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3D imaging of heterogeneous surfaces on laterite drill core materials

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Contents

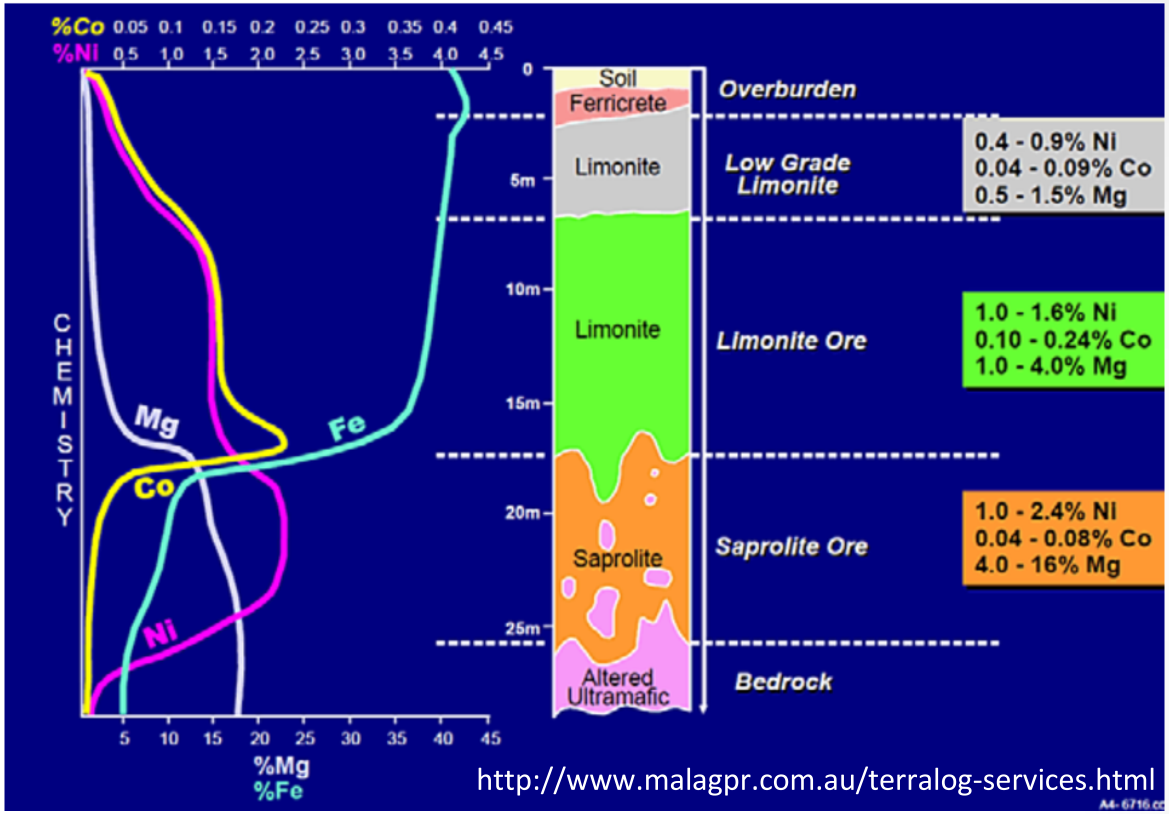
Nickel laterites

- Ni resources:
  - Sulfide ores
  - Ni laterites

- Ni laterites
  - Consitute 60 – 70% of the world's Ni resources
  - Reach 60% of total Ni production in 2014
  - Contribute 20 – 30% of the total Co supply.

Butt *et al.*, 2013

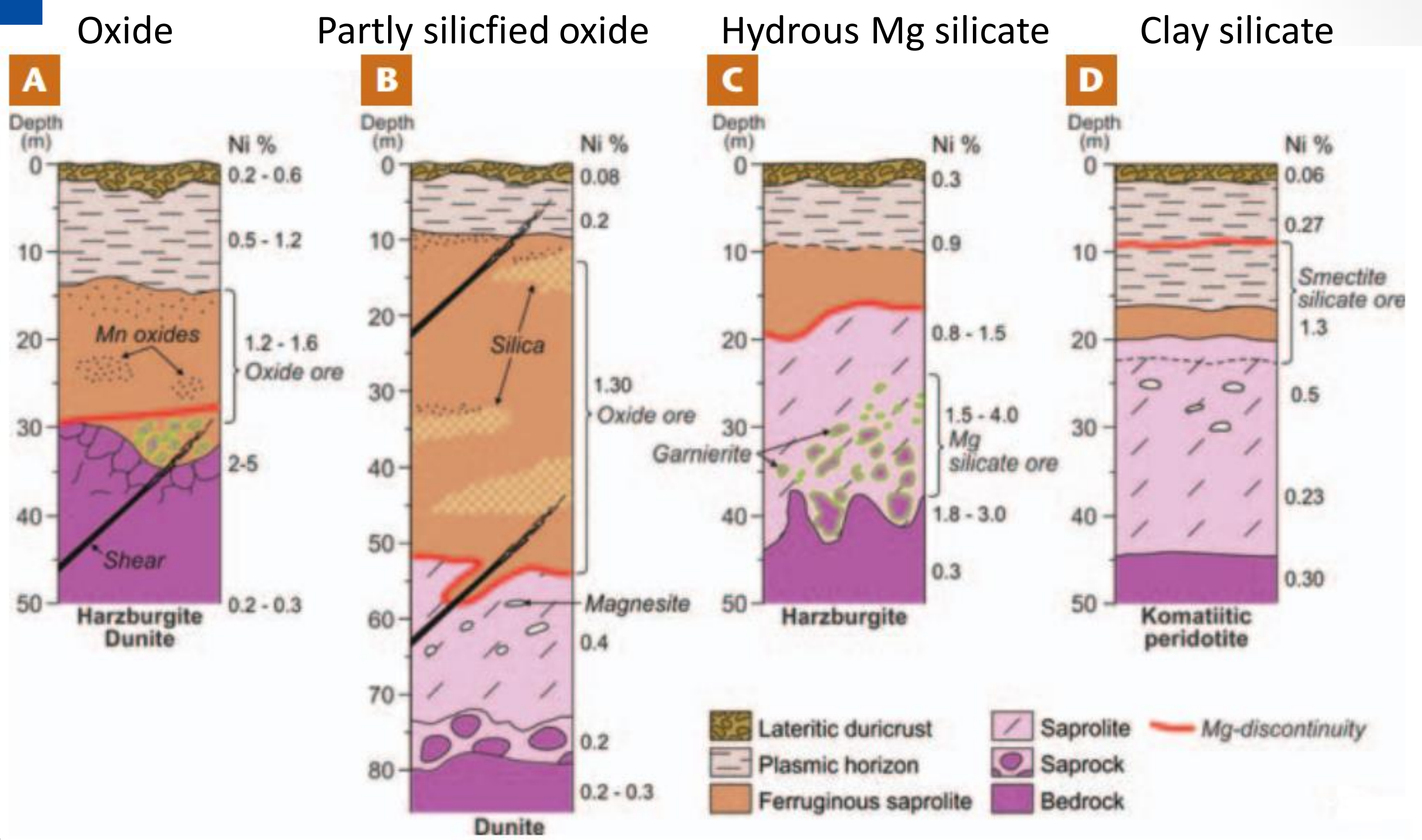
Average chemical variations on the laterite profile:



