Multi- and Hyperspectral Geologic Remote Sensing: a Review

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23 May 1991
Pioneering work in laboratory spectroscopy by Graham Hunt and John Salisbury in 1970’s and 1980’s. ->this led to the Development of hyperspectral sensors.

**MULTISPECTRAL: LANDSAT ERA**

**OPTIMUM INDEX FACTOR (OIF)**

- The Optimum Index Factor (OIF)
- Select 3 bands for FCC
- highest amount of ‘information’ (= highest sum of standard deviations)
- least amount of duplication (=lowest correlation among band pairs)

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MULTISPECTRAL: LANDSAT ERA
RATIO, DÉCOR STRETCH, SATURATION ENHANCEMENT

Different ages of lava flows

Figure 2.27: Decomposition stretched TM image of part of the north flank of Mauna Loa. Bands 3, 5, and 7 are displayed as red, green, and blue, respectively. Age and vegetation cover information are given in Figure 2.28.

MULTISPECTRAL: THE LANDSAT ERA
PCA BASED CROSTA COMPOSITES

Alvaro P. Crosta
professor of geology, university of campinas
geology - mineral exploration - remote sensing - impact craters
Verified email at ge.uni.mp.br

Google scholar
Search Authors
Get my own profile - Help

Enhancement of Landsat Thematic Mapper imagery for residual soil mapping in SW Minas Gerais state, Brazil: a prospecting case history in greenschist belt terrain
Authors: Alvaro P. Crosta, J Moere
Publication date: 1989
Journal name: THEMATIC CONFERENCE ON REMOTE SENSING FOR EXPLORATION GEOLOGY
Volume: 7
Pages: 1173-1187

Total citations: 157
Citations per year

Scholar articles:
Enhancement of Landsat Thematic Mapper imagery for residual soil mapping in SW Minas Gerais State, Brazil: A prospecting case history in greenschist belt terrains
A Crosta, J Moere - Thematic Conference on Remote Sensing for Geology, 1989
Cited by 157 - Related articles
MULTISPECTRAL: LANDSAT ERA
GEOLOGIC USE OF LANDSAT TM

- Geologic mapping (Schetselaar et al., 2000, Fraser et al., 1997)
- Lithologic mapping (Gad and Kusky, 2006)
- Structural mapping (Boccaletti et al., 1998, Yesou et al., 1993)
- Volcano monitoring (Oppenheimer et al., 1993)
- Coral reef mapping (Mumby et al., 1997)
- Natural oil seep detection (Macdonald et al., 1993)
- Landslide mapping (Singhroy et al., 1998, Lee and Talib, 2005)
- Gneissic terrains (De Souza, 1998)
ASTER VERSUS LANDSAT TM
GLOBAL EARTH OBSERVATION DATA!

<table>
<thead>
<tr>
<th>'Iron'</th>
<th>'Argillic/Phyllic'</th>
<th>'Silica'</th>
<th>DEMs</th>
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<td>1 2 3</td>
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ASTER

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Landsat 7

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<th>'Yellow Iron'</th>
<th>'Red Iron'</th>
<th>Hydroxyl Minerals 'Clay'</th>
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<tr>
<td>Wavelength (um)</td>
<td>Visible - Near IR</td>
<td>Short Wave IR</td>
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</table>

Graphite schists
Carboneras fault
Volcanic crater - Gabo de Gata volcanics

ASTER RGB = 4, 6, 8

ITC course GRS
3D surface view of color composite: RGB = bands 4, 6, 8

Dark oval units -> graphite schists units; Linear range of hills -> Carboneras fault; Oval crater near hill top: volcano crater; etc.

