SOLSA

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A NEW HYPERSPECTRAL LIBRARY CONNECTED TO SOLSA OPEN DATABASES

for on-line-real-time analyses of Ni laterites & Bauxite

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ThermoFisher SCIENTIFIC · Eijkelkamp SonicSampDrill · brgm Géosciences pour une Terre durable · ERAMET · UNIVERSITÀ DEGLI STUDI DI TRENTO · CRISMAT · EMC UMR6508 · ENSICAEN · Vilniaus Universitetas · Institute of Biotechnology

- Introduction
- Databases
  - Sample database
  - Raman open database
  - Hyperspectral library
- Hyperspectral imaging
  - Hyperspectral library
  - Sparse unmixing techniques
  - Results
- Conclusions and perspectives

WHAT IS SOLSA ?

Interactive & interconnected

- ❖Drilling **(presentation Eijkelkamp et al.)**
- ❖Chemical & mineralogical analyses systematic

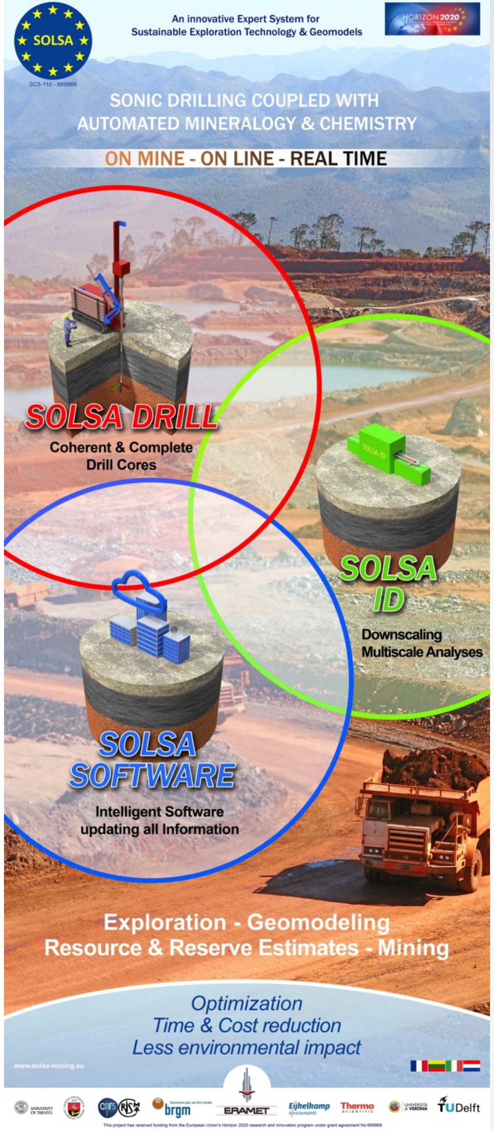
= > definition & analyses of Regions of interest

- ❖Actionable Data

=> NEAR-REAL-TIME DECISION MAKING

....towards automated, continous exploration, mining & processing

4-years 10 M€, 4 countries, 9 partners



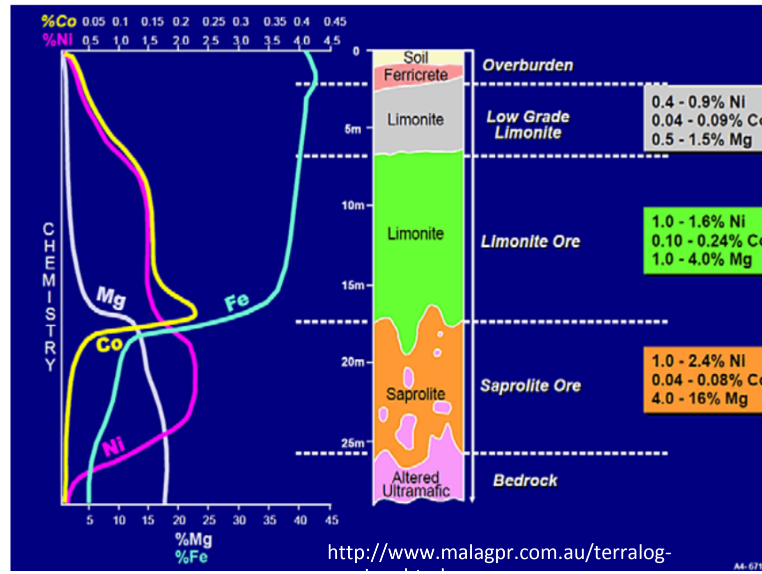
- ❖ Common & efficient Data Architecture
- ❖ Reliable, validated Open data bases
- ❖ Deep learning Software

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 689868

1st SOLSA prototype validated for Nickel-laterites (ERAMET end user)

Ni- laterites (tropical countries): 70 % world's Nickel resources (40% of Ni production), but also Co, (Sc target) EU for steel-alloy-chemical industries = > EU technologies

(Sub-) SURFACE ores



- Grade decrease (0.5 – 1 % Ni)
- Multiple metal (Ni, Co, Sc) carrier-minerals of different physico-chemical properties (part in swelling clays)
- Heterogeneities: hard – loose material

➢ Inaccurate resources & reserves estimates,
➢ Insufficient Metal Recovery
➢ Dysfunction in processing

Complex materials need a multi-instrumental approach

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SOLSA ID
Analyse & Identification in **field & industrial applications**