- Three nickel laterite ore types, based on the dominant minerals hosting Ni:

Ores	Mean grades of Ni	Principle ore minerals	% of total Ni laterite resources	Position in lateritic profiles
Oxide	1.0 – 1.6 wt%	Goethite, absolane, lithiophorite	60%	Mid to upper saprolite and upwards to the plasmic zone
Hydrous Mg silicate	1.44 wt%	Serpentine, talc, chlorite, sepiolite	32%	Mid to lower saprolite
Clay silicate	1.0 – 1.5 wt%	Smectite, saponite	8%	Mid to upper saprolite

Lateritic profiles



Butt *et al.*, 2013

OXIDE ORE

Goethite	Oxide	α-(Fe^{3+})O(OH)	2% Ni, 0.2% Co
Asbolane	Oxide	$(Ni^{2+},Co^{3+})_xMn^{4+}(O,OH)_4 \cdot nH_2O$	16% Ni, >4% Co
Lithiophorite	Oxide	$(Al,Li)Mn^{4+}O_2(OH)_2$	1% Ni, ~7% Co

CLAY SILICATE ORE

Nontronite	Smectite	$Na_{0.3}Fe_2^{3+}(Si,Al)_4O_{10}(OH)_2 \cdot nH_2O$	~4% Ni
Saponite	Smectite	$(Ca/2,Na)_{0.3}(Mg,Fe^{2+})_3(Si,Al)_4O_{10}(OH_2) \cdot 4H_2O$	~3% Ni

HYDROUS MG SILICATE ORE

Ni lizardite - népouite	Serpentine	$(Mg,Ni)_3Si_2O_5(OH)_4$	6–33% Ni
7Å garnierite	Serpentine	Variable, poorly defined	15% Ni
Nimite	Chlorite	$(Ni_5Al)(Si_3Al)O_{10}(OH)_8$	17% Ni
14Å garnierite	Chlorite	Variable, poorly defined	3% Ni
Falcondoite	Sepiolite	$(Ni,Mg)_4Si_6O_{15}(OH)_2 \cdot 6H_2O$	24% Ni
Kerolite-willemseite	Talc	$(Ni,Mg)_3Si_4O_{10}(OH)_2$	16–27% Ni
10Å garnierite	Talc	Variable, poorly defined	20% Ni

Observations on drill cores

Observations on drill cores

To develop an imaging system of drill cores

- Need to take into account the following features/information:
  - Depth, drilling speed
  - Textures:
    - RGB camera, profilometer
  - Roughness
    - Profilometer
  - Hardness, porosity:
    - Drilling system, hyperspectral cameras, RGB camera(?)
  - Principal ore minerals:
    - Hyperspectral imaging: diagnostic absorption features,
  - Ni content:
    - Portable XRF

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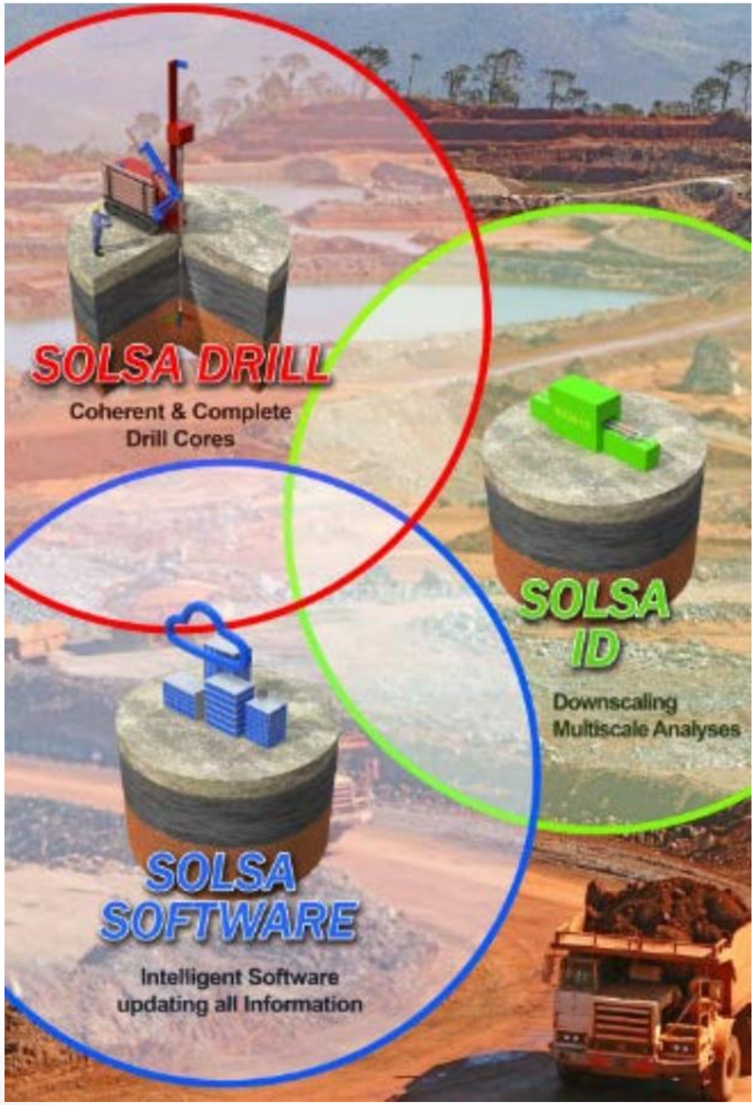


