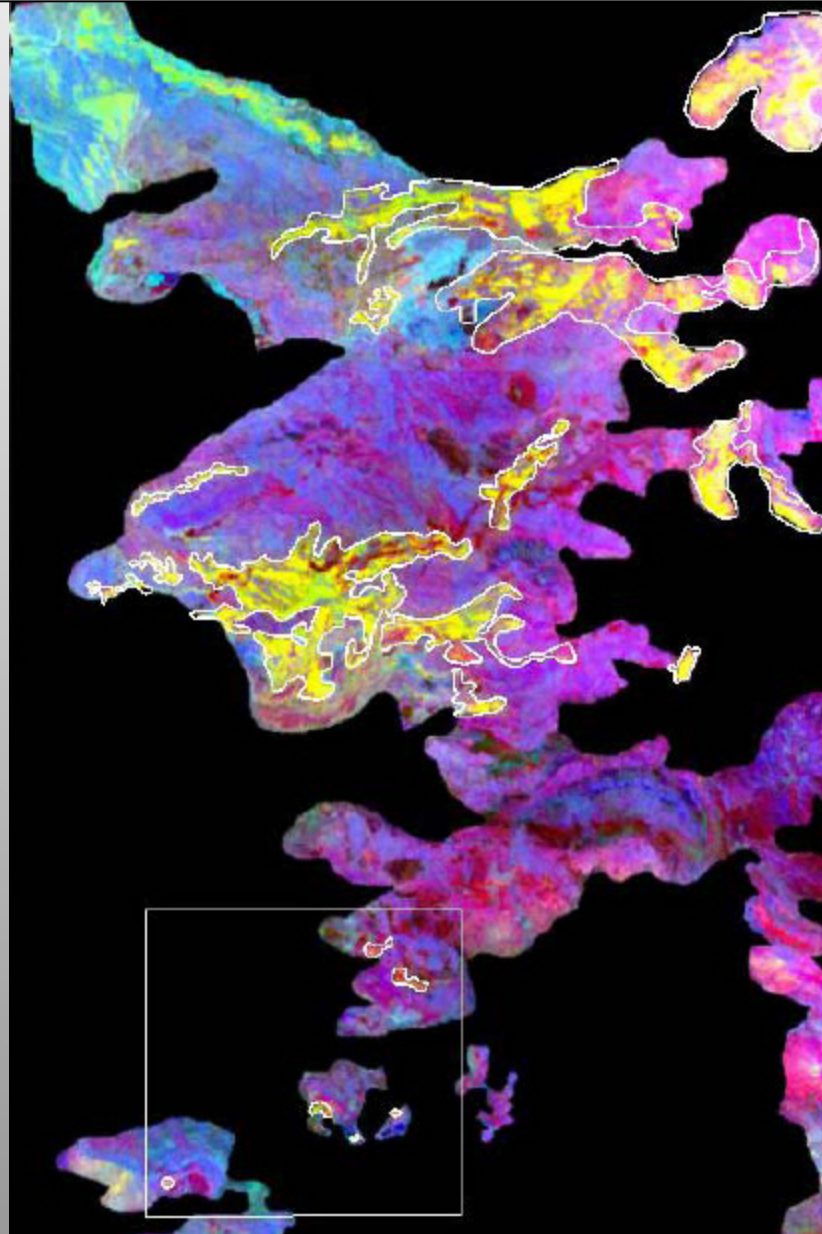
Only one
class
displayed



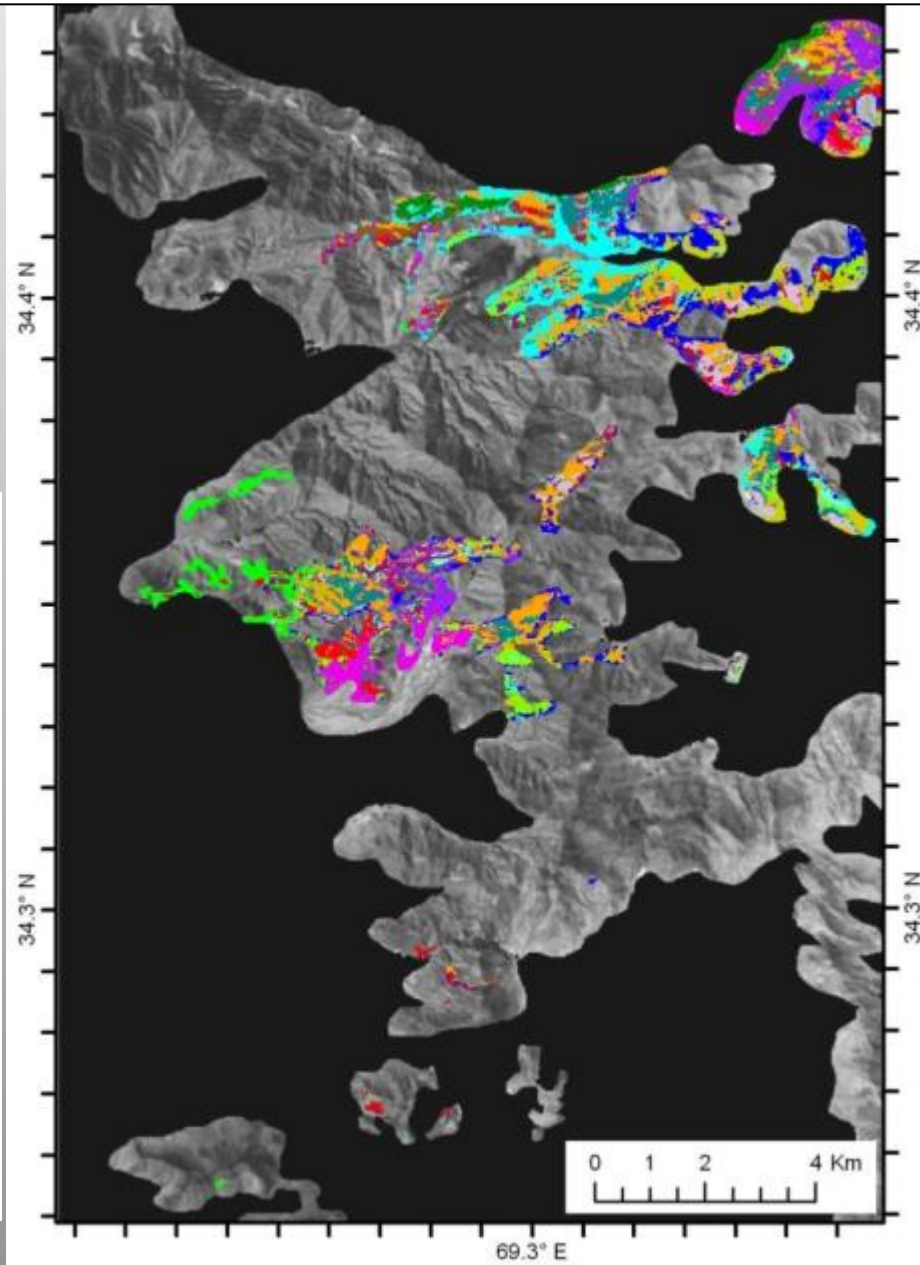
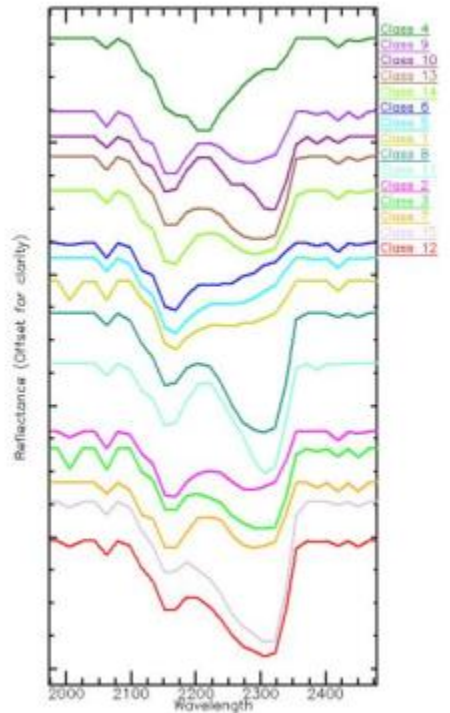
Just process within “dolomitic” outcrops

Unsupervised
classification
done on
MNFs 2-12
within these
dolomitic
outcrops

Reduce the
size of the
target areas



15 Spectral Classes – only 4 near Chinese Cu Mine

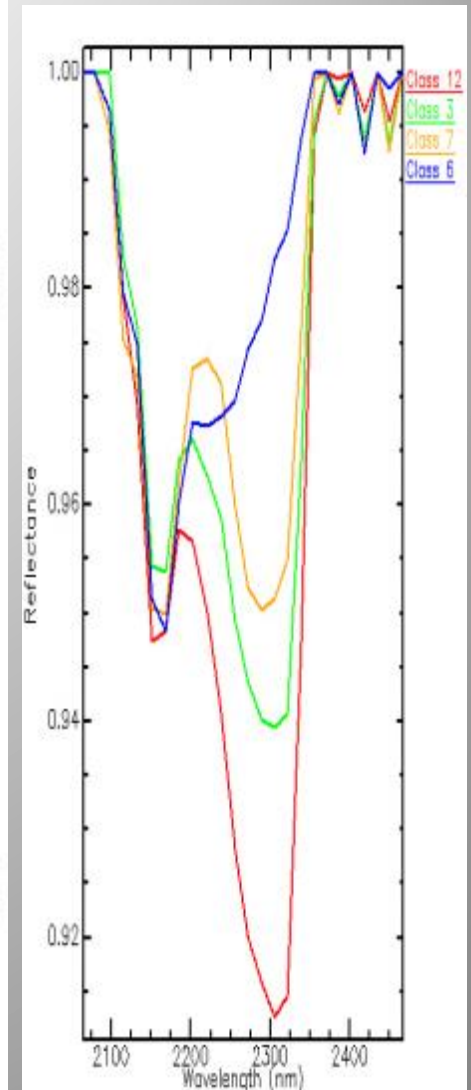
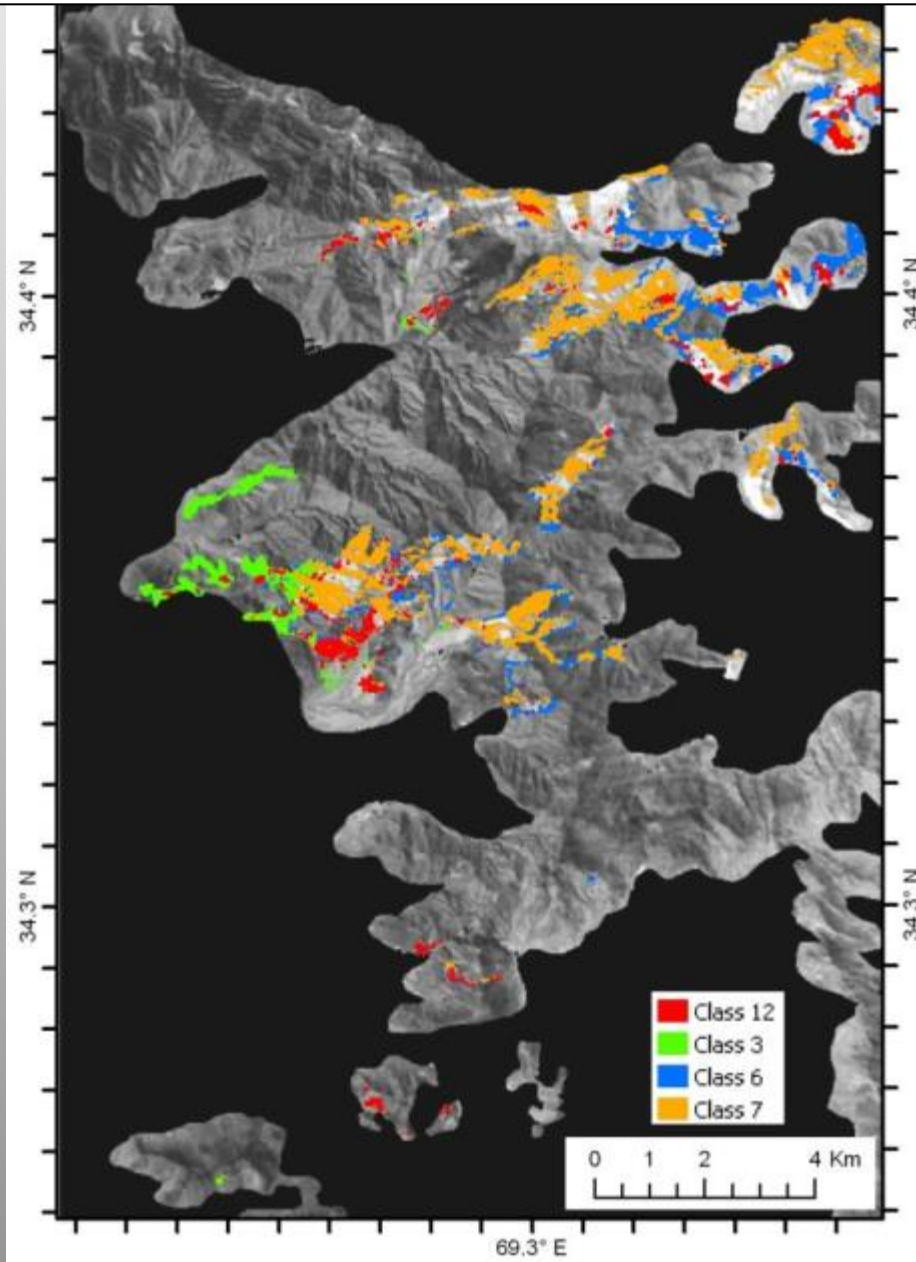