ASTER band ratio’ show alteration centers

Alteration centers

Ratio band 4 / band 6

FCC 4,6,8

ITC course GRS
Band ratio 4/6

Field-based alteration map (Arribas, 1995)

ASTER MEASURING GROUND DISPLACEMENT
CO-REGISTRATION OF OPTICALLY SENSED IMAGES - COSICORR

http://www.tectonics.caltech.edu/slip_history/spot_coseis/index.html
Cosicorr = Sebastien Leprince
Figure 4-3  Displacement measured along the fault at a specified location
MULTISPECTRAL ERA: ASTER

- 100 ASTER scenes (Rockwell and Hofstra, 2008, Hewson et al., 2005).
- Lithologic mapping (Li et al., 2007, Qiu et al., 2006, Rowan and Mars, 2003, Gomez et al., 2005, Khan et al., 2007).
- Granites (Massironi et al., 2008, Watts et al., 2005),
- Ophiolite sequences (Qiu et al., 2006, Khan et al., 2007)
- Basement rocks (Qari et al., 2008, Gad and Kusky, 2007, Vaughan et al., 2005).
- Sedimentary terrains (Pena and Abdelsalam, 2006).
- Mineral exploration - geothermal (Vaughan et al., 2005)
- Evaporate systems (Kavak, 2005).
- Offshore hydrocarbons (Lammoglia et al., 2012)

THE HYPER SPECTRAL ERA

- each pixel has an associated spectrum used to identify surface materials
- 224 spectral bands
- cross-track (614 pixels x 20 m/pixel)
- along track (512 pixels per scene)
- reflected light (kaolinite)
- Wavelength (μm)
- Reflectance
- Host rock
- Hydrothermal fluids
- Lithologic composition
- Fluid chemistry
- Pressure, temperature

UNIVERSITY OF TWENTE.
Surface composition mapping

AVIRIS spectra distance 22km.

Buddingtonite

Alunite

Kaolinite

andesitic volcanic rock
marine sediments (reef limestones)
unconformity
volcanic tuffs - highly altered by high-sulfidation epithermal fluids - containing alunite, dickite and illite
alluvium
tailing material of Rodalquilar gold-mine transported downstream
"There is no reason anyone would want a computer in their home." Ken Olson, president, chairman and founder of DEC
Intrusives = granite
Extrusives = basalt
Sediments = ocean sediments

White mica, Al → Mg, Fe
Al-rich → Al-poor

Image fusion product of Landsat TM and gravity
Data courtesy CSIRO

Cudahy, 1999, Mapping the Panorama...
Case study Cu-Zn deposits Pilbara
Integrated interpretation of the results

Reconstruction of physico-chemical conditions

- 150 - 210°C: Seawater recharge-related, low temperature Si-altered felsic rock
- 200 - 250°C: Recharge-related medium-temperature K-altered felsic and mafic rock
- 210 - 310°C: Medium-temperature somewhat K-altered mafic rock
- 250 - 400°C: Fluid-discharge-related high temperature Fe- and Mg-altered felsic and mafic rock

Note: Position of mineralization relative to fluid pathways. Impact on target generation!

Van Ruitenbeek et al. RSE
PILBARA, AUSTRALIA

Depth of the main FeOH absorption feature at 2250nm

- IntChlorite+*Hornblende+*Actinolite
- Hornblende
- IntChlorite

SMECTITE-ILLITE CRYSTALLINITY AND COMPOSITION

SWIR vs. XRD
- XRD: interlayer space
- SWIR crystallinity

MSc, Guatame Garcia, ITC 2012
Epithermal gold systems (Crosta et al., 1998, Kruse et al., 2006, Chen et al., 2007, Rowan et al., 2000, Gersman et al., 2008, Bedini et al., 2009, Van der Meer, 2006b)


Carlin-type systems (Rockwell and Hofstra, 2008)

Archean lode (Bierwirth et al., 2002)

Skarns (Windeler, 1993)

Calcic skarn (Kozak et al., 2004, Rowan and Mars, 2003, Bedini, 2009)

VMS (Berger et al., 2003)