Thanh M. BUI

on line-on-mine

measurement drillcore-real time

ID A

Profilometer, RGB camera, XRF,VNIR/ SWIR cameras,

processing

Definition of ROIs on drill cores

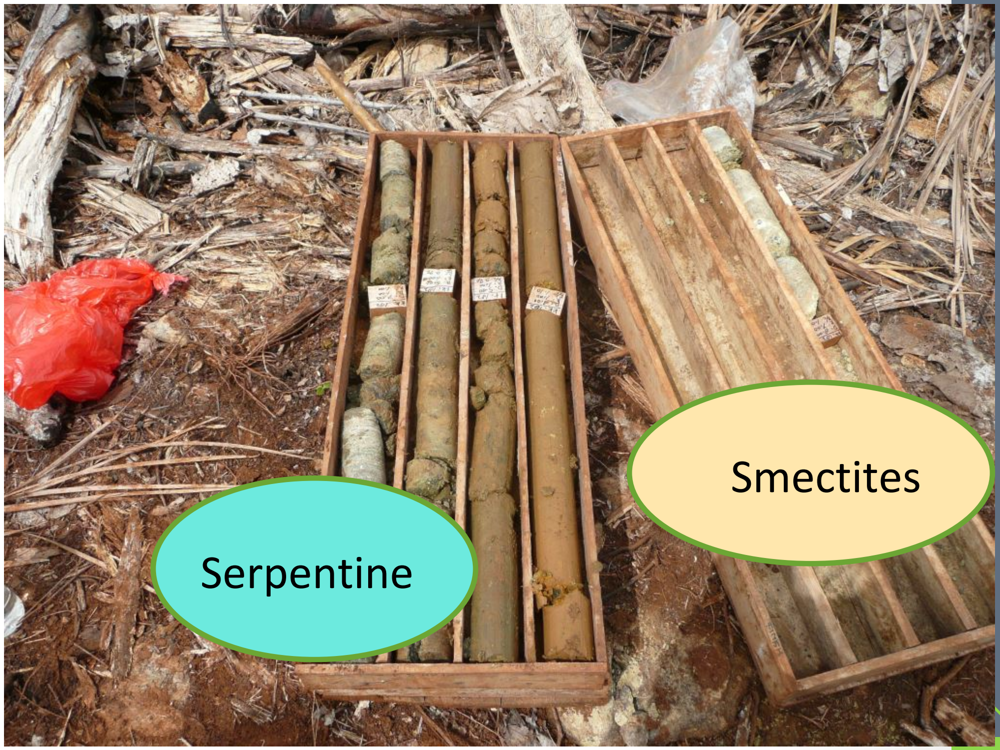
measurements off-line

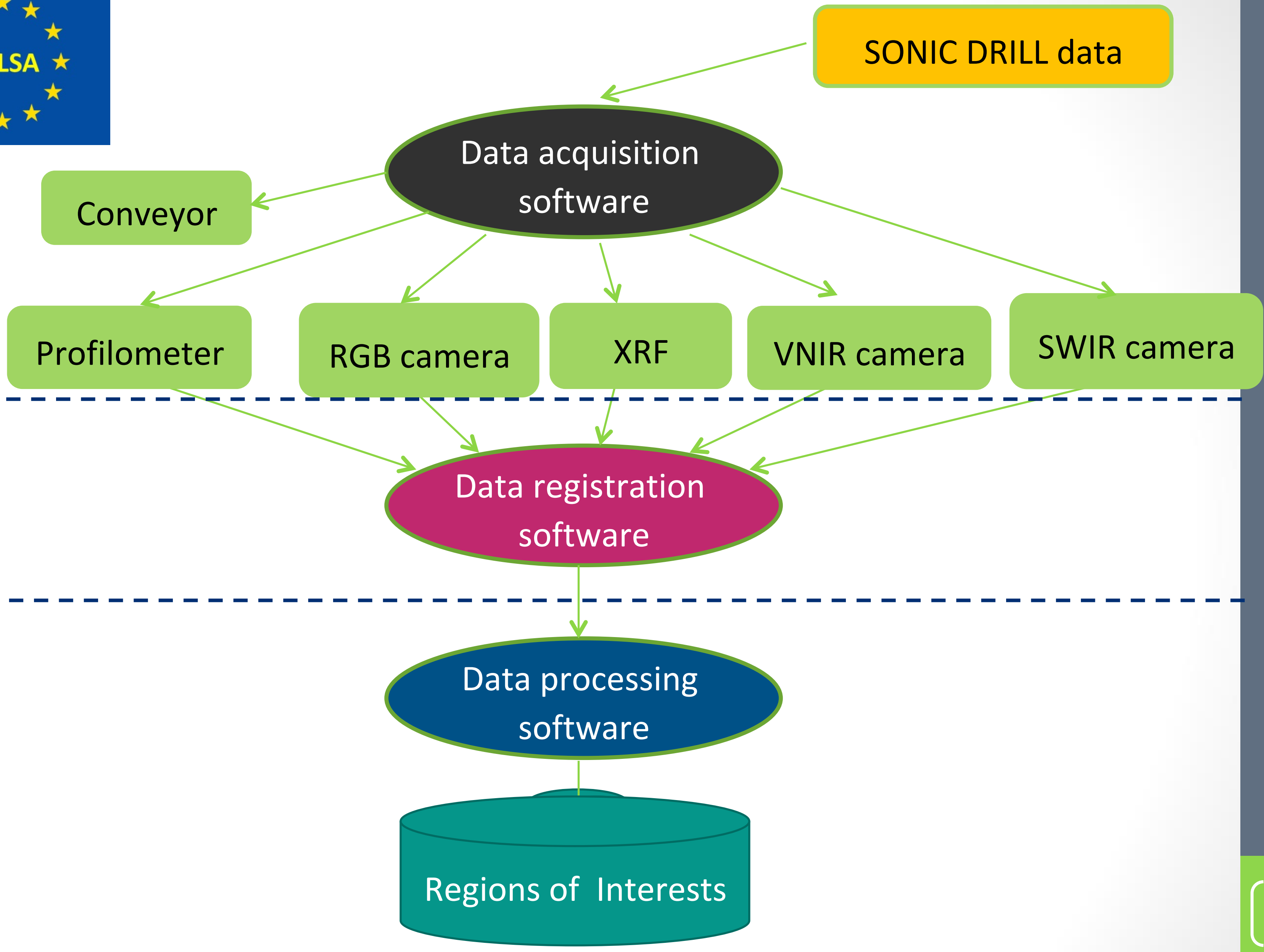
ID B

XRD – XRF – Raman on ROIs

processing

Data processing





Software development scheme

- Introduction
- Databases
  - Sample database
  - Raman open database (ROD) *(El Mendili et al, this session)*
  - Hyperspectral library
- Hyperspectral imaging
  - Hyperspectral library
  - Sparse unmixing techniques
  - Results
- Conclusions and perspectives

Sample database: Key issues

- ID cards of reference samples-sample library: geological-mine context, macroscopic and microscopic description (ISO 14688, 14689), laboratory analyses (XRF, EPMA, XRD), (mine specific here for Ni-laterites)

- Relational SQL database: comparing lab, handheld (pXRF, pPIR) and SOLSA on-line analyses.