Four Spectral Classes near Chinese Cu Mine

Four Classes occur within or near Southern Chinese Mine

Envi's Spectral Analyst used to compare signature of each class with Library

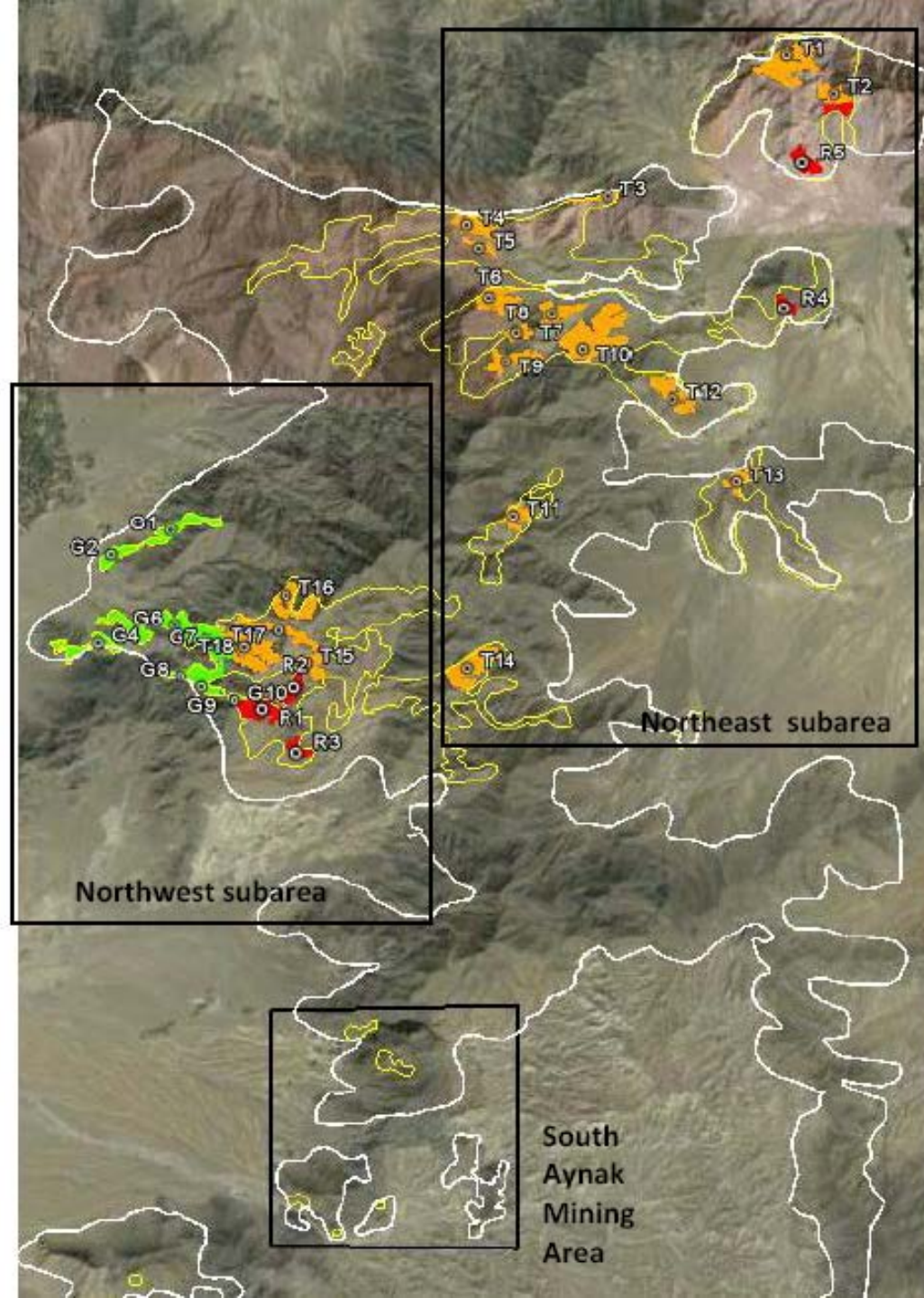
Class 6 often at edge of 3, 7, 12 - mixed pixels? clay-rich, wx shist? - eliminated



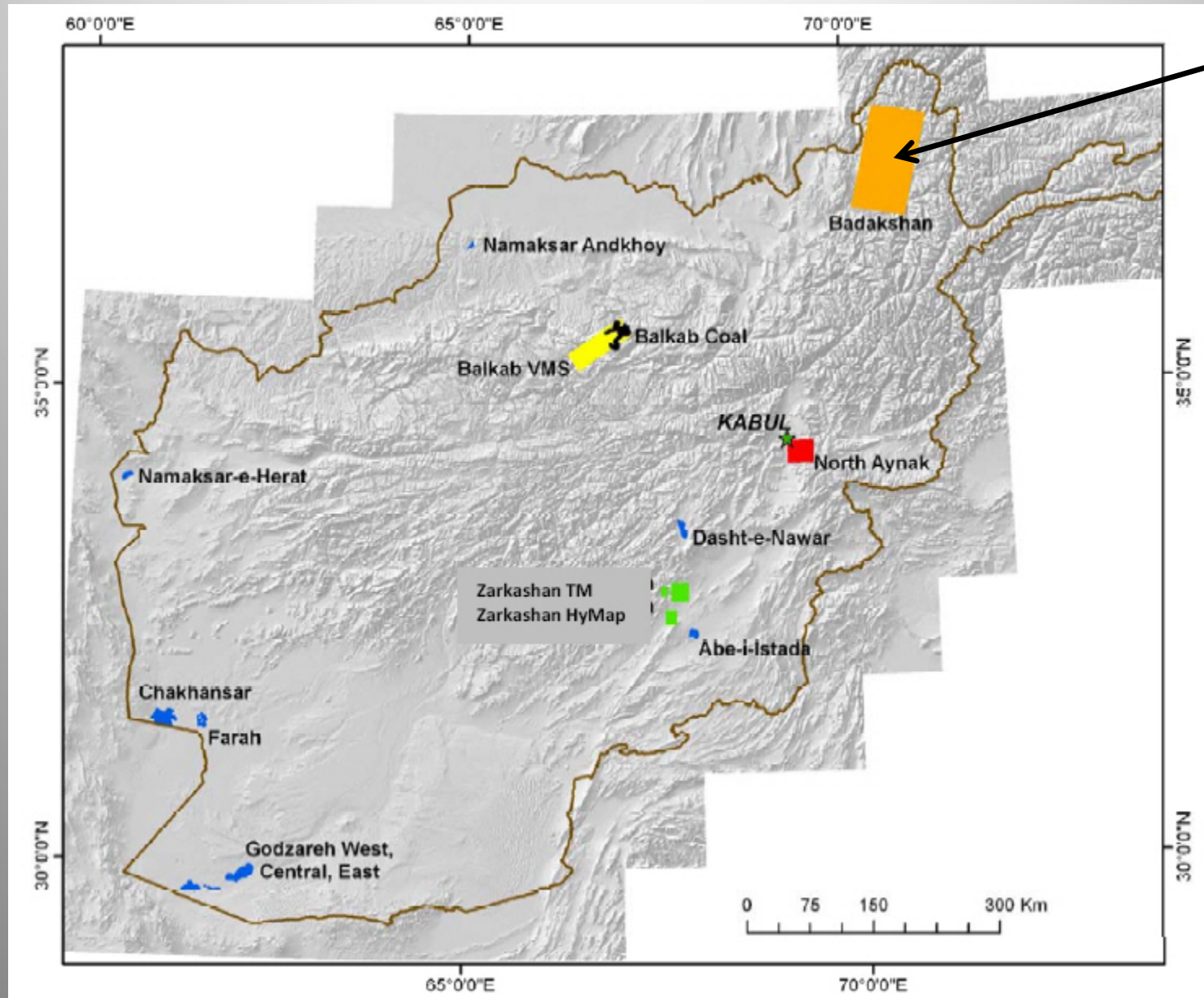
Class 3 : ankerite-rich
Class 12: ankerite-rich
Class 7: ferroan dolomite & ankerite-rich

Copper Target Map

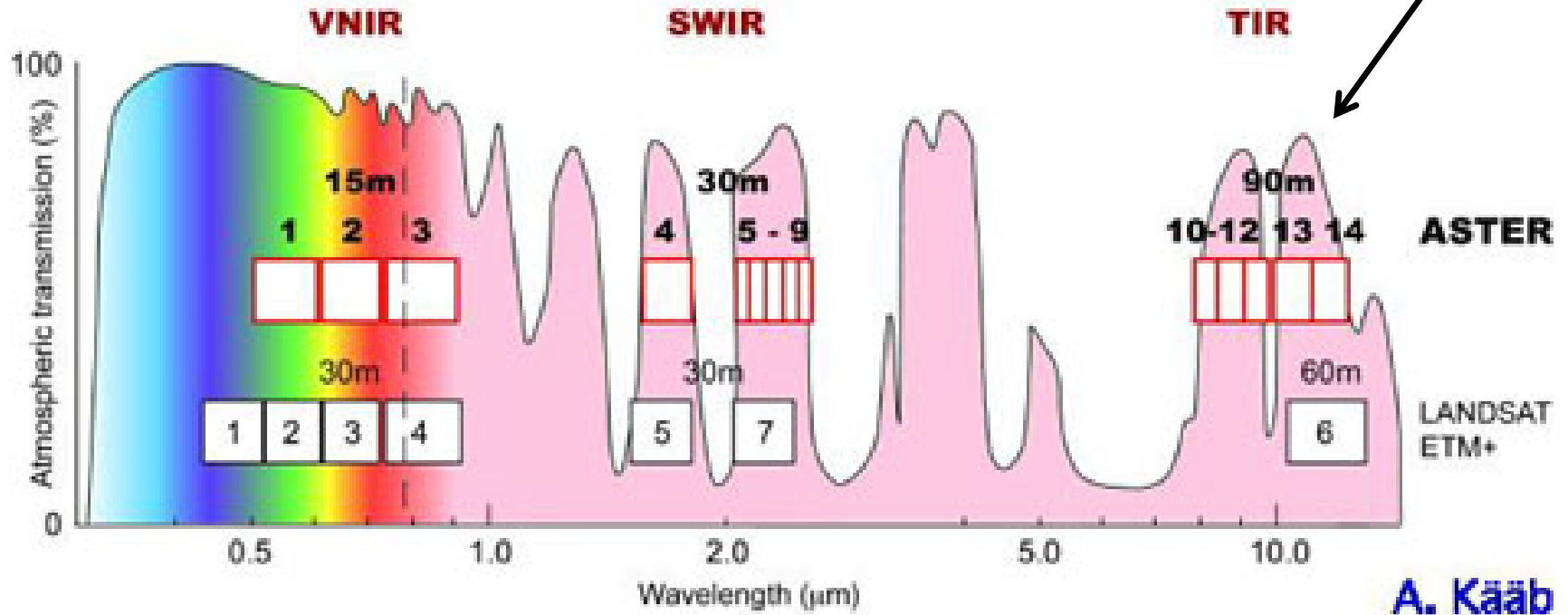
Narrowed
Target Areas
Within
Dolomitic
Loy Khwar



3) Gold in Quartz Veins



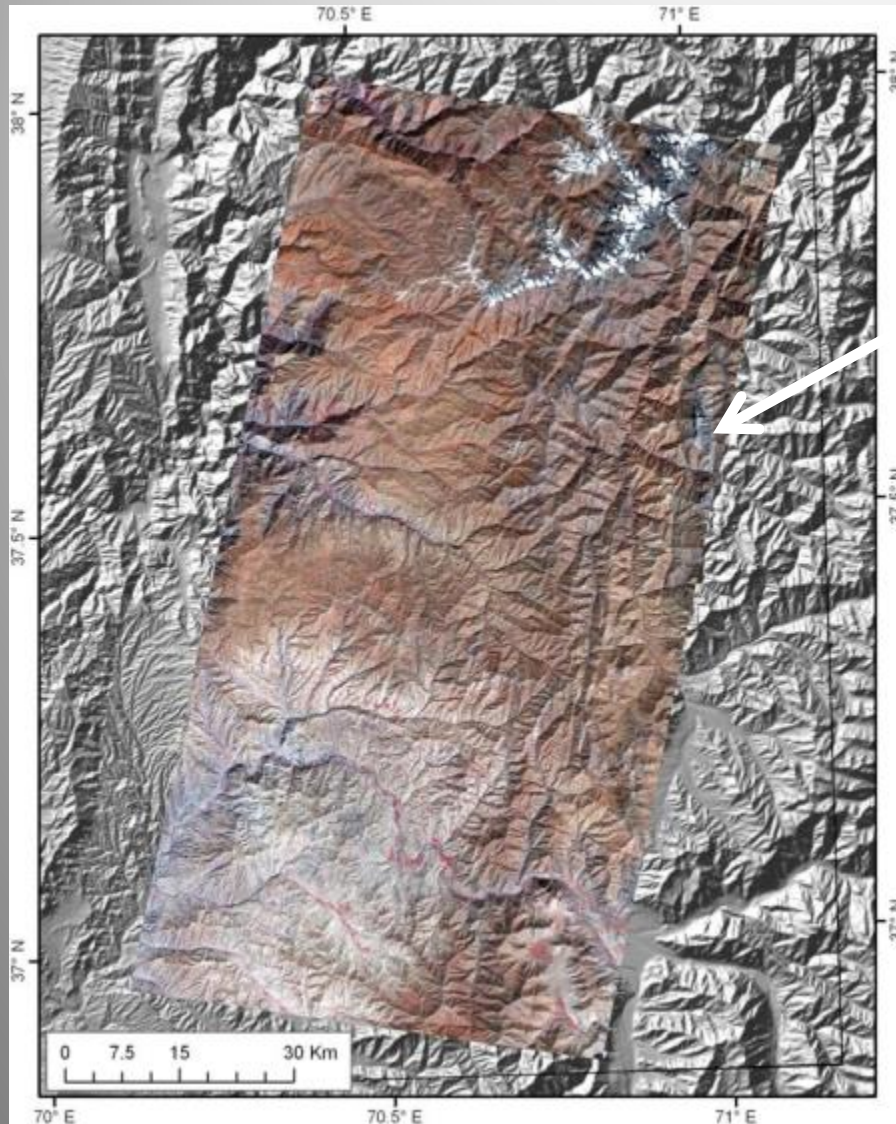
ASTER Thermal IR (TIR)