Dolomitization (Gaffey, 1986, Van der Meer, 1996, Windeler and Lyon, 1991)

Lithologic mapping in Arctic conditions (Harris et al., 2005)

Granitic terrain (Rivard et al., 2009)

Ophiolite sequence (Roy et al., 2009, Chabrillat et al., 2000, Launeau et al., 2004)


Oil seeps onshore (Horig et al., 2001, Kuhn et al., 2004)

Oil seeps offshore (Lammoglia et al. 2012)

Gas seeps (Van der Meer et al., 2002, Van der Werff et al., 2006)

Tar sands (Lyder et al., 2010, Rivard et al. 2010).

Drill core (Gallie et al., 2002, Bolin and Moon, 2003, Brown et al., 2008).

Outcrops (Ragona et al., 2006).

SEBASS TIR system (Vaughan et al., 2003, Vaughan et al., 2005).
OVERVIEW OF RELEVANT MISSIONS

1996: Mars Global Surveyor
1999: Mars Climate Orbiter
2001: Mars Odyssey
2003: Mars Express
2005: MRO
2007: Phoenix
2009: MER

Indications of hydrated minerals
Wavelength map of minerals
Indications in mafic minerals

Red: Depth of water feature
(hydrated minerals)
Green: Dnep 2300 nm
(Fe/Mg phyllosilicates)
Blue: Dnep 2400 nm

Red: Olivine
Green: Low-Calcium Pyroxene
Blue: High-Calcium Pyroxene

Processed hyperspectral imagery obtained with the OMEGA sensor at the Mars Express orbiter showing mineral diversity in the Nili Fossae area on Mars.

Source: Mustard, 2010

UNIVERSITY OF TWENTE.
What is the origin of these water bearing clay minerals on Mars: hydrothermal or weathering

FURTHER INTERPRETATION IN ‘CAVE’
MARTIAN GEOLOGY

- Mars general (Bibring et al., 2005, Poulet et al., 2005, Mustard et al., 2005)
- Mars sulfates (Wang et al., 2006, Mangold et al., 2008, Aubrey et al., 2006)
- Mars hydrated silicates (Mustard et al., 2008, Ehlmann et al., 2009)
- Mars phyllosilicates (Loizeau et al., 2007)
Geothermal Energy Industry

Developing methods to characterize geothermal system dynamics, fluid pathways, link surface to subsurface expressions thus assessing heat-renewable energy potential in a context of electricity pricing and climate debate.
ALEXANDER GOETZ, 2009 REVIEW
RAISED 4 MAIN ISSUES OR OBSERVED 4 TRENDS

- Need for more accurate measurements
- Education of students
- Advance of computer and sensor technology
- An hyperspectral ‘of the quality of AVIRIS’ imager in orbit
QUANTIFIABLE, VERIFIABLE, REPEATABLE
SURFACE COMPOSITIONAL MAPPING/CLASSIFICATION

R=alunite
B=kaolinite
G=illite

US data cube  Spectral library

SAM  CCSM
CEM  SFF

Mineral Map

? Geological Model ?

Process model

Binary encoding  Minimum distance

Spectral angle  SID

WARRANTY

Second User
Perfect Working Order

Sorry! No Warranty
EMPIRICAL MODELS
QUANTIFIABLE (YES), REPRODUCIBLE (?)
SWOT ‘TOO MANY BANDS’

- **Strength:**
  - Mimicking field reflectance
  - Cross comparison to field data
  - Cater for many applications

- **Weakness:**
  - Engineering challenge to produce sufficient NER
  - Computing power
  - Calibration complexity
  - Data redundancy per channel and per application

Picture source: Karl Staenz, CCRS

DATA CONTINUITY AND TIME SERIES
THE IMAGING SPECTROMETRY PLAN IN 1984

Hyperion
- 220 bands
- 0.4 to 2.5 μm
- 30 m.
- 7.5km strips

Source: Goetz, 2009, RSE 119, fig 17
### Spectral Coverage and Swath Width

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*Proposed instrument – Pre-decisional for planning and discussion purposes only.*