- Definition of key parameters of the reference samples important for the mining company (based on macroscopic description).

- Defintion of homogeneous units when implementing data

ROD and Hyperspectral library

- **Raman open database:**
  - Collection of Raman spectra of standard samples.
  - Available at http://solsa.crystallography.net/rod/

  talk: Yassine El Mendili et al. this session

- **Hyperspectral library (under construction):**
  - Collection of spectra of pure minerals
  - Will be available at http://solsa.crystallography.net/hod/

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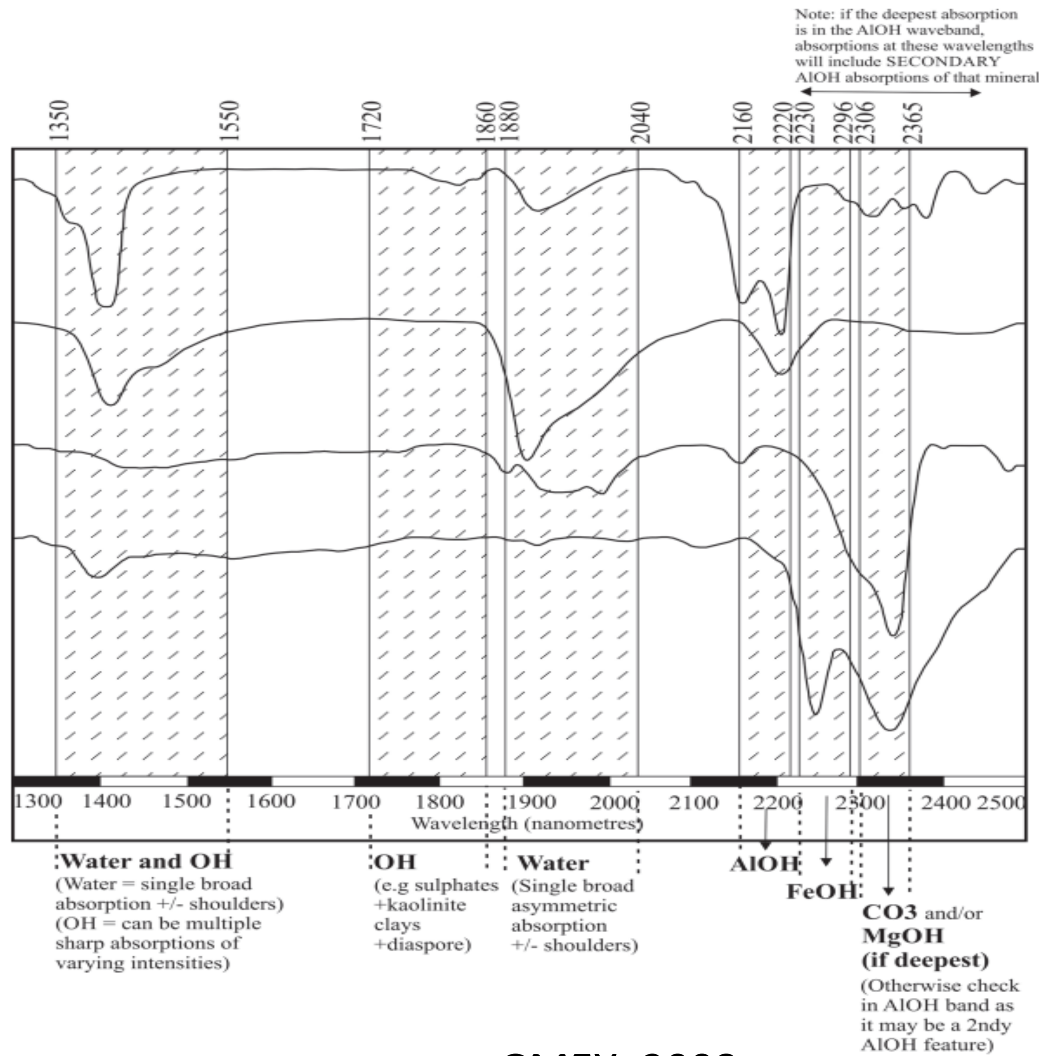
Hyperspectral imaging for mineral identification

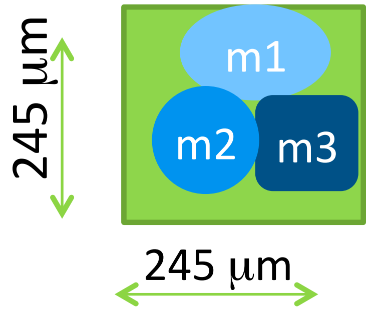
Molecules	Dominant absorption features
OH	1400nm (1550nm and 1750-1850nm in some minerals)
Water	1400nm and 1900nm
AlOH	2160-2228nm
FeOH	2230-2295nm
MgOH	2300-2370nm
CO_3	2300-2370nm (and also at 1870nm, 1990nm and 2155nm)