SOLSA ID 1
Analyse & Identification in **laboratory conditions**
->Test configurations to be used for ID 2

↓

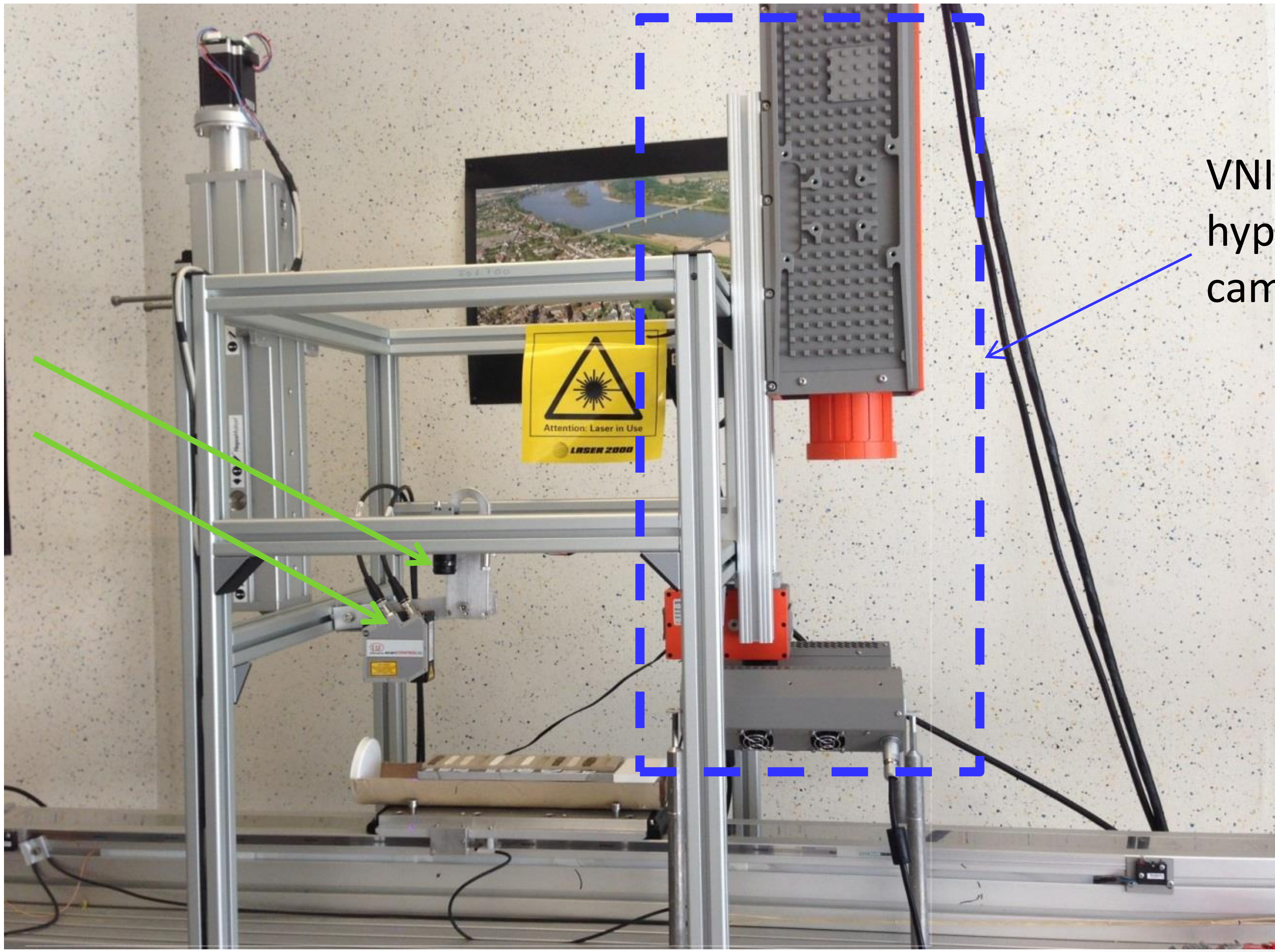
SOLSA ID 2
Analyse & Identification in
field and industrial applications

SOLSA ID 2A, measurement	Profilometer, RGB camera, VNIR/SWIR cameras, pXRF
SOLSA ID 2A, processing	Localisation of ROIs on drill cores
SOLSA ID 2B, measurement	XRD – XRF – Raman – (DRIFT) on ROIs
SOLSA ID 2B, processing	Data processing

ID2A scanning prototype

Goal: to built a system for scanning drill cores by imaging. Two results are expected:

- to know the outer shape of the core, in order to help for automatic positionning of the analytical system.
- to identify regions of interest on the surface of the core



RGB camera

Profilometer

VNIR, SWIR hyperspectral cameras

Work in progress

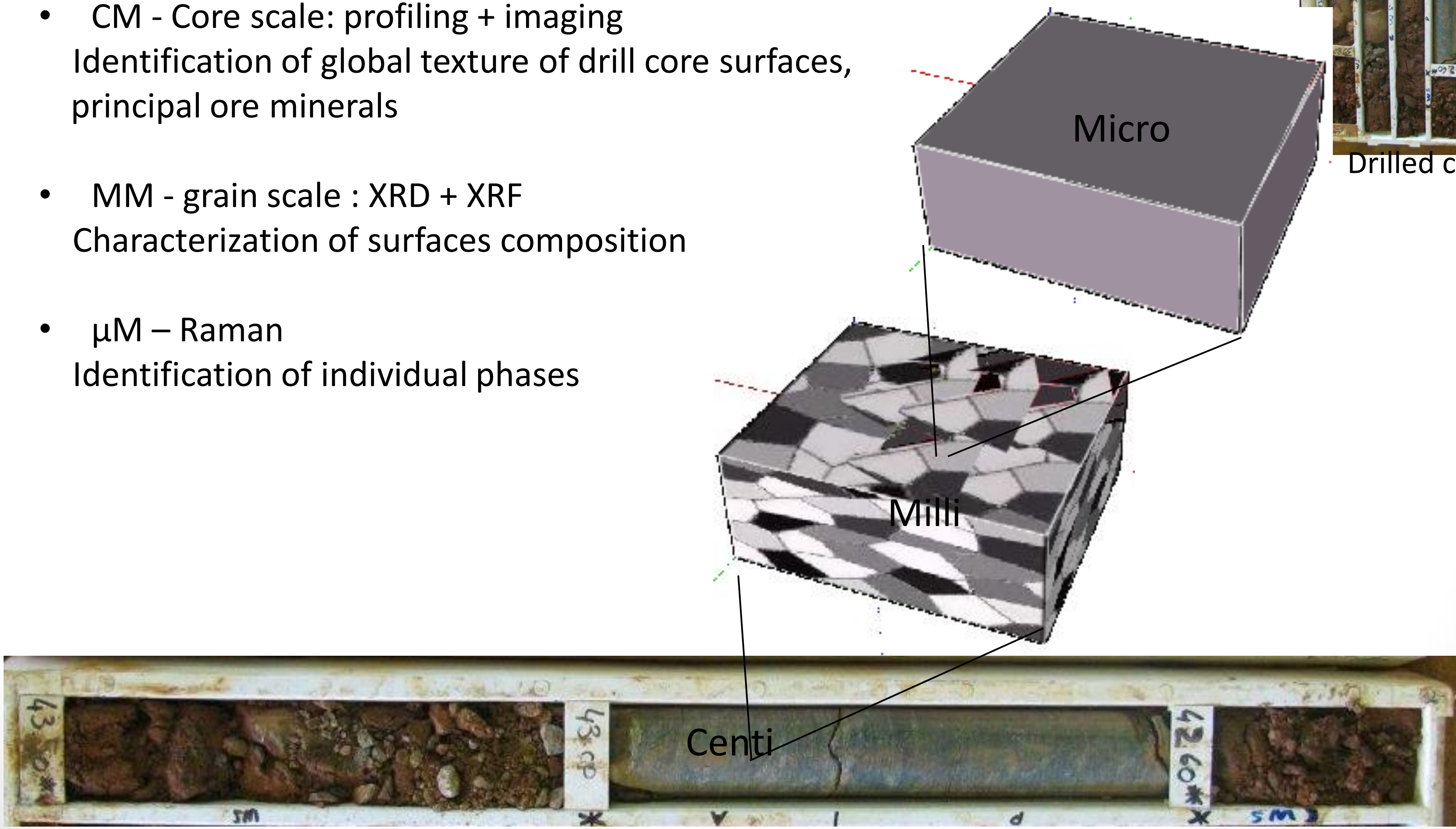
- Hyperspectral imaging: to identify the principal ore minerals, (crystallinity)
  - Building spectral library: collection of spectra of pure minerals (endmembers)
  - Spectral classification: to classify different minerals using their spectra
    - A classification method based on Support Vector Machines has been developed.
  - Spectral unmixing: to infer pure spectral signatures (endmembers) and their corresponding proportions (abundances)
    - A method of sparse unmixing based on a spectral library has been developed.
- Profile data (profilometer) and RGB images:
  - To quantify the roughness of the surface
  - To obtain the structure of grains and texture information of the drill cores
  - To support hyperspectral interpretation and pXRF analysis

Multi-scale strategy

For a better understanding, correlations should be done at a multi-scale:

- CM - Core scale: profiling + imaging
  Identification of global texture of drill core surfaces, principal ore minerals
- MM - grain scale : XRD + XRF
  Characterization of surfaces composition
- µM – Raman
  Identification of individual phases