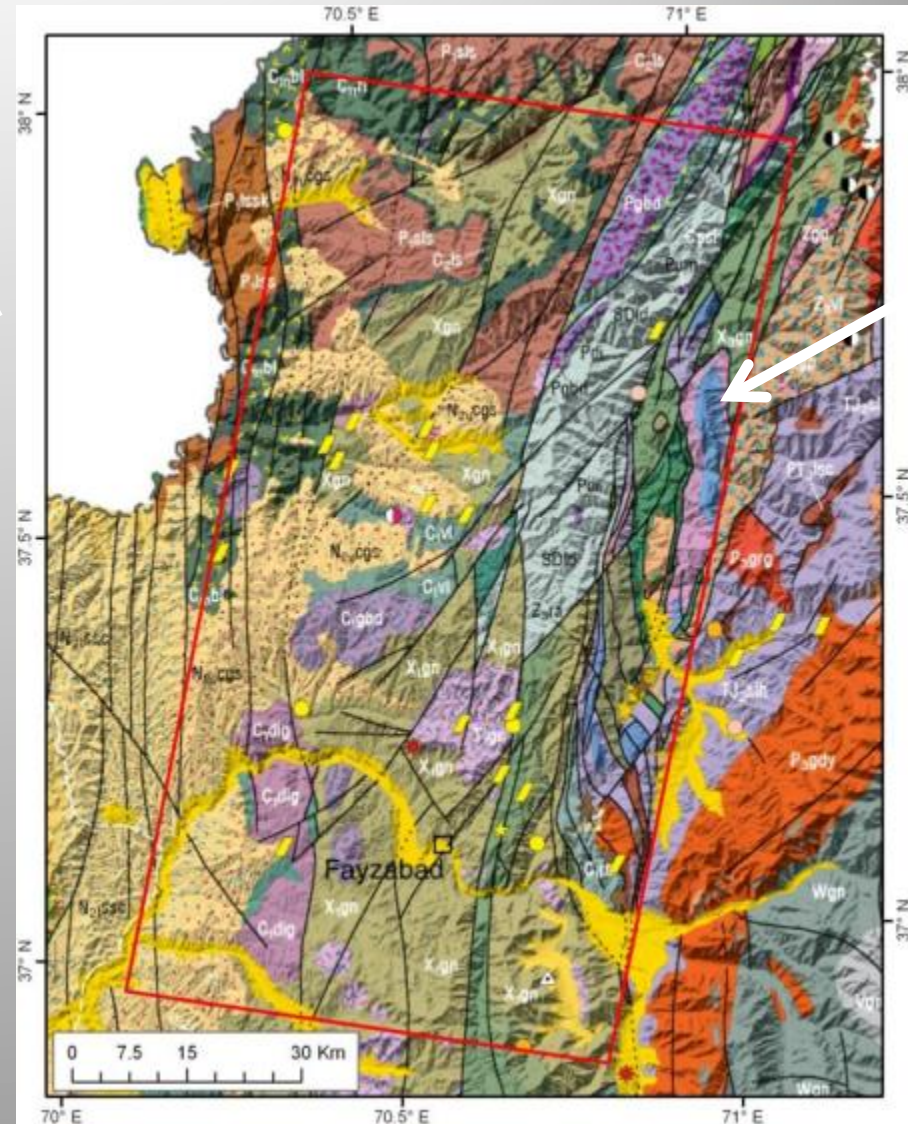
Reflected Energy from
Earth's Surface

Emitted Energy from
Earth's Surface

ASTER Thermal IR



ASTER CIR 15 m

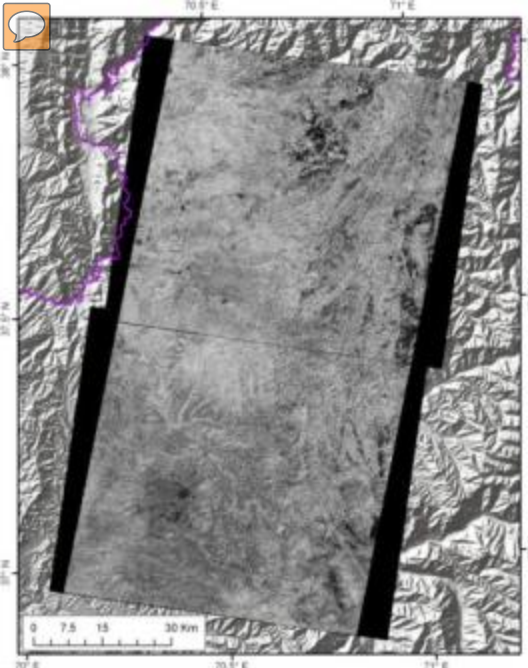


Geologic Map

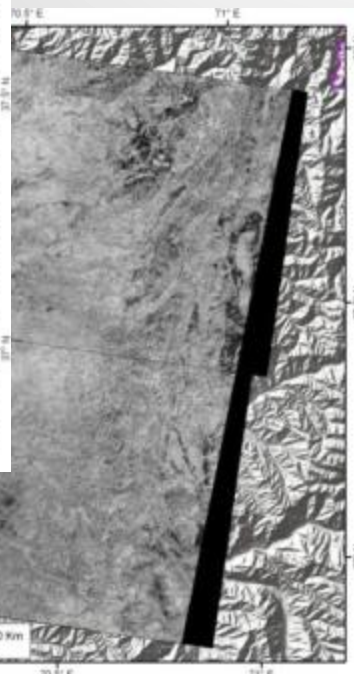


ASTER Thermal IR

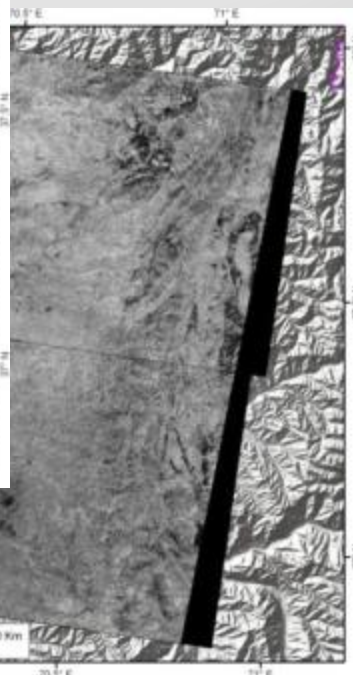
Bernard Hubbard
USGS
Ward Kilby
CalData



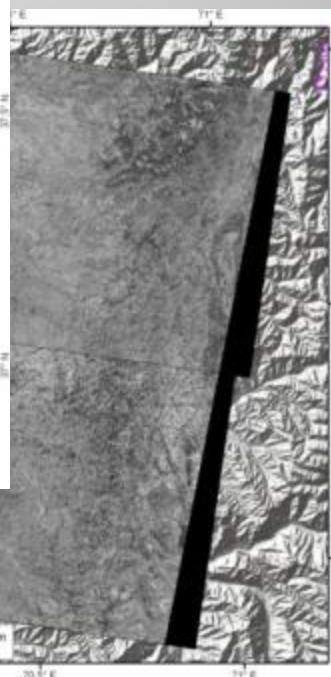
Band10



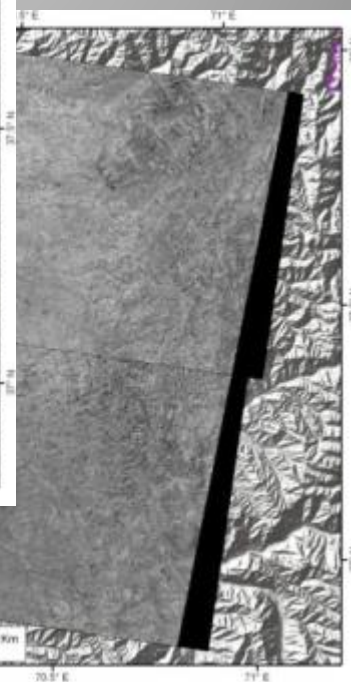
Band11



Band12



Band13

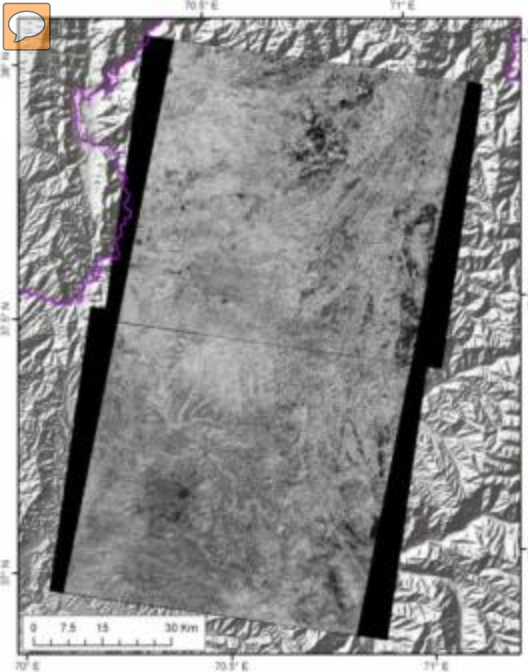


Band14

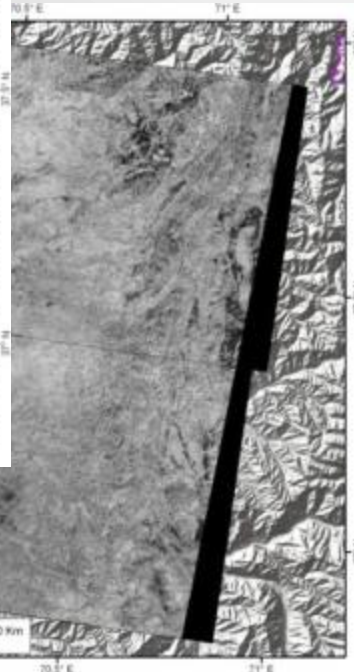
~10AM
radiant Energy
being Emitted from
the Earth - calibrate

ASTER Thermal IR

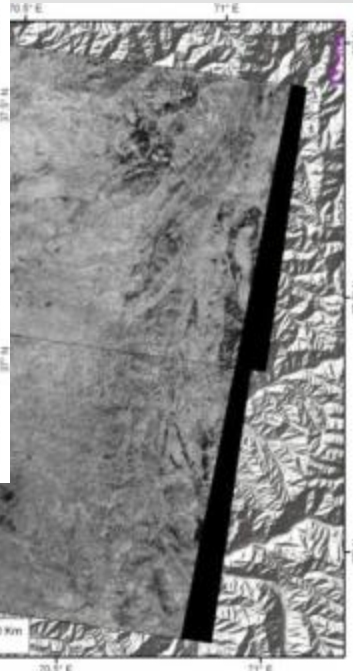
Mars & Rowan,
2011, GeoSphere,
v.7, p 1-14