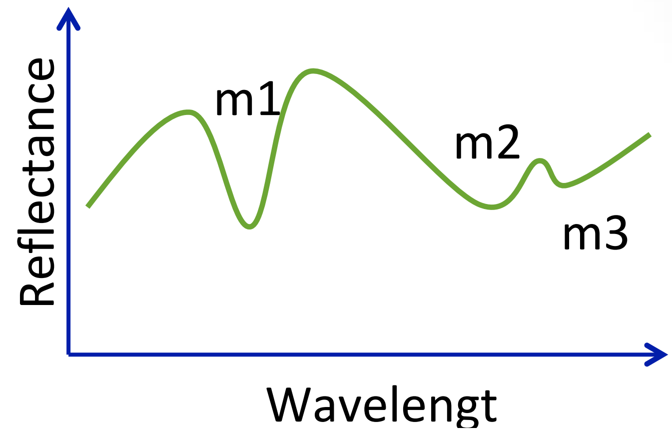


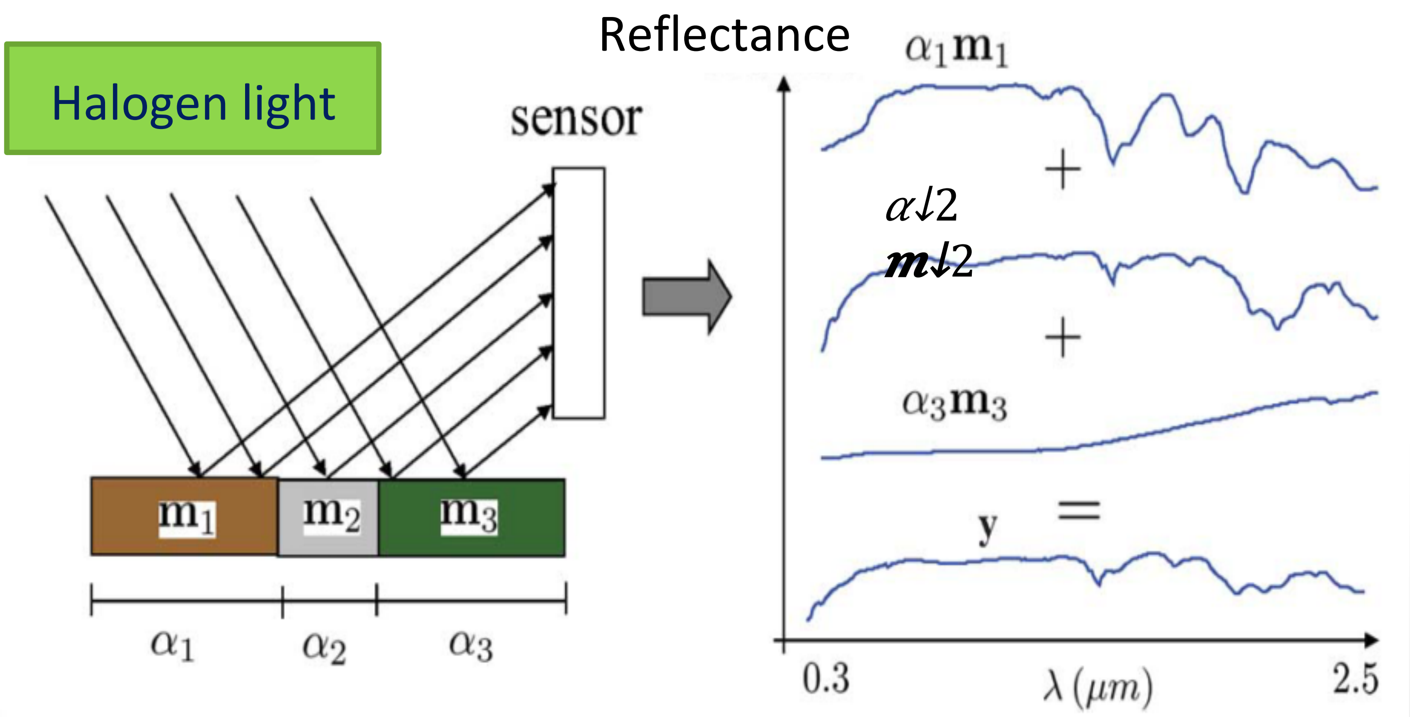
Crystallinity variations -> shape variations
Compositional variations -> wavelength shifts

GMEX, 2008,
Pontual et al. 1997

Hyperspectral unmixing







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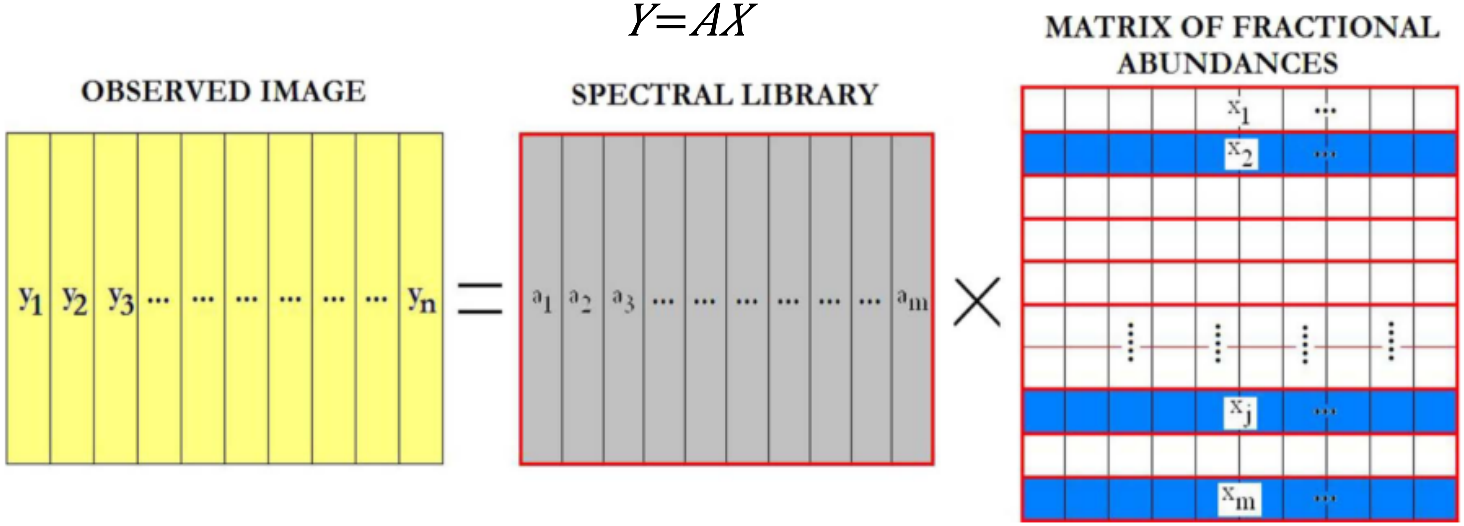
Hyperspectral unmixing