Drilled core box

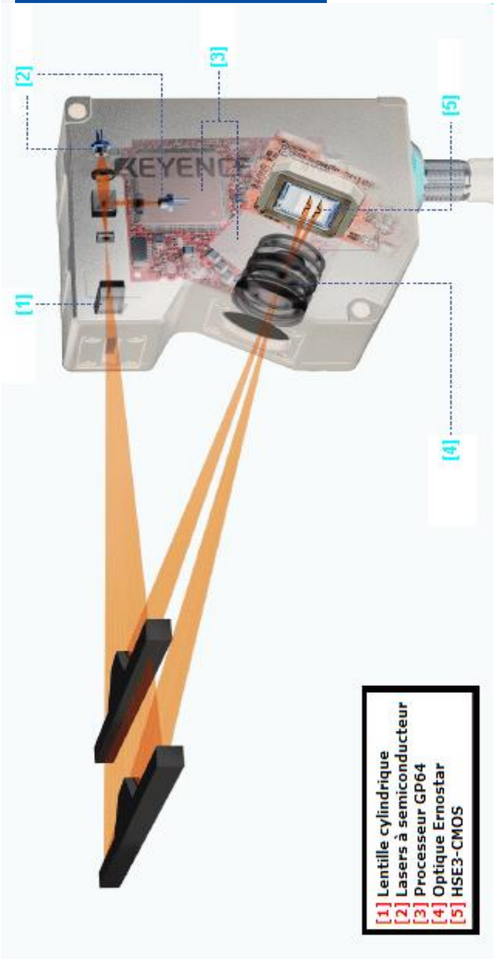


Methodology to rely on multiscaling probing/mineralogy/Ni content/depth

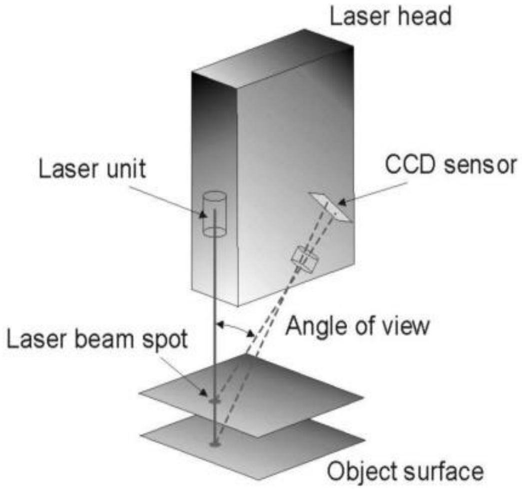
This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 689868

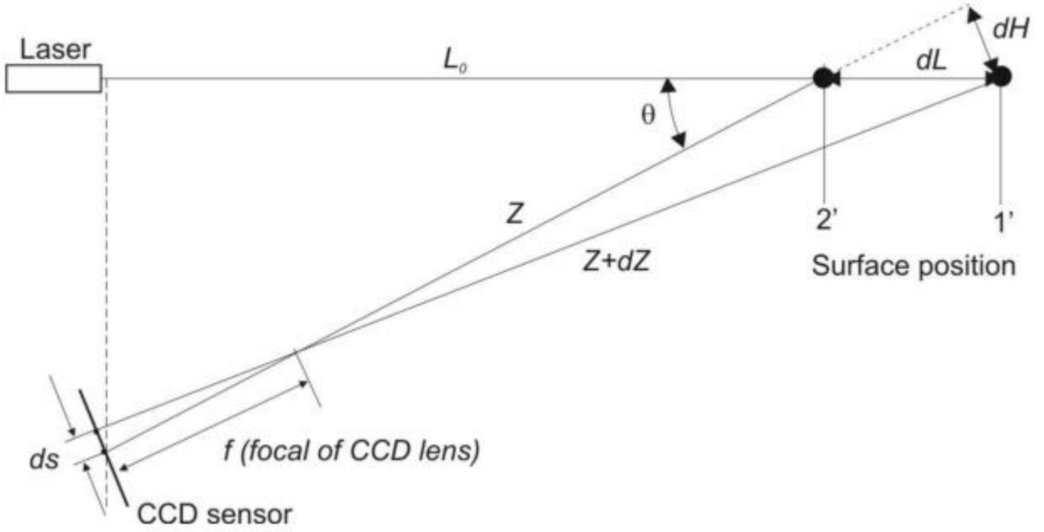
Contents

Triangulation profilometer principle

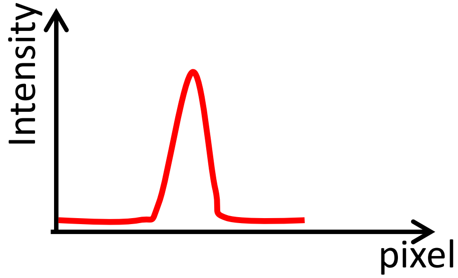


Non-contact laser triangulation





When the laser beam illuminates the surface of an object, the illuminated point is projected, towards the focal depth of the camera, onto the image CCD sensor.



The position of the laser spot on the CCD sensor is related to the position of the laser splot on the object surface. The measurement sensitivity:

$$\frac{ds}{dZ} = \frac{f}{Z}\sin\theta$$

ne European Union's Horizon 2020
grant agreement No 689868

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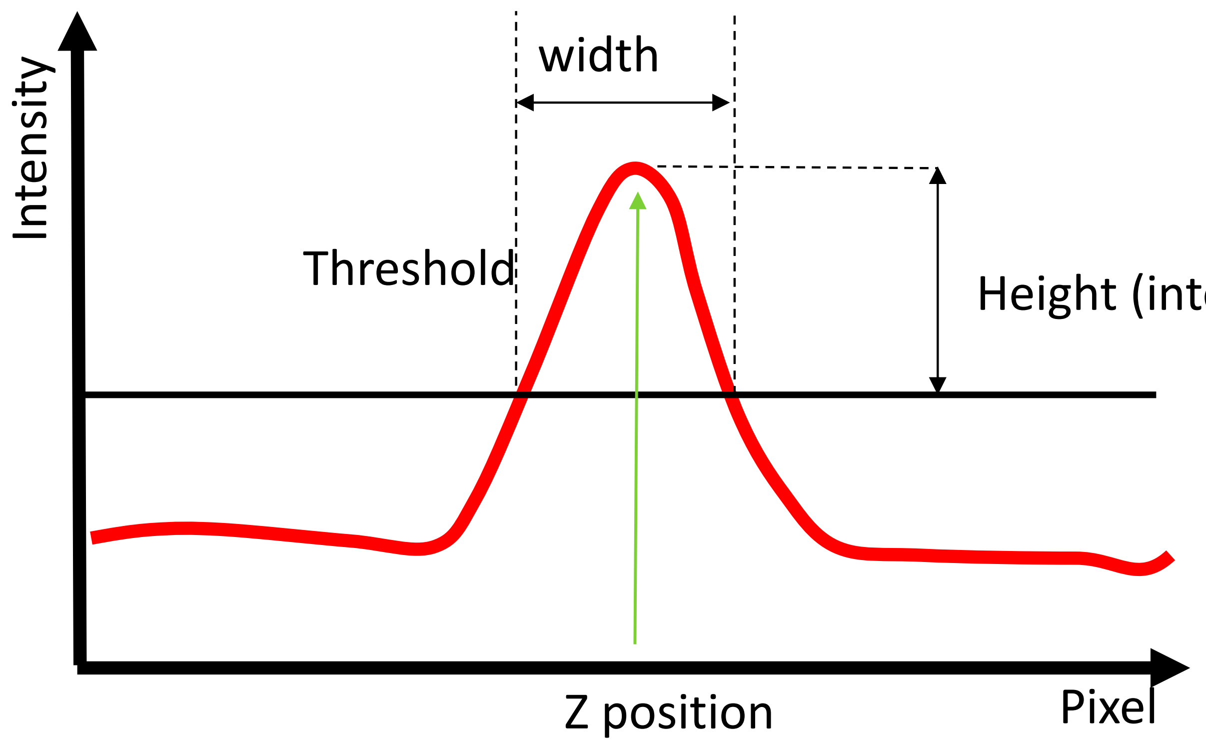
Description of the reflected signal

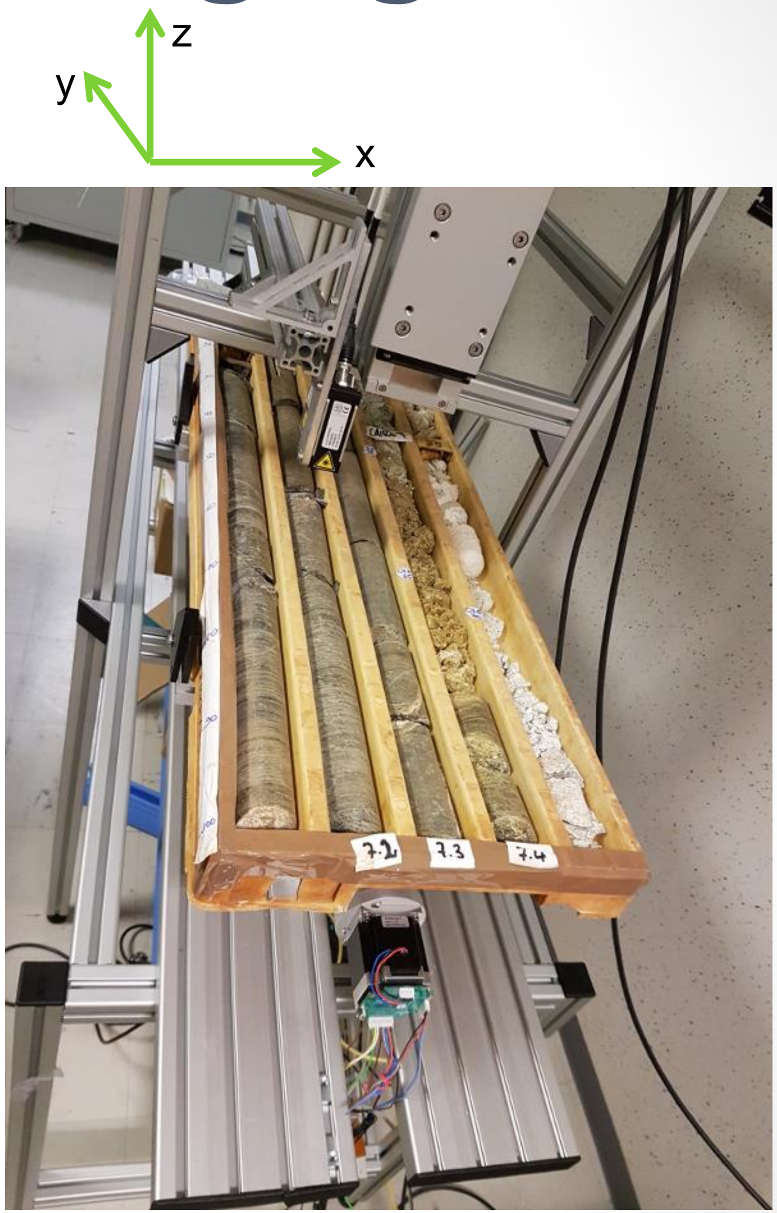
- **Threshold:** Actual threshold
- **Height (intensity):** Maximum intensity of the reflection above the threshold
- **Position:** the position (in pixel) corresponds to the pixel row on the CMOS sensor with maximum intensity. This is indicative of the surface profile.
- **Width:** The width of reflection in pixel. This value is indicative of the signal diffusion.