### Instrument Lifetimes

Note that lifetimes estimated are 5 years, luckily in reality instruments by far outlive their lifetime - > ASTER, 1999 onward.
GMES dedicated missions: Sentinels

**Sentinel 1 – SAR imaging**
All weather, day/night applications, interferometry

- **2011**

**Sentinel 2 – Multispectral imaging**
Land applications: urban, forest, agriculture,...
Continuity of Landsat, SPOT

- **2012**

**Sentinel 3 – Ocean and global land monitoring**
Wide-swath ocean color, vegetation, sea/land surface temperature, altimetry

- **2012**

**Sentinel 4 – Geostationary atmospheric**
Atmospheric composition monitoring, trans-boundary pollution

- **2017+**

**Sentinel 5 – Low-orbit atmospheric**
Atmospheric composition monitoring (S5 Precursor launch in 2014)

- **2019+**
Next in line: SWARM – ESA’s magnetic field mission

- Swarm will provide the best-ever survey of the Earth’s geomagnetic field and its variation in time
- Swarm will allow to gain new insights into the Earth’s interior and climate
- Launch scheduled for October 2012

Swarm: earth magnetic field

- Understanding “Earth’s dynamo” in the outer core
- Looking into the composition of the mantle
- Mapping “magnetic fingerprints” in Earth’s crust
- Sensing the weak signature of the ocean currents
• **GEO = Group on Earth Observation**
  - 88 Nations
  - European Commission
  - 67 Participating Organizations

• **GEOSS = One Vision**
  - The global earth observation system of systems

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**THE BIG SCIENCE QUESTIONS**

NASA DEcadAL SURVEY

- How is the global earth system changing?
- What are the primary forces of the Earth system?
- How does the earth system respond to natural and human-induced changes?
- What are the consequences of change in the earth system for human civilization?
- What are the consequences of processes such as urbanization and global economic development for system Earth?

**Two remarks:**
Global coverage from earth observation needed with frequent revisit!
Geologists unite and voice your contribution to answer these questions!!
HOW BIG IS OUR WORLD?

- Landsat AND mineral = 233
- Hyperspectral AND mineral = 472
- Landsat AND vegetation = 3896
- Hyperspectral AND vegetation = 1723
- Landsat AND water = 2626
- Hyperspectral AND water = 1540

WEB OF KNOWLEDGE™

CHALLENGES
CORE LOGGING, HYPERSPECTRAL ROCK, THERMAL EMISSIVITY SPECTROSCOPY

Terrestrial hyperspectral scanning ‘virtual outcrop models’ – PhD Tobias Kurz, Uni Bergen

Hyperspectral scanning of rocks A. Agus MSc -ITC

Mineralogy + texture

Sulfide
Tourmaline
Muscovite
Illite
Kaolinite

ITC
WENET
CONCLUDING THOUGHTS

- Hyperspectral RS is accepted technology by the mining industry
- Quantification, verification, repeatability; in search for standards and protocols
- Empirical versus physical models
- Monitoring means time series to contribute to the Big q.’s
- ‘no single analytical technique can be used to fully deconvolve hyperspectral data in the absence of ancillary data’ - Cloutis, 1996
- GRS = evolution not revolution (cf InSAR)

- Lord Kelvin - “There is nothing new to be discovered in physics now. All that remains is more and more precise measurement” – few years later Albert Einstein proposed relativity theory.

ACKNOWLEDGEMENT

- Michael Berger ESA
- Mike Abrams JPL
- Tom Cudahy CSIRO
- GEO secretariat
- ITC geological remote sensing group
- ITC MSc graduates: Abweny, Bedini, Guatame Garcia, Yaseen
- ITC PhD graduates: Van Ruitenbeek, Hecker