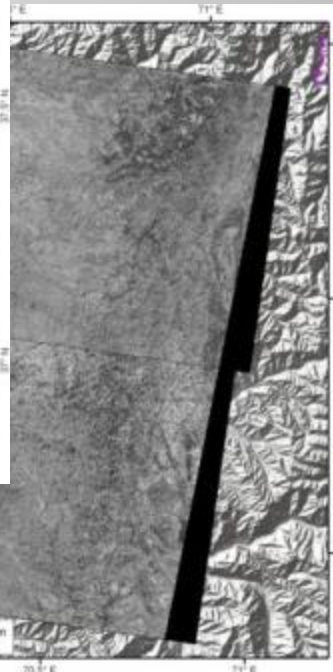
Band10



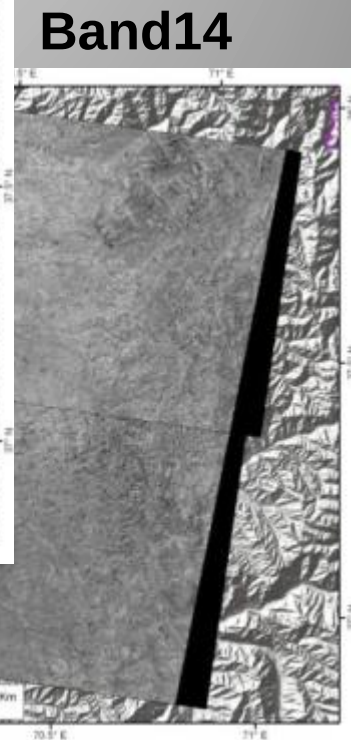
Band11



Band12



Band13



Band14

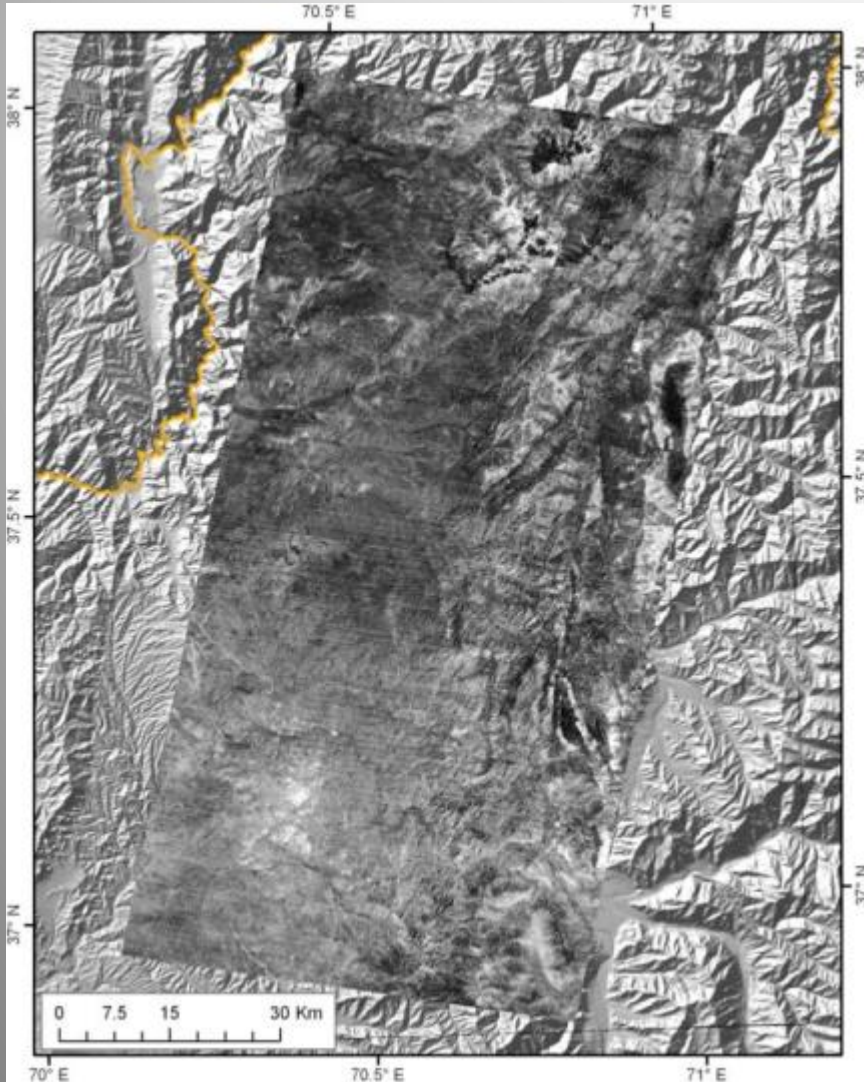
TIR Band Ratios

Quartz 14/12

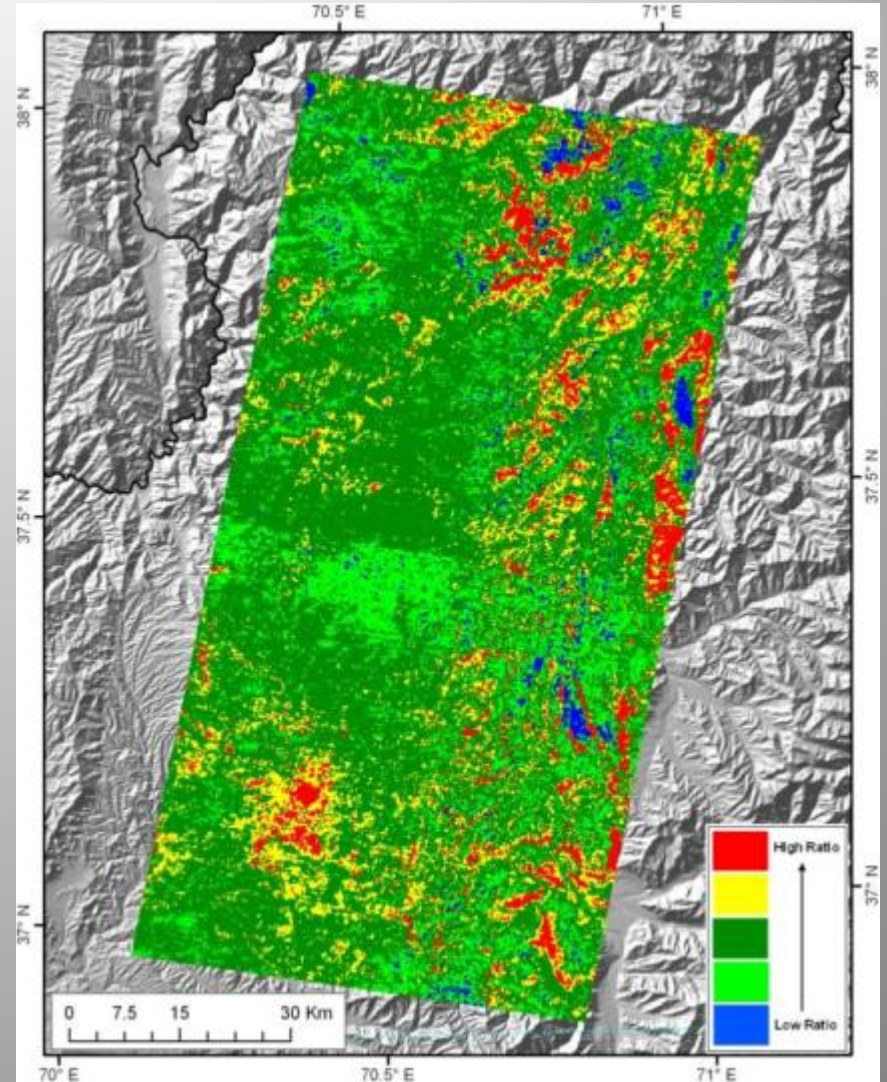
Calcite 13/14

Mafic 12+14/13

ASTER Thermal IR

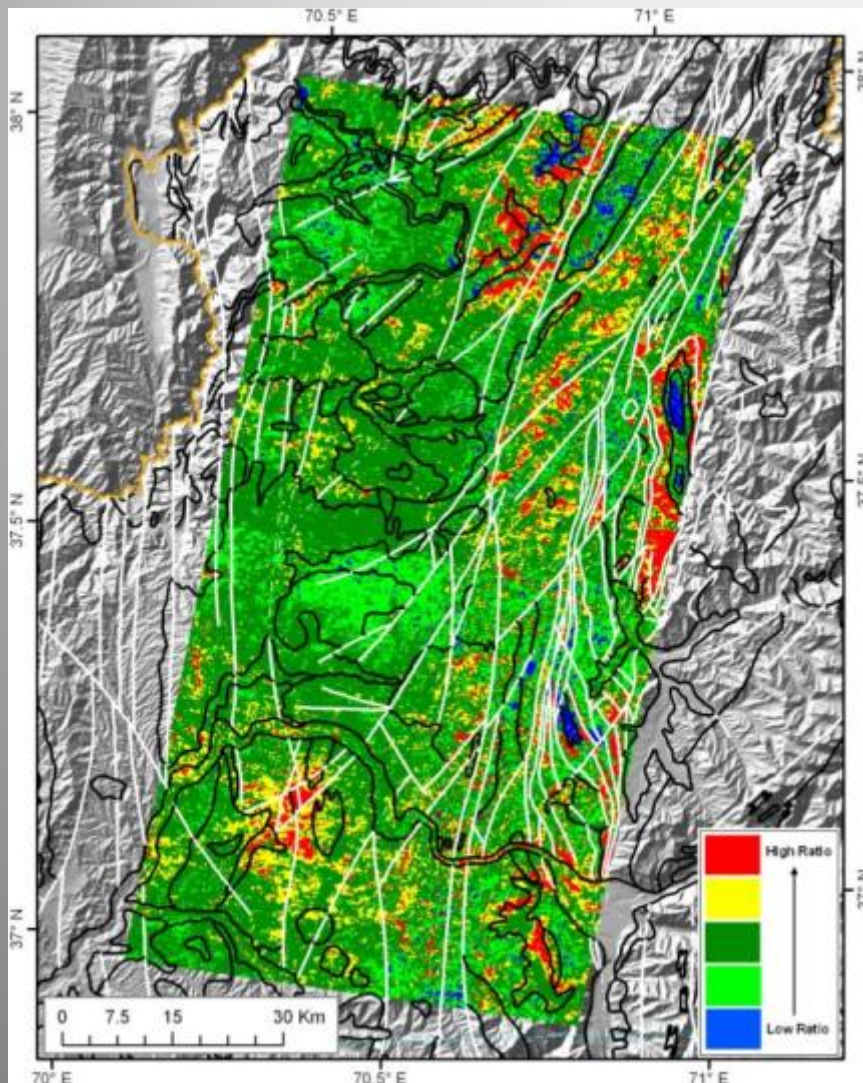


Quartz Band Ratio

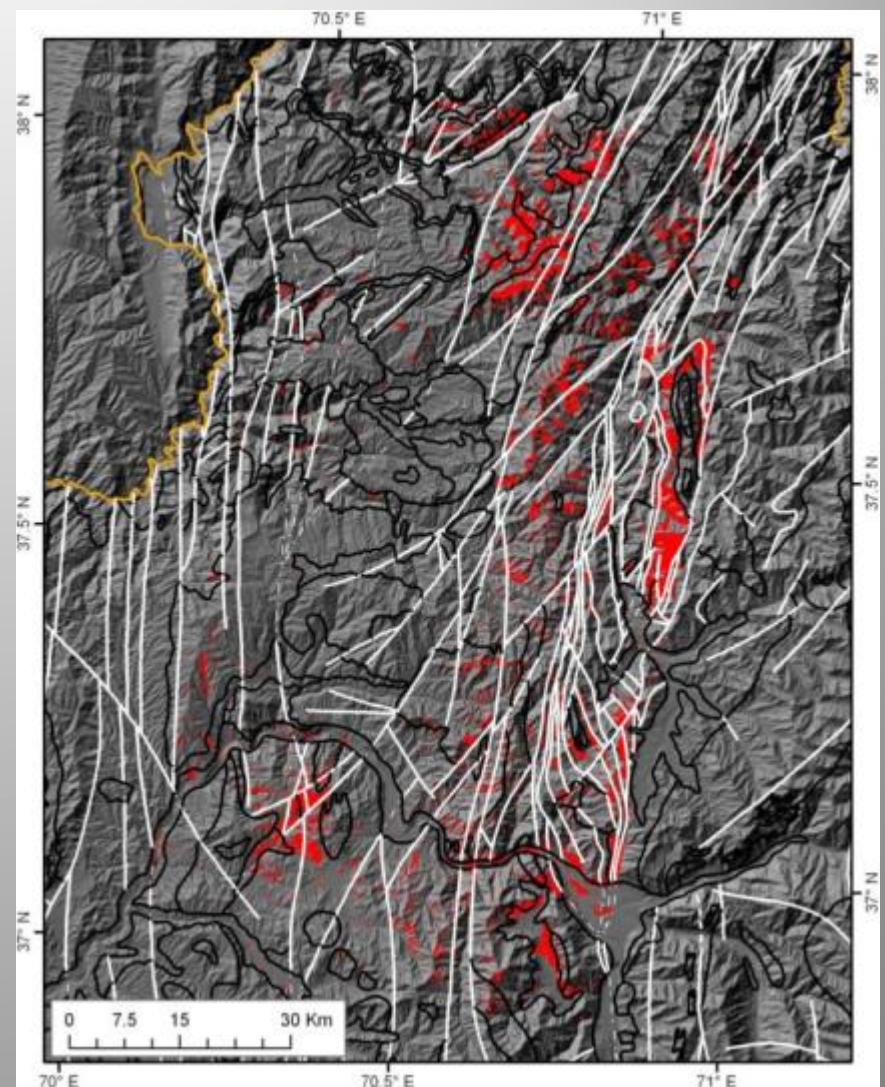