Conveyor and imaging

Imaging part is composed of:

- Conveyor (along y-axis)
- Profilometer (x, y, z, Intensity, width)
  - Need to movement of conveyor to reconstruct the surface profile
- RGB camera: (x, y, RGB)
  - No z information



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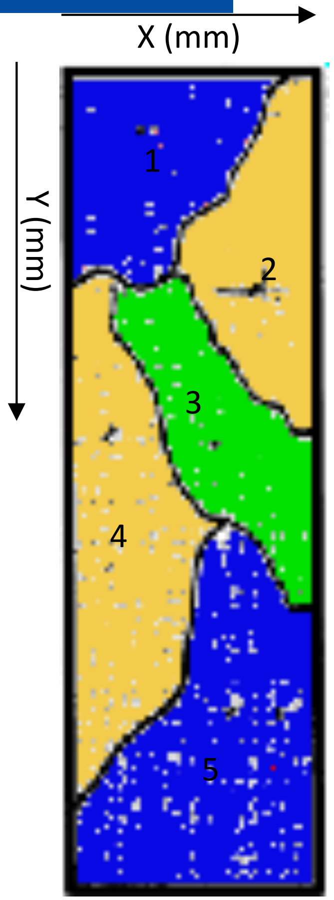
Scheme of profiling processing



Drilled core

Manual Core positionning on Y-axis → **Core auto positionning on Y-axis** → **Core preparation (drying, cleaning …)** → **Profiling acquisition** → **Profile reconstruction** → **Data processing** →

Results:
- Set of surfaces/volume
- Identification of ROI family
- Morphology information

→ **Action**

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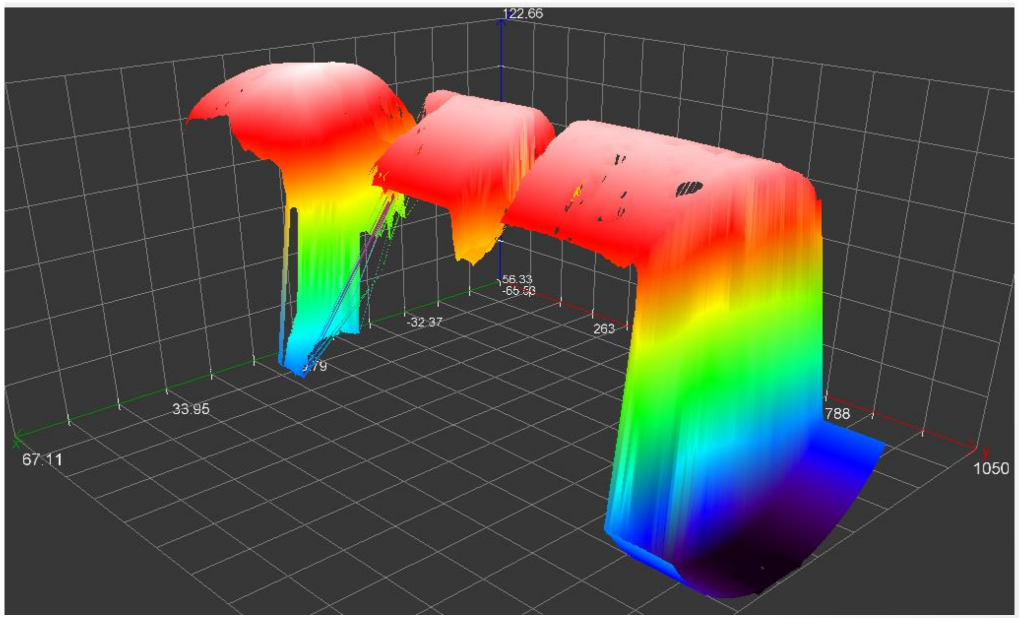
Contents