- Statistical approaches *(Debigion et al. 2008 ; Altmann et al., 2015)*
  - The likelihood: data generation models
  - Priors: constraints on the endmembers
- Geometrical approaches (Nascimento et al., 2005; Bioucas-Dias et al. 2009)
  - The observed hyperspectral vectors: simplex set whose vertices correspond to the endmembers.
- Sparse regression

Sparse unmixing

$Y = AX$



Iordache *et al.*, IEEE Trans, 2014

Y	**A**	**X**
L x n	L x m	m x n

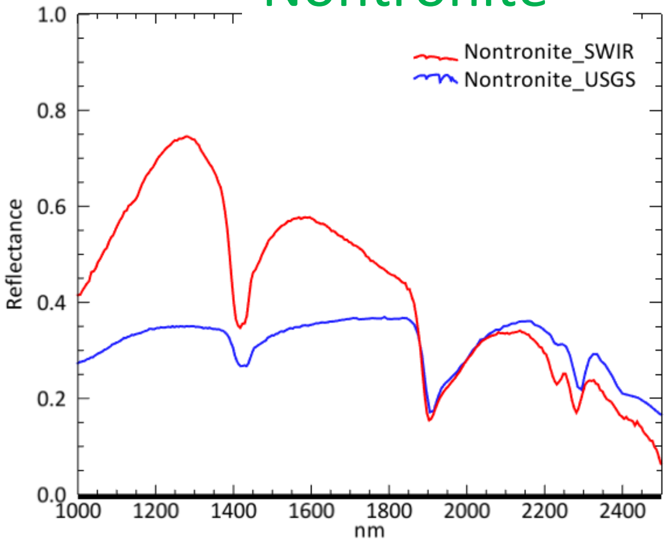
$\min_X \|AX - Y\|_F^2 + \lambda \|X\|_{2,1}$, *subject to:* $X \geq 0$, $1^T X = 1$

- The observed image signatures can be expressed in the form of linear combinations of a number of pure spectral signatures known in advance (spectral library).
- Unmixing amounts to finding the optimal subset of signatures in a spectral library that can best model each mixed pixel in the scene.
- The sparse unmixing exploits the usual very low number of endmembers (maximum of 4, Berman *et al.*, CSIRO, 2017) present in real images, out of a spectral library.

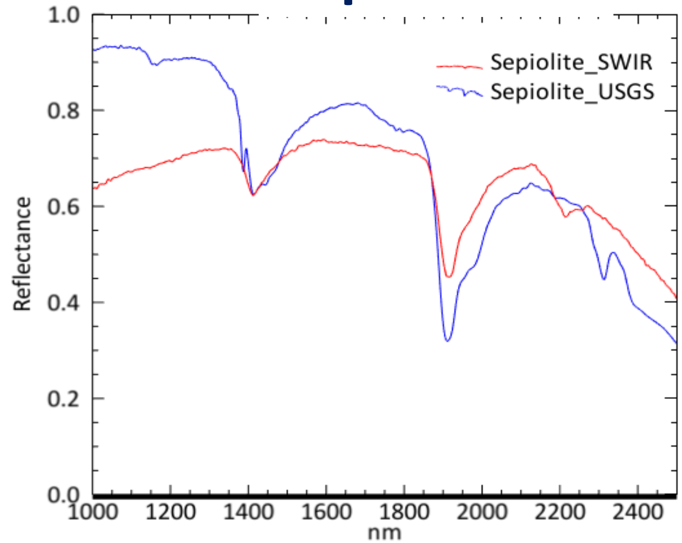
Hyperspectral library

- Other libraries (e.g., USGS, CSIRO, John Hopikins Univ.) may not contain spectra of pure minerals.
- SOLSA includes spectra that are collected with our instruments used in our operational exploration.
- Minerals and mineral associations typical for Ni laterites (and different mine types) may not be present in other libraries.