Color Density Slide of Quartz Ratio

ASTER Thermal IR

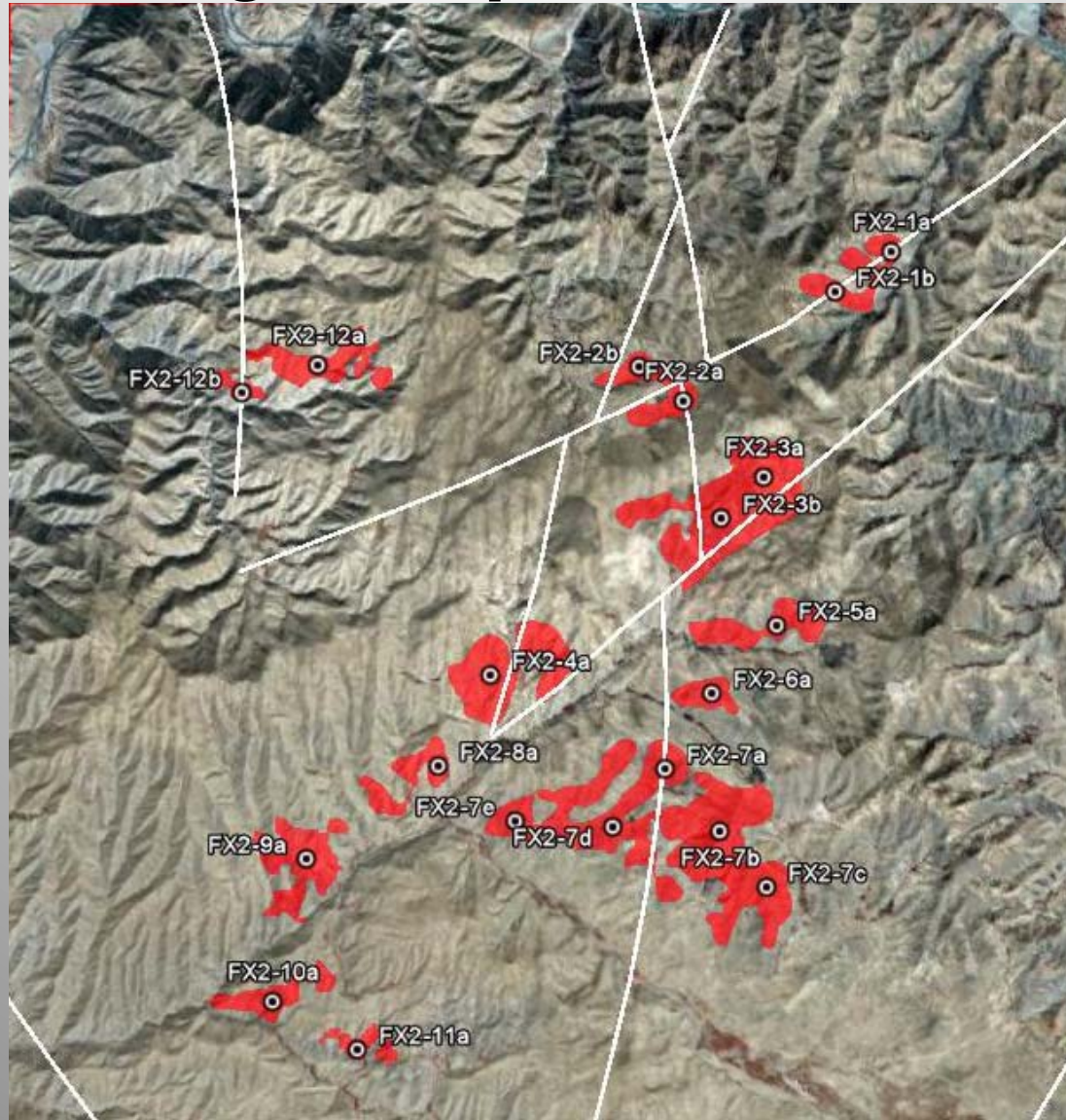


Quartz Rich Zones



Quartz Rich Zones along Faults

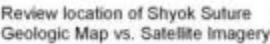
Gold Target Map from ASTER TIR

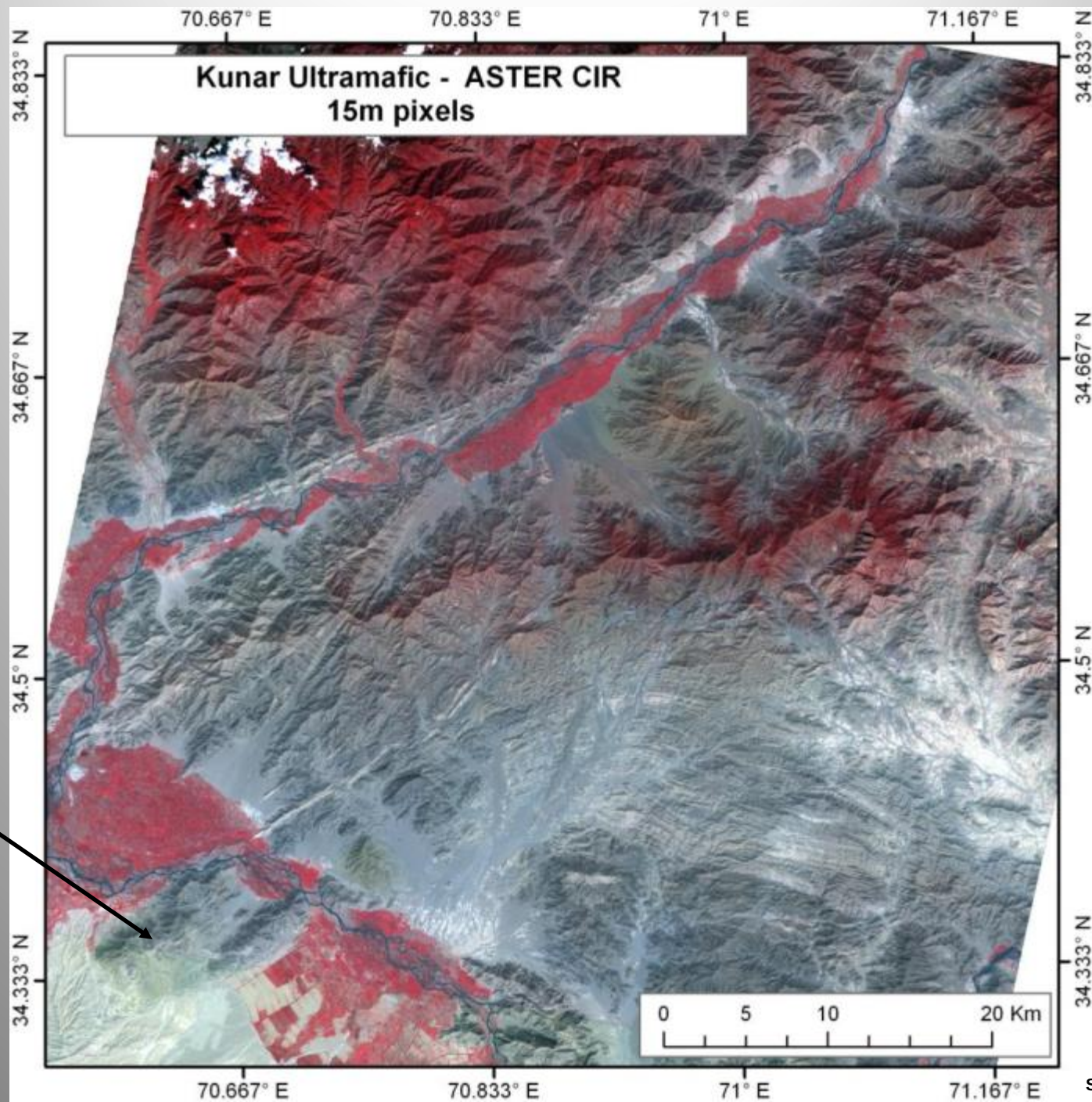


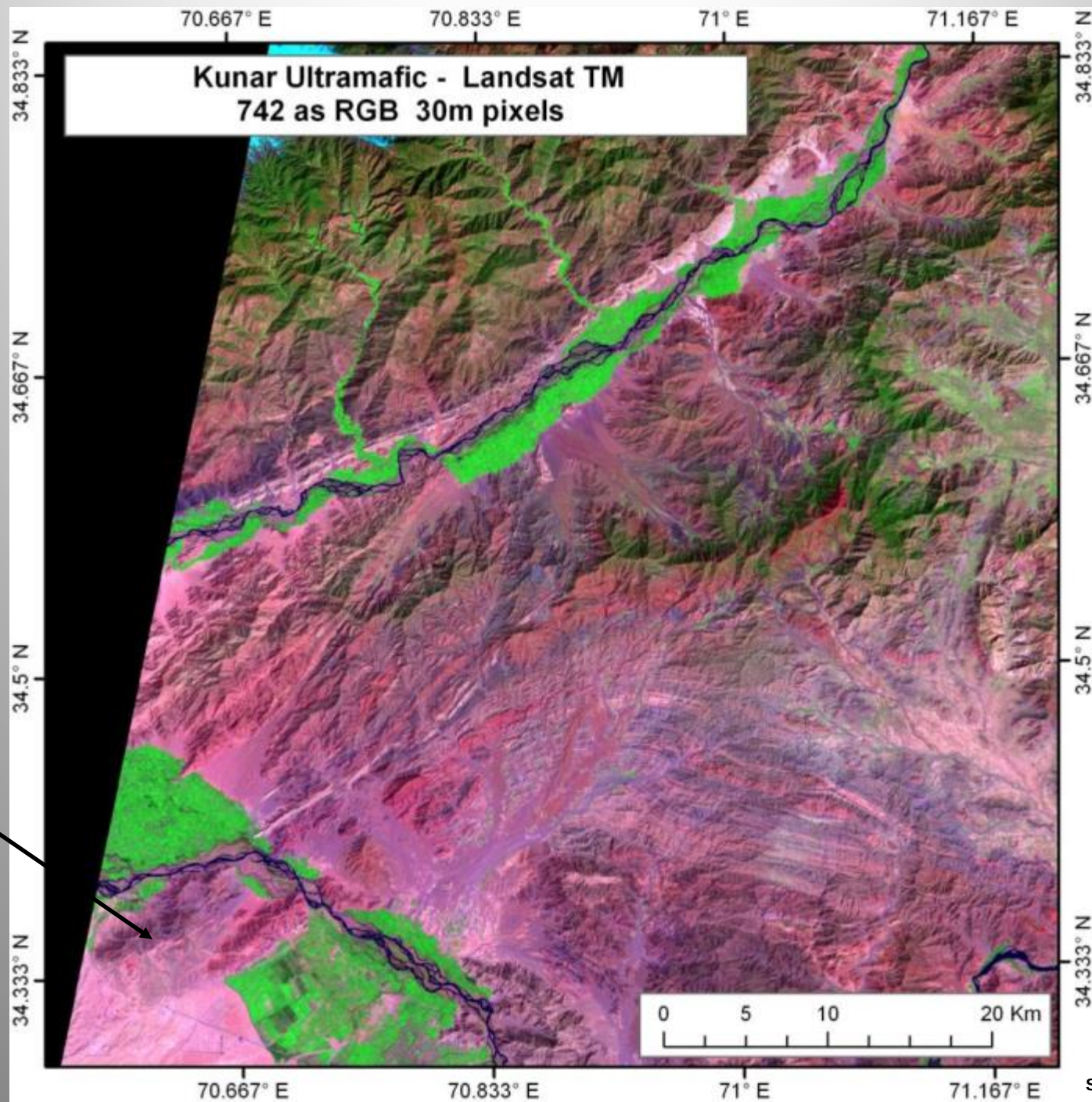
Quartz Rich Zones (Red) concentrated along Faults