Nontronite



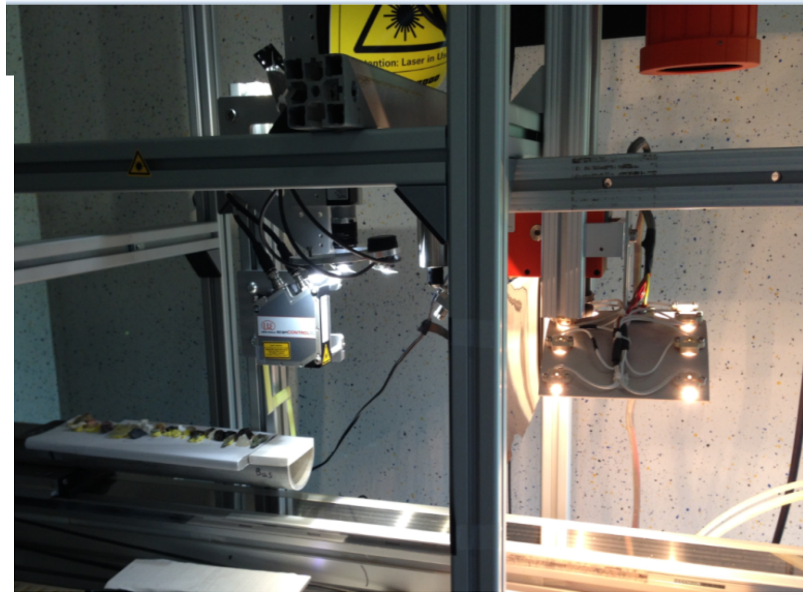
Sepiolite

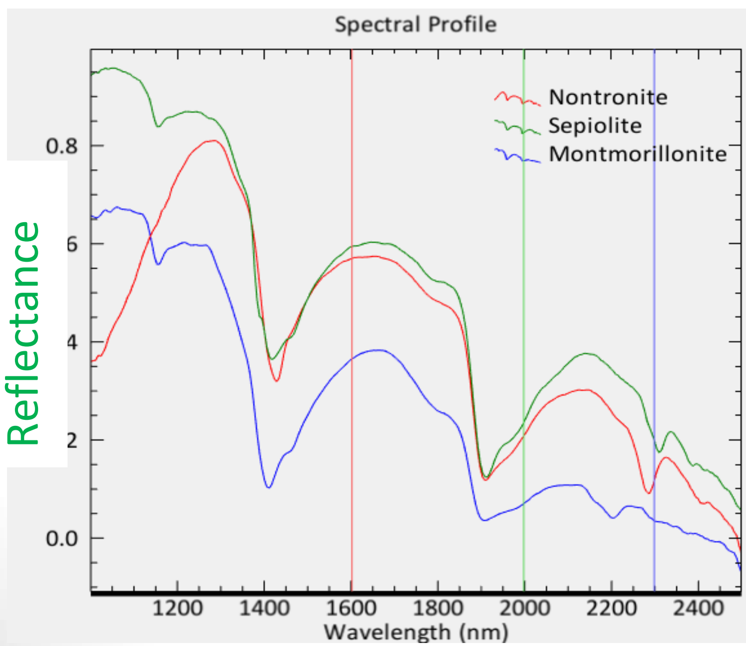


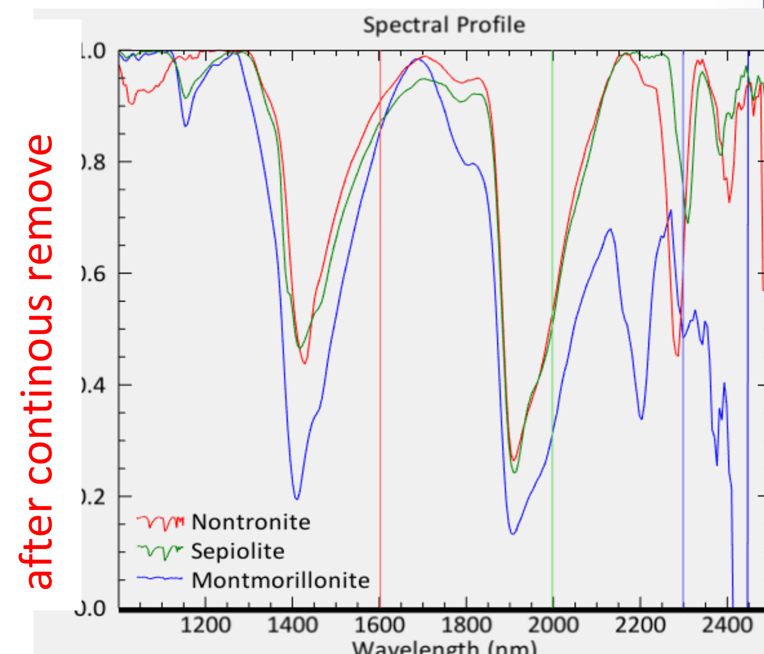
Reference spectral libraries: USGS: https://speclab.cr.usgs.gov/ NASA ASTER: https://speclib.jpl.nasa.gov/

SOLSA Hyperspectral library at present

- Rocks, pure mineral samples: BRGM, ERAMET, National Museum of Natural History, France
- Spectra extraction: ENVI 5.4 & G-MEX (taking into account: wavelength positions, the relative intensities of the absorption features.







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Sparse unmixing techniques

CLSUnSAL

(Collaborative sparse unmixing by variable splitting and augmented Lagrangian):

$$\min_{X} \square ||AX-Y||_{F}^{2} + \lambda ||X||_{2,1}$$

subject to: $X \geq 0$, $\mathbf{1}^{T} X = 1$

SUnSAL

(Sparse unmixing by variable splitting and augmented Lagrangian):

$$\min_{X} \square ||AX-Y||_{F}^{2} + \lambda ||X||_{1,1}$$

subject to: $X \geq 0$, $\mathbf{1}^{T} X = 1$

FCLS

(Fully contrained least squares):

$$\min_{X} \square ||AX-Y||_{F}^{2}$$

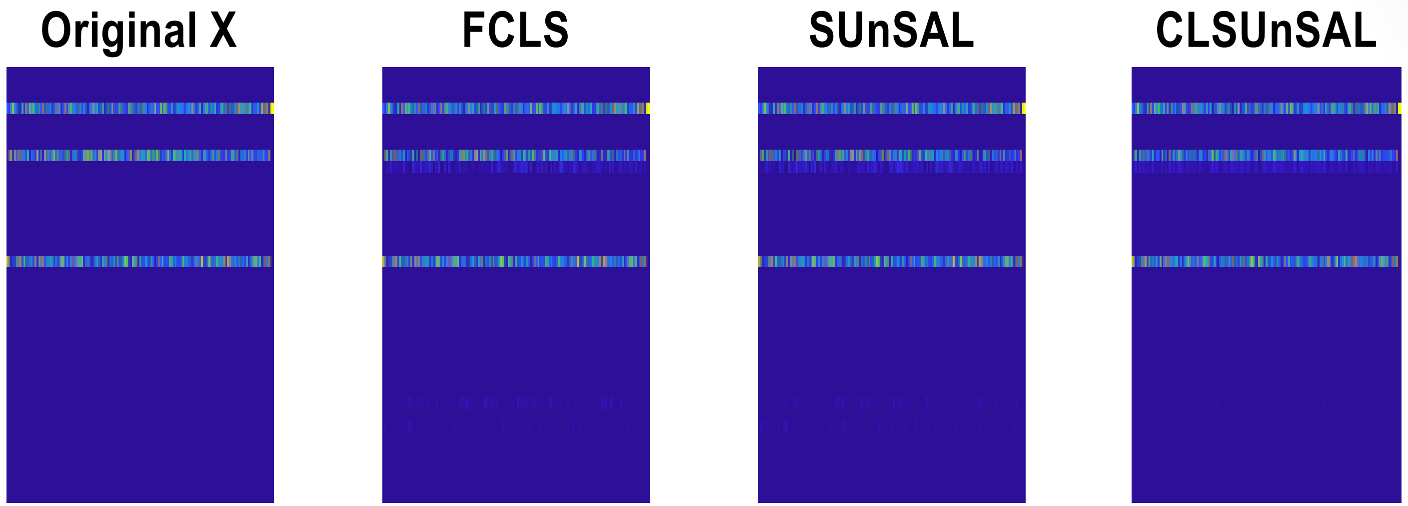
subject to: $X \geq 0$, $\mathbf{1}^{T} X = 1$