4) Chromite in Ultramafics



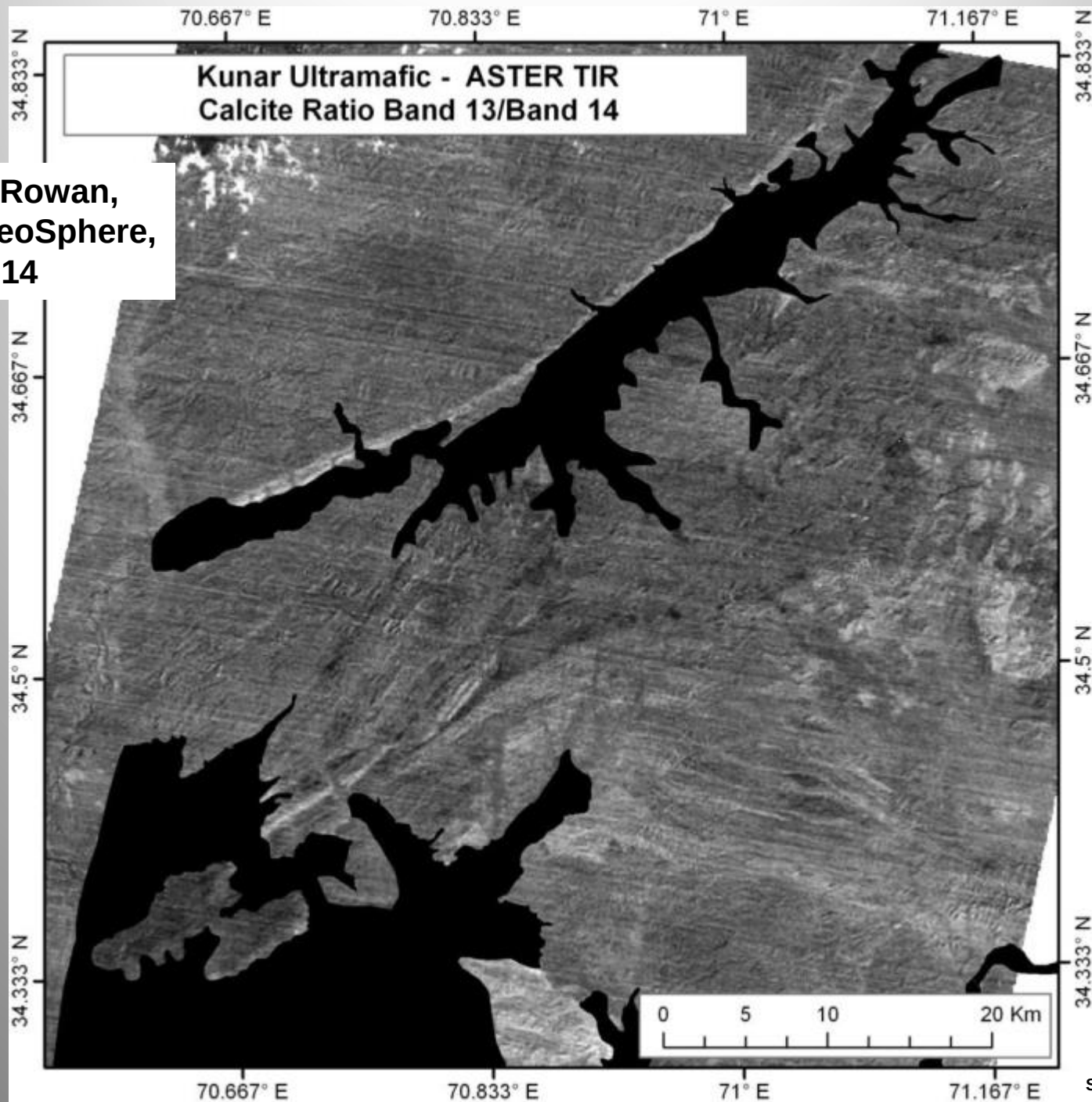






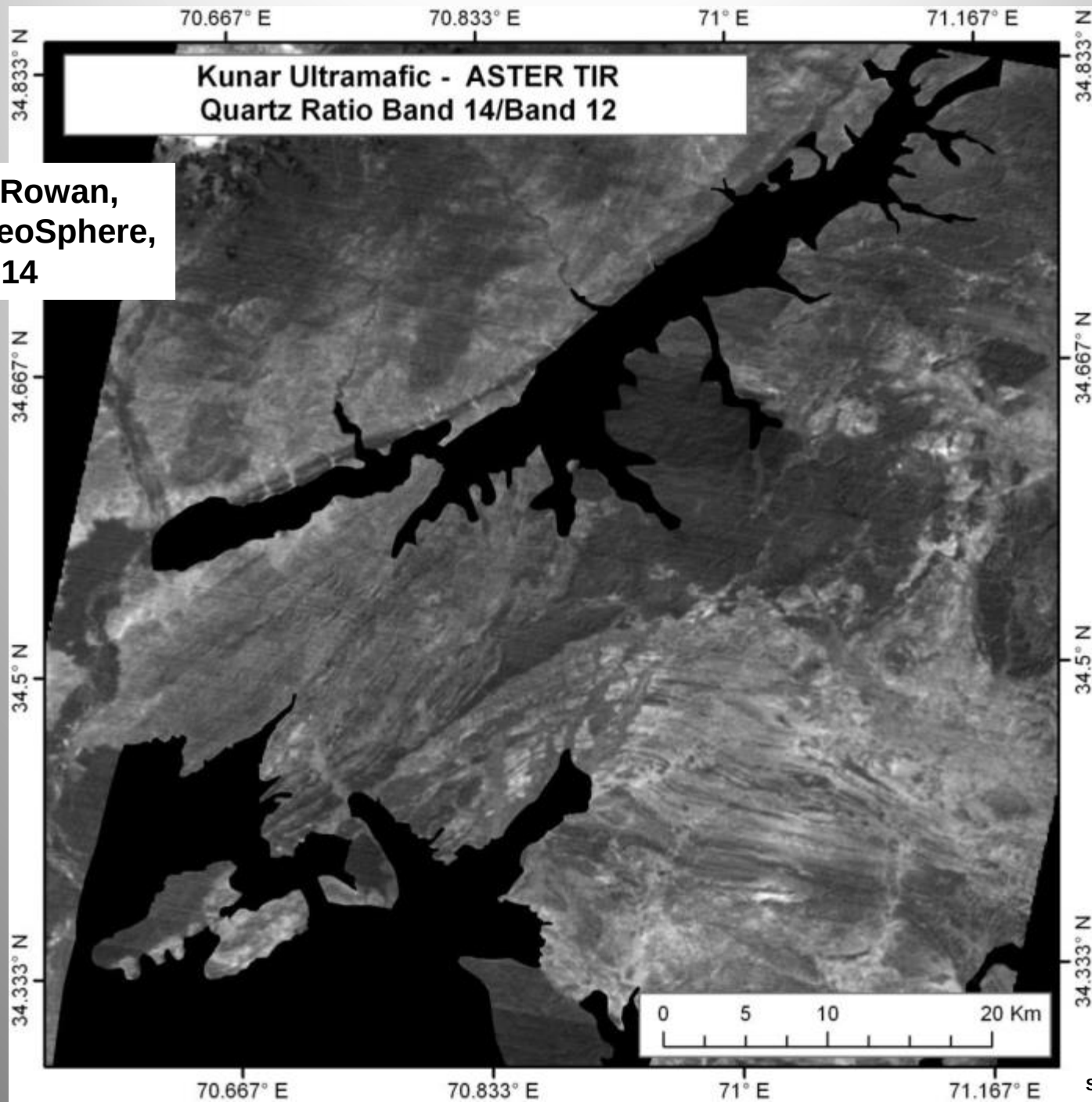


Mars & Rowan,
2011, GeoSphere,
v.7, p 1-14



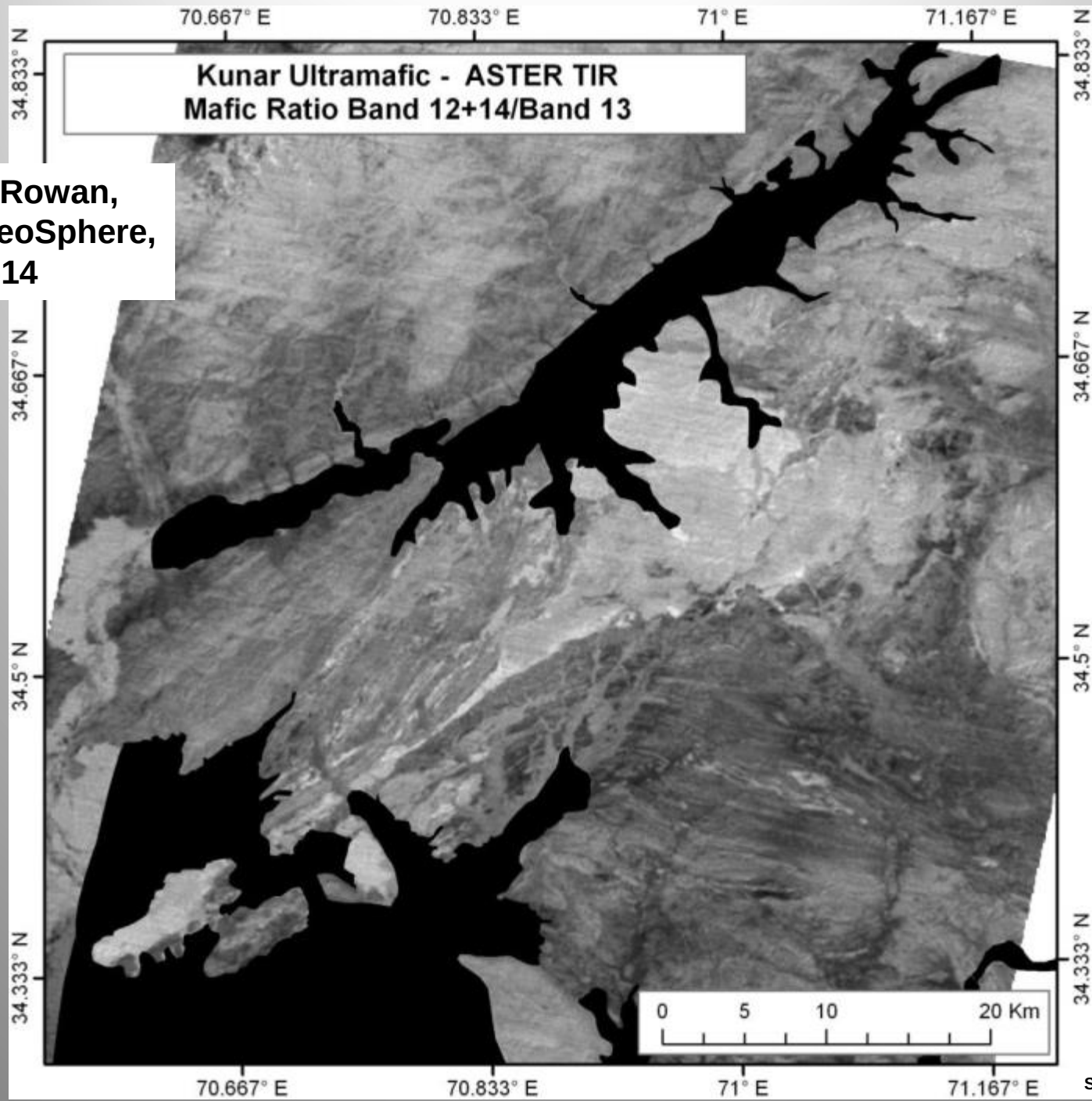


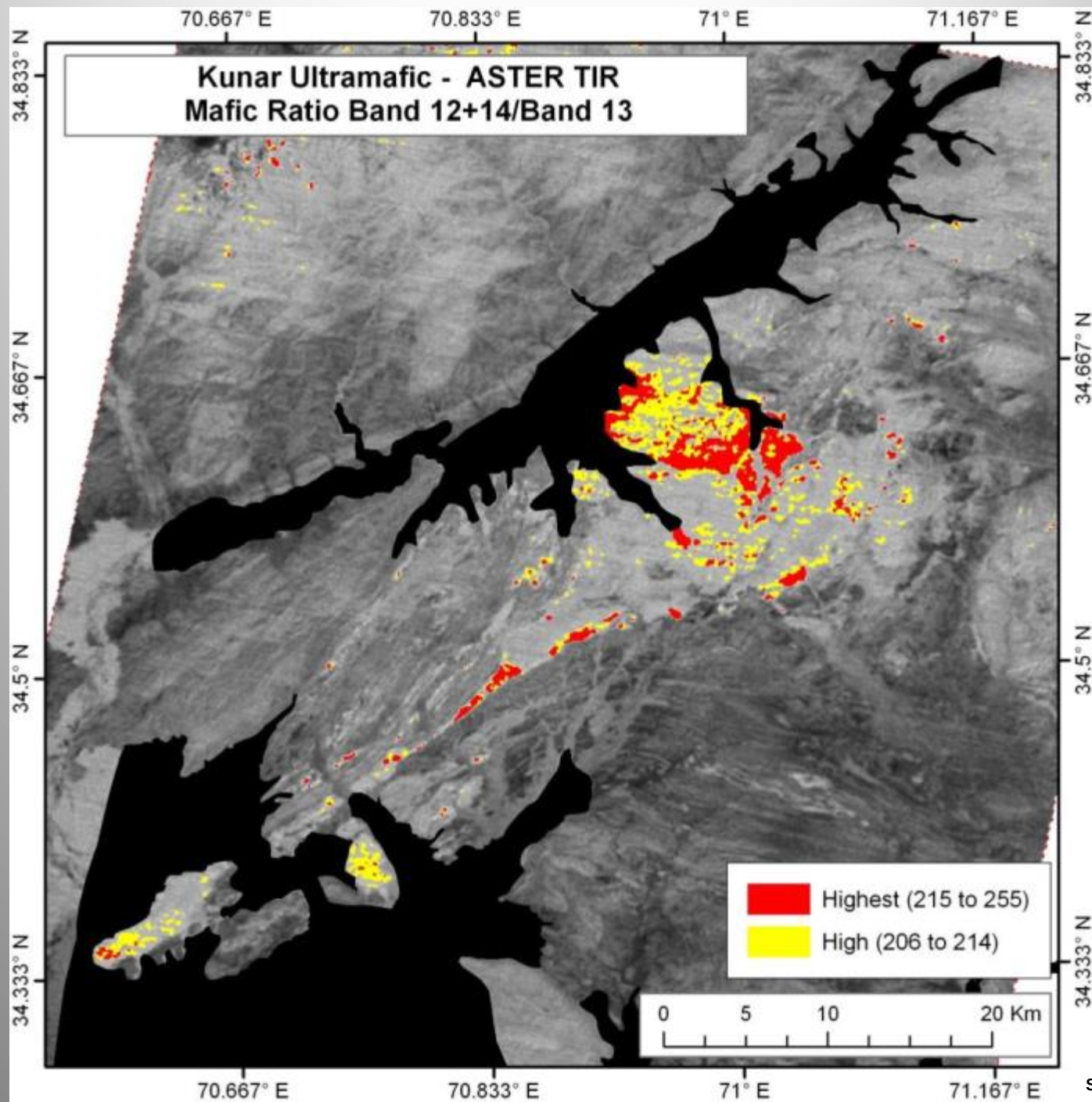
Mars & Rowan,
2011, GeoSphere,
v.7, p 1-14