The optimization is based on the alternating direction method of multipliers (ADMM)

Bioucas-Dias *et al.*, 2010
Iordache *et al.*, IEEE Trans, 2014
Afonso *et al.*, IEEE Trans, 2011

Hyperspectral unmixing

Simulated data



Signal to reconstruction error (SRE) ratio:

$$SRE = 10\log_{10}\left(E\|\boldsymbol{x}\|_2^2 \,/\, E\|\boldsymbol{x}-\hat{\boldsymbol{x}}\|_2^2 \right)$$

SNR = 40 dB

K	FCLS		SUnSAL		CLSUnSAL	
	SRE	Time	SRE	time	SRE	time
2	14.24	0.022	14.94	0.254	16.74	0.228
3	6.41	0.019	7.45	0.259	11.95	0.230
4	5.25	0.022	7.07	0.499	7.16	0.453

FCLS: Fully constrained least squares
SUnSAL: Sparse unmixing by variable splitting & augmented Lagrangian
CLSUnSAL: Collaborative sparse unmixing by variable splitting & augmented Lagrangian

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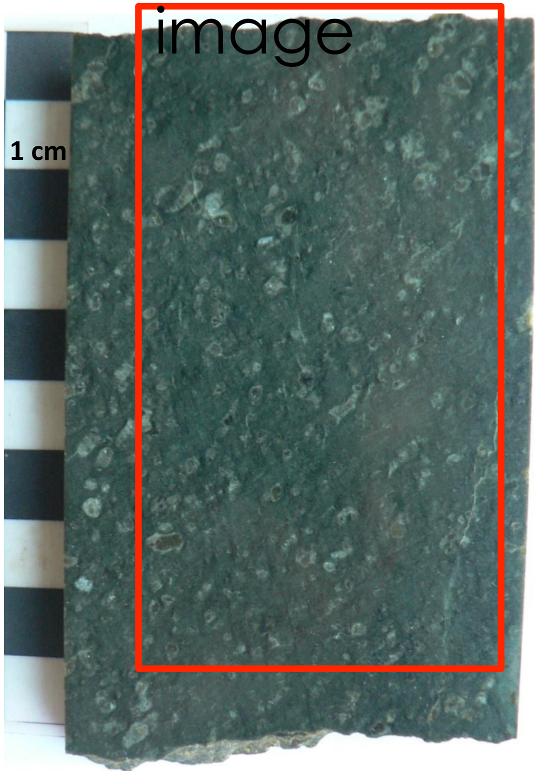
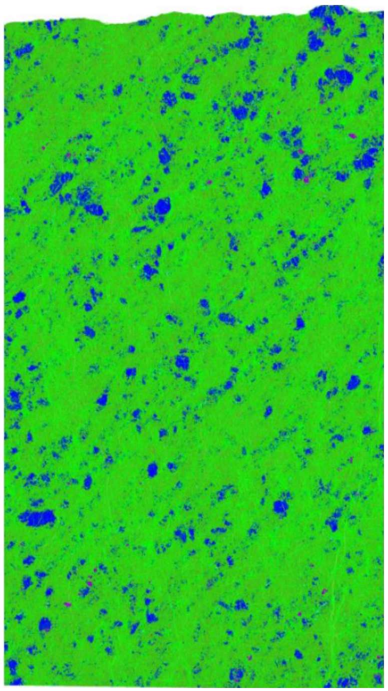
Hyperspectral unmixing

Data acquired: serpentinized harzburgite sample

RGB image



QEMSCAN results



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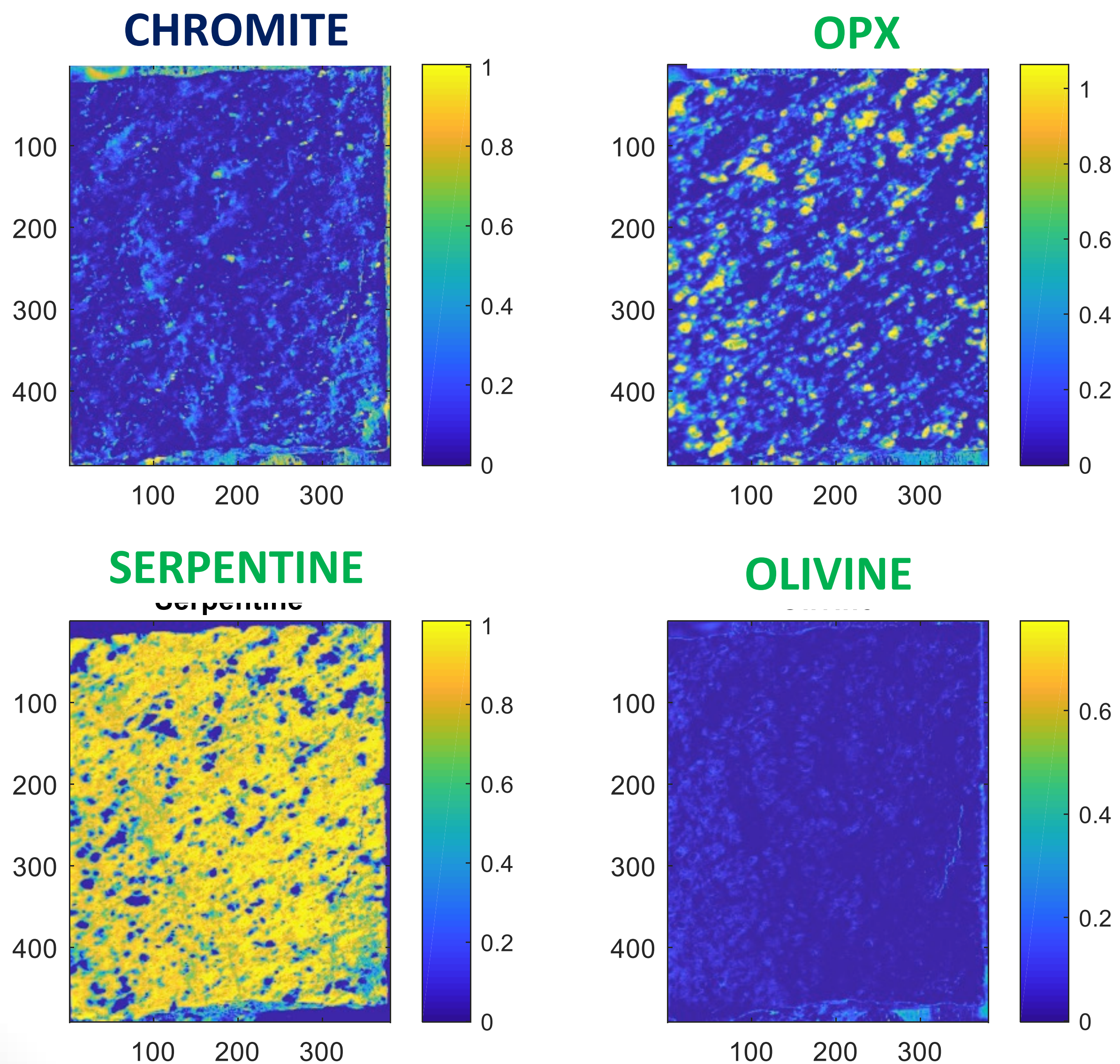
Hyperspectral unmixing