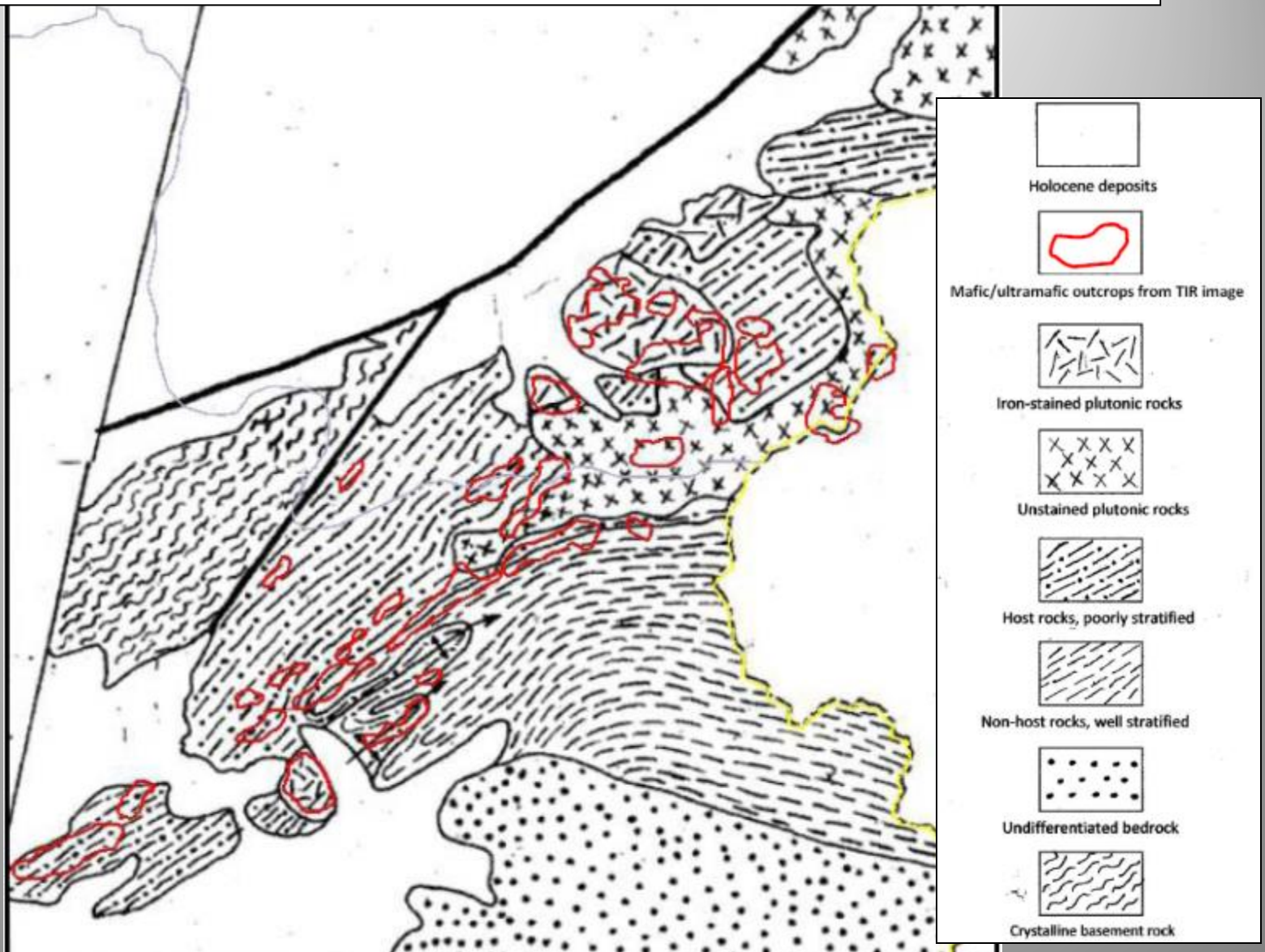


Mars & Rowan,
2011, GeoSphere,
v.7, p 1-14

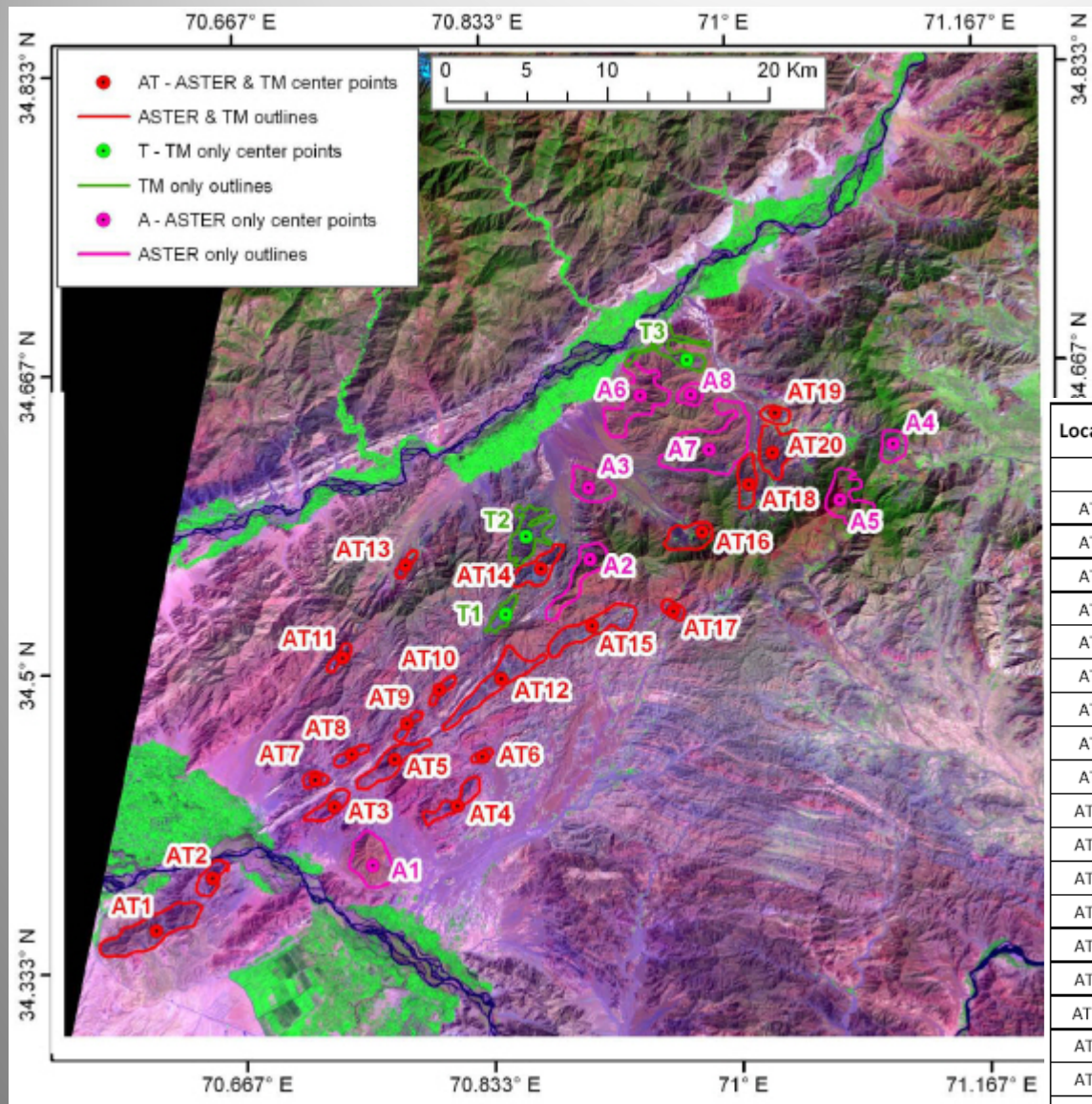




F. Sabins Geologic Interpretation Map

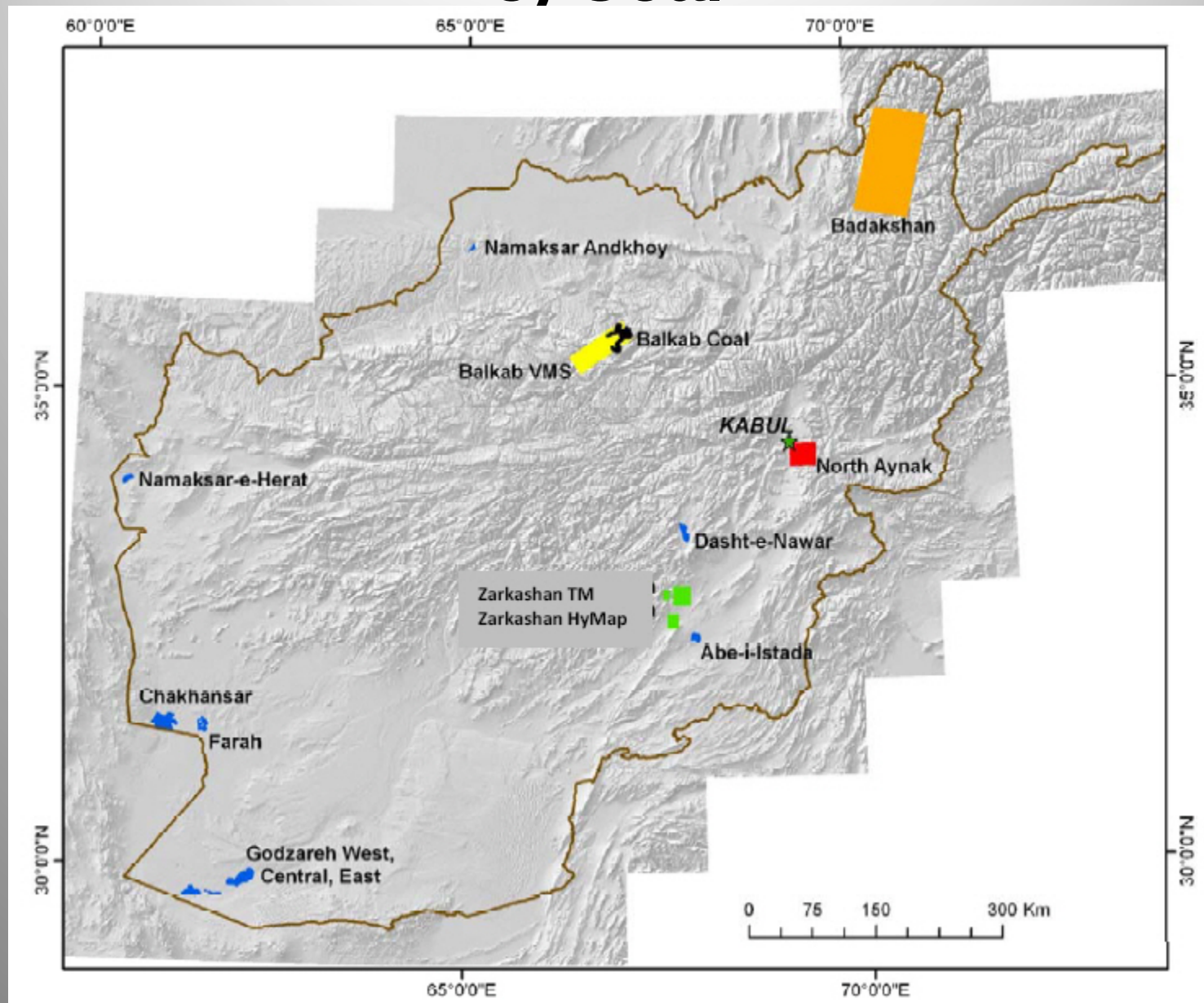


Chromite Targets with Coordinates



Locality	Longitude, North	Latitude, East	Host Rock
Category 1 Exploration Targets			
AT1	34.356984°	70.606936°	Host Rock – Poorly Stratified
AT2	34.385675°	70.645328°	Host Rock – Poorly Stratified
AT3	34.424339°	70.728129°	Host Rock – Poorly Stratified
AT4	34.423926°	70.811177°	Host Rock – Poorly Stratified
AT5	34.450428°	70.769185°	Host Rock – Poorly Stratified
AT6	34.450851°	70.828409°	Host Rock – Poorly Stratified
AT7	34.439600°	70.715557°	Host Rock – Poorly Stratified
AT8	34.453606°	70.740524°	Host Rock – Poorly Stratified
AT9	34.470359°	70.777975°	Host Rock – Poorly Stratified
AT10	34.488651°	70.800183°	Host Rock – Poorly Stratified
AT11	34.507440°	70.735297°	Host Rock – Poorly Stratified
AT12	34.494365°	70.841820°	Host Rock – Poorly Stratified
AT13	34.558647°	70.778635°	Host Rock – Poorly Stratified
AT14	34.555233°	70.870182°	Host Rock – Poorly Stratified
AT15	34.522911°	70.903798°	Host Rock – Poorly Stratified
AT 16	34.574053°	70.979437°	Unstained Pluton (may be a xenolith)
AT17	34.530198°	70.958919°	Host Rock – Poorly Stratified
AT18	34.600103°	71.011314°	Host Rock – Poorly Stratified
AT19	34.639785°	71.030183°	Host Rock – Poorly Stratified
AT20	34.617609°	71.028046°	Host Rock – Poorly Stratified

5) Coal

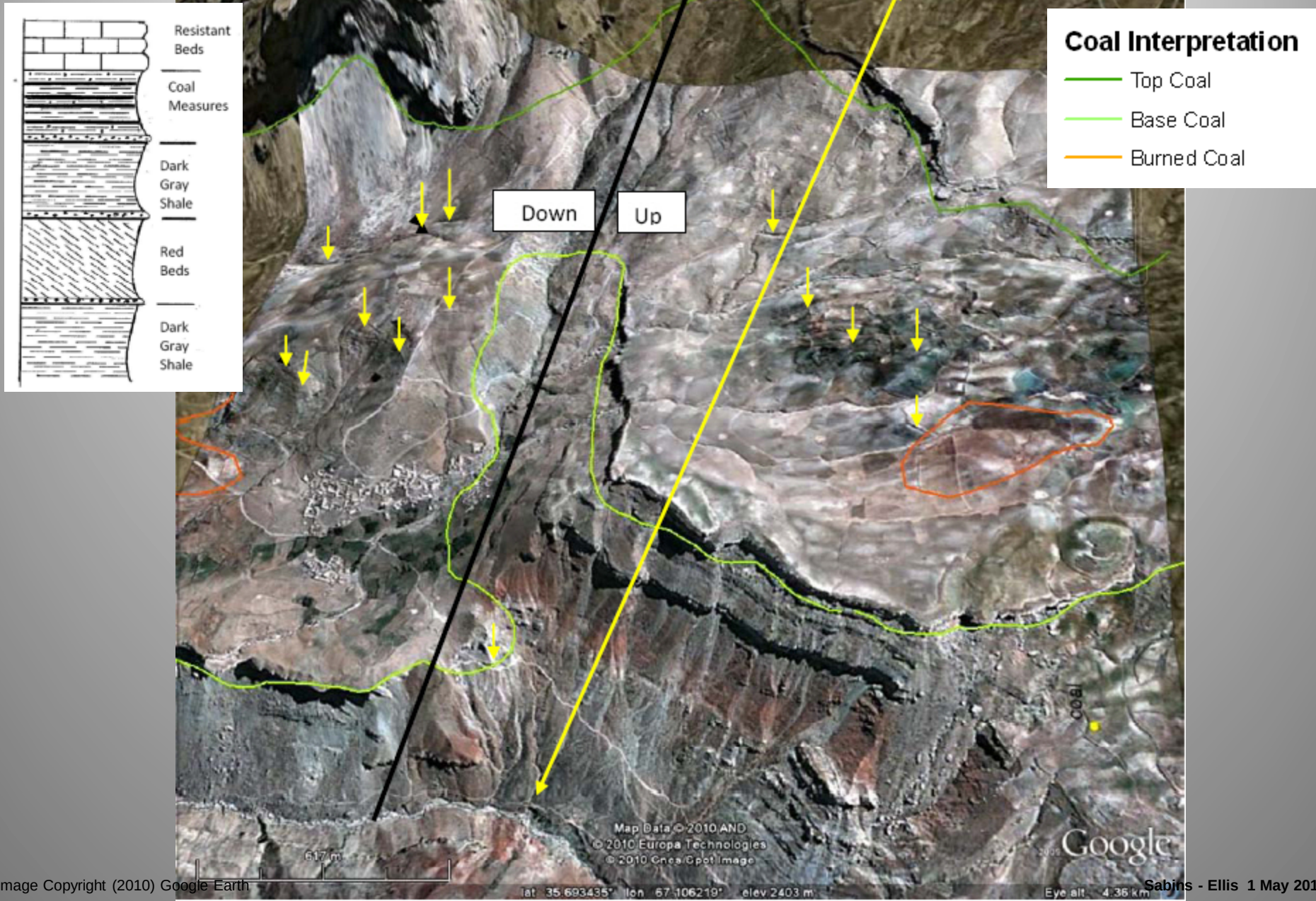


Tiles of GeoEye Imagery Loaded into Google Earth

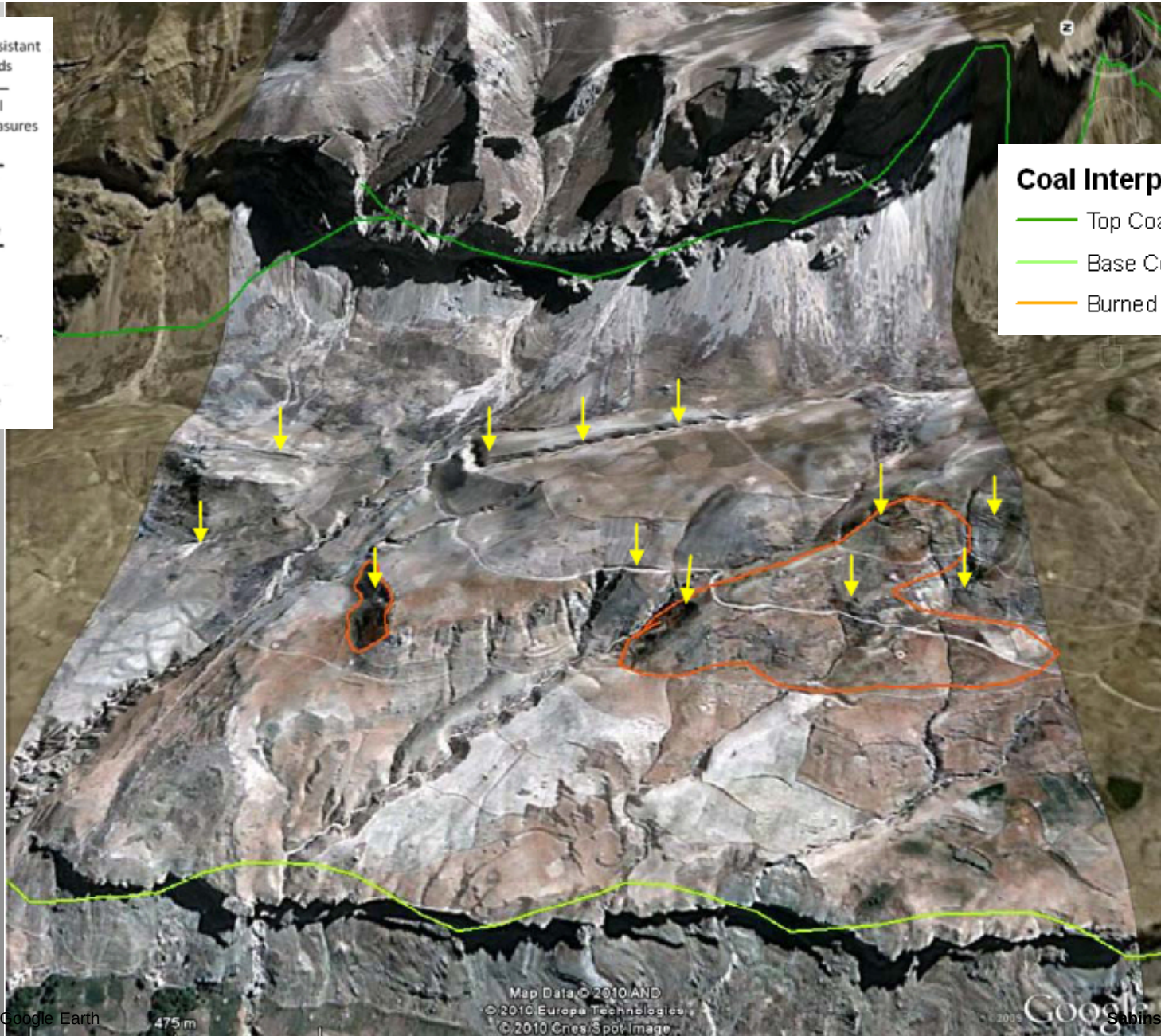
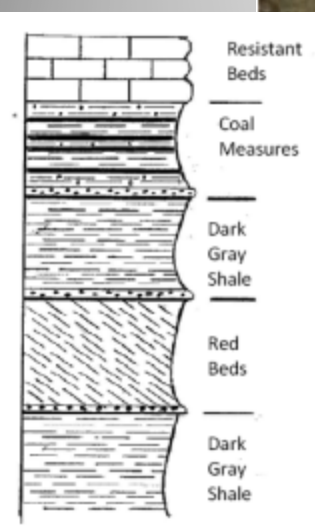
Needed
to extract
overlapping
tiles from
large
USGS
Mosaic
(red outline)



GeoEYE imagery Draped on GoogleEarth DEM

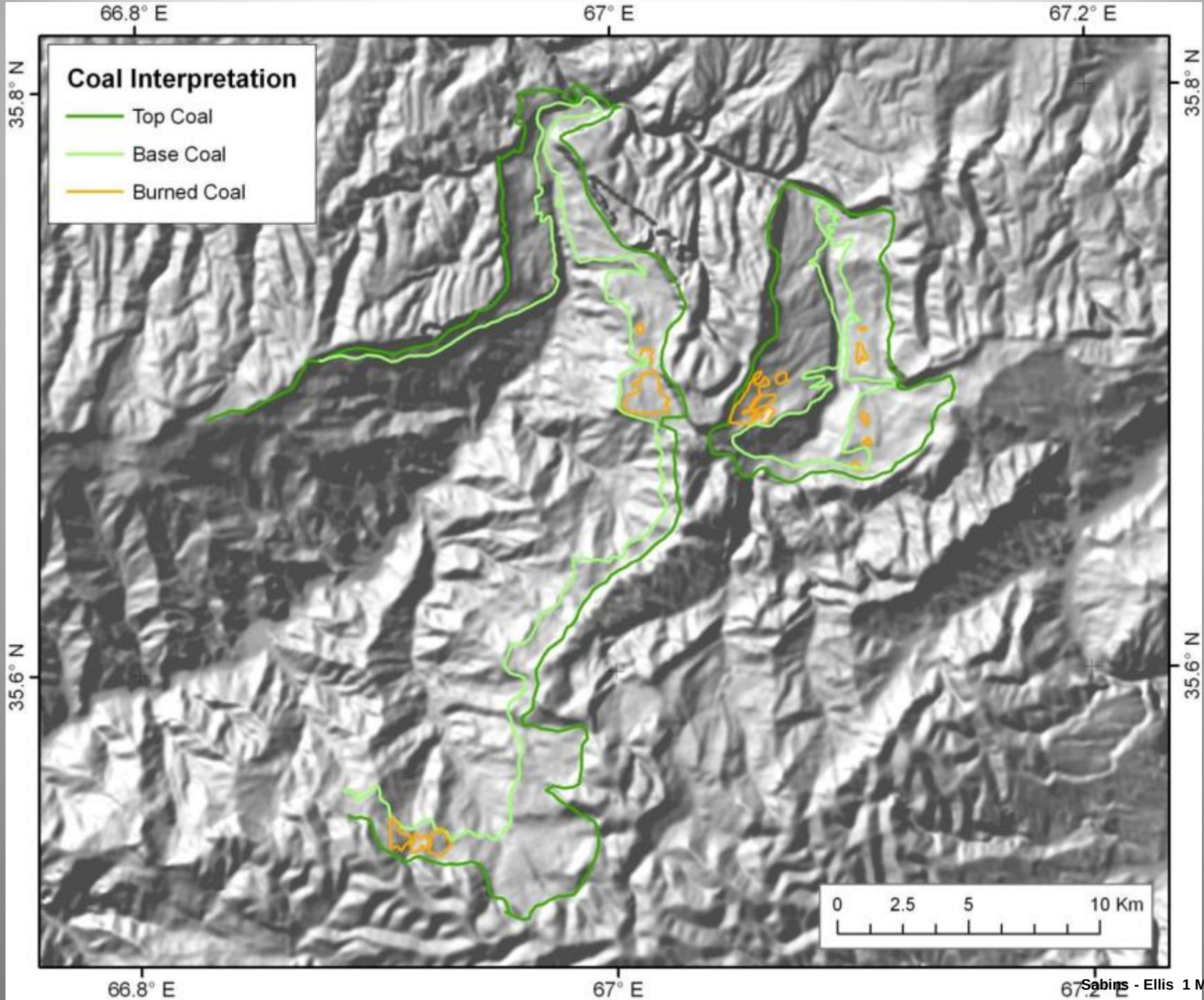


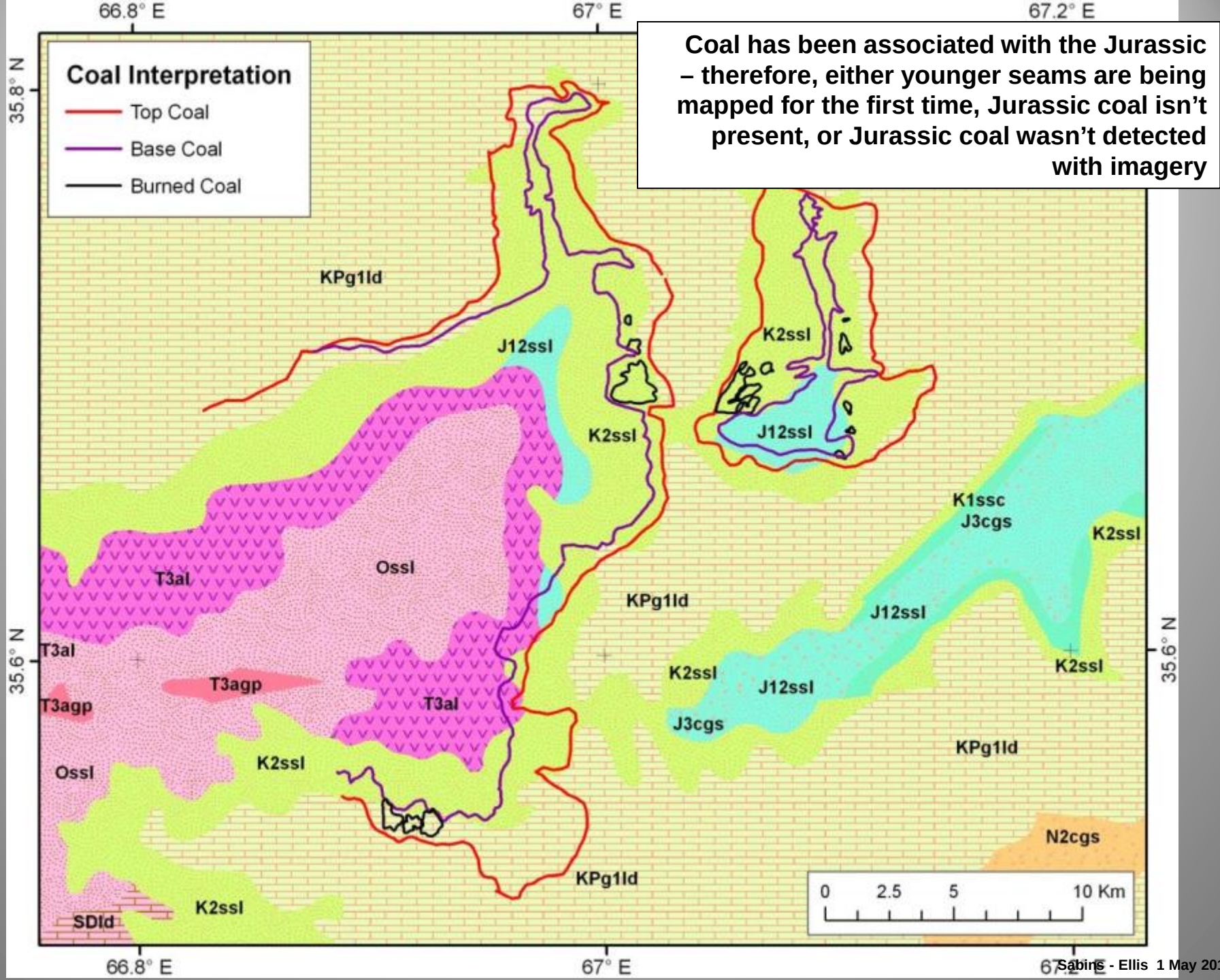
GeoEYE imagery Draped on GoogleEarth DEM



Coal Interpretation

- Top Coal
- Base Coal
- Burned Coal







Conclusions

Image processors can team with field geologists around the globe via Internet tools to build better maps

Online collaboration makes \$\$ sense

Remote sensing is a very versatile exploration tool

Having a geological model improves image selection and processing



Acknowledgements

Robert Miller, Cathy Oil & Gas Ltd

Stephen Peters, USGS

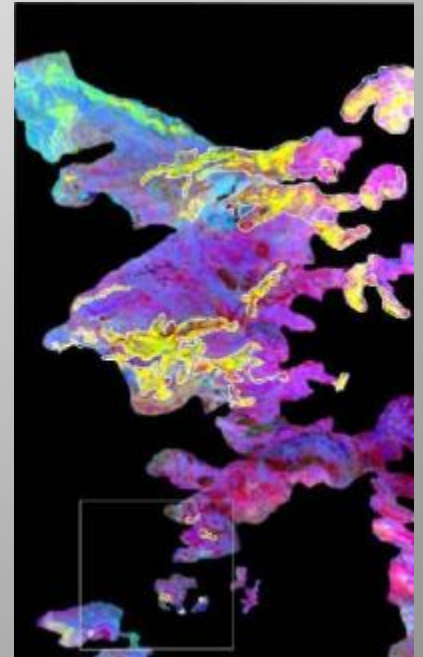
Emily Peters, TFBSO

Siddiq Kalaly, USGS

Bernard Hubbard, USGS

Ward Kilby, CalData

Joe Zamudio, Exelis



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