Proportion (abundance) of each mineral:

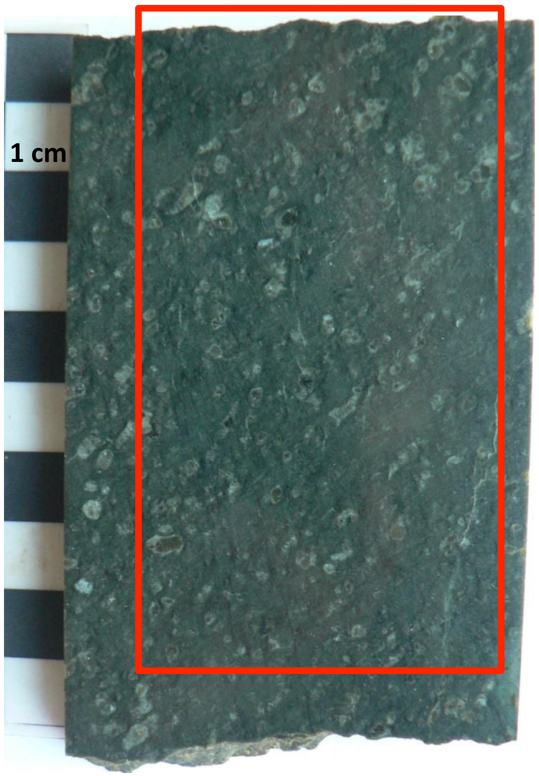


Computation time: 4 mins

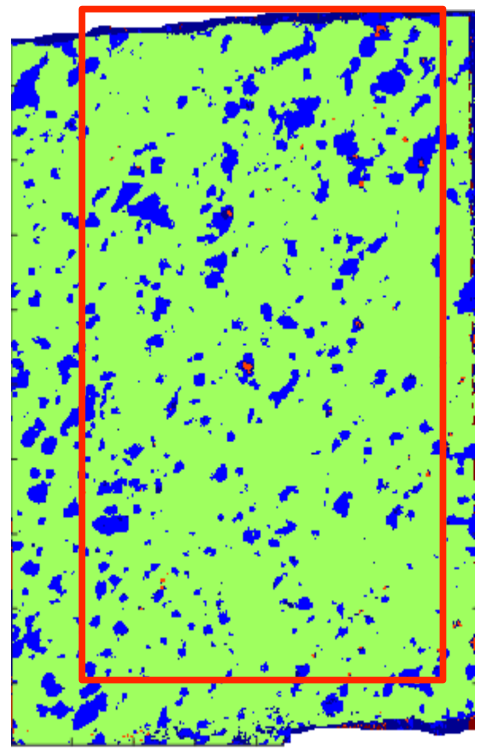
Hyperspectral unmixing

serpentinized harzburgite sample

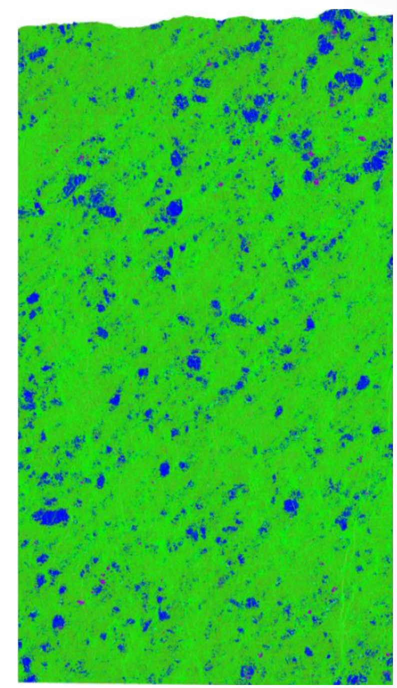
RGB image



Unmixing



QEMSCAN



Computation time: 4 mins

Conclusions and Perspectives

- Using our hyperspectral library, the CLSUnSAL provided the highest accuracy.
  - Need to improve the computation time.
  - Incorporate the spatial context to the unmixing problem
- The hyperspectral library is constantly extended
  - 257 spectra have been extracted for 49 minerals
- A graphic user interface is under development
- Machine learning classification approaches have been implemented.
- The connection between the databases will be done.

Thank you for your attention!