Example: cylindrical surface of breccia

70 mm

Sample « breccia » series 2

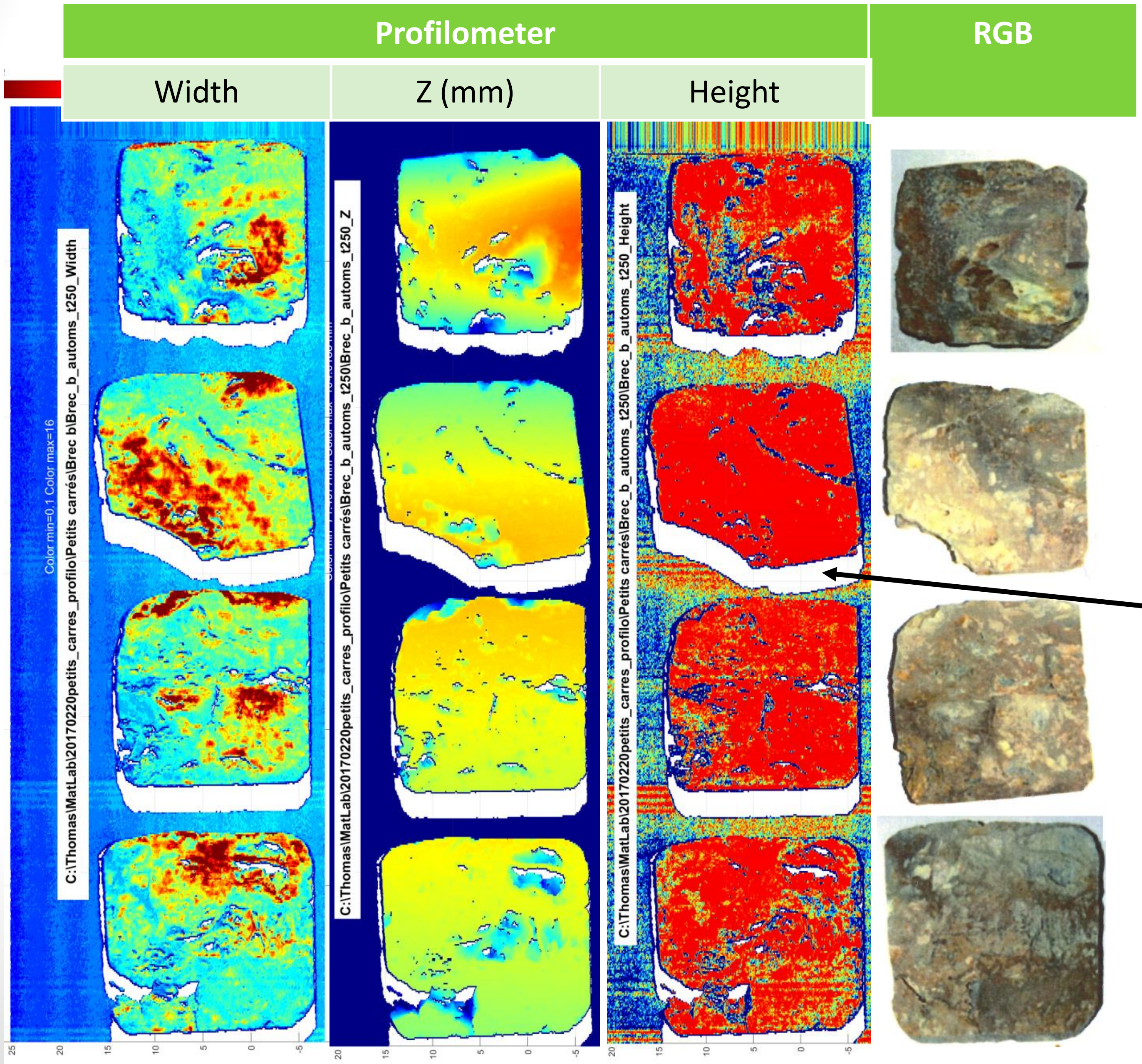


Sample « breccia » XYZ profile

<u>Performing</u>:
- Real surface reconstruction

-Analysis of defects (cracks and porosity)

Example: surfaces effect on breccia



- Z and Height: no effect on mineralogy
- Width: effect on mineralogy

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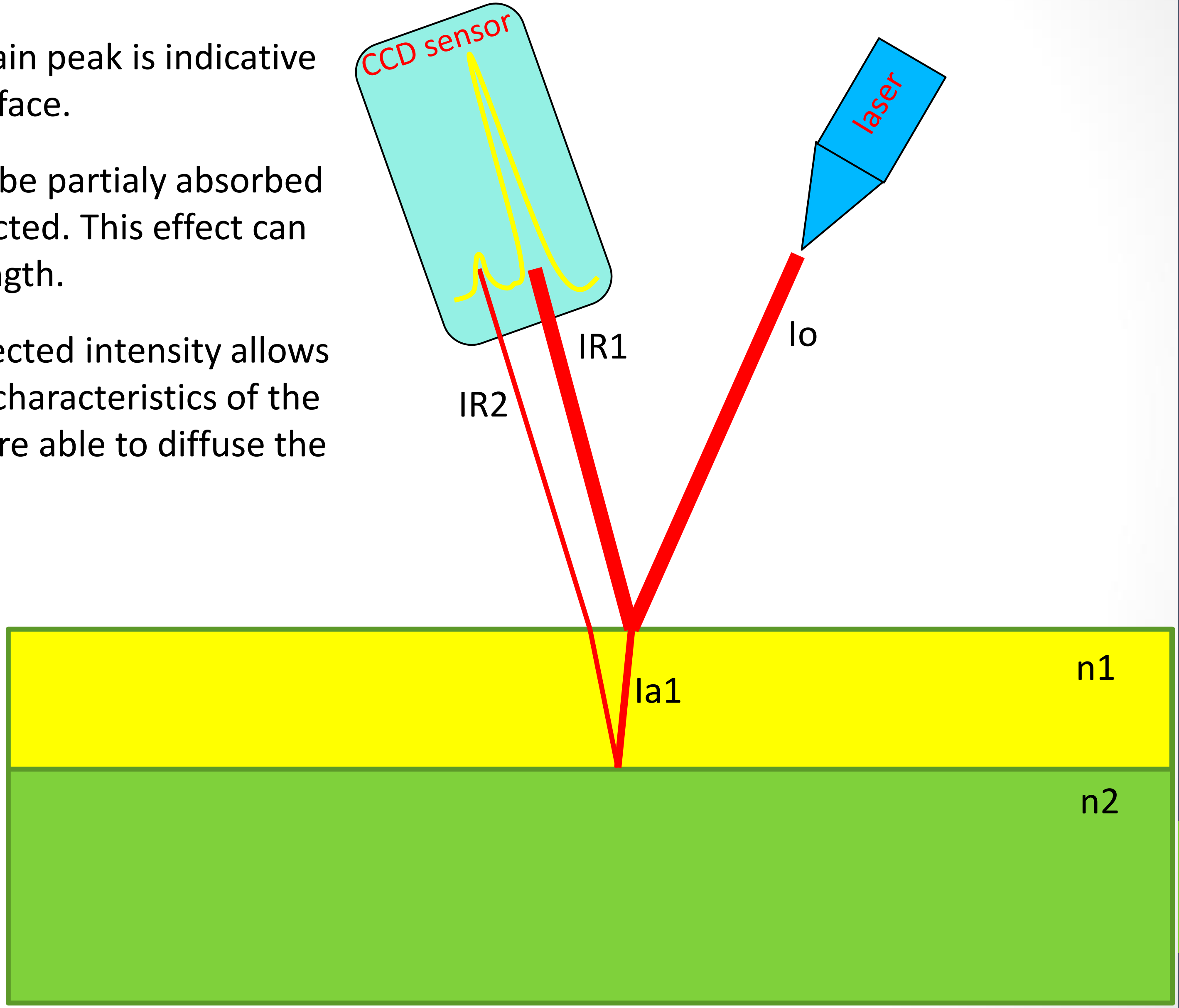
Profiling principle: interaction light/matter

- The deviation of the main peak is indicative of the height of the surface.
- The incident beam can be partialy absorbed by the surface, or refracted. This effect can depend on the wavelength.
- The analysis of the reflected intensity allows to quantify the optical characteristics of the surface. All interfaces are able to diffuse the incoming light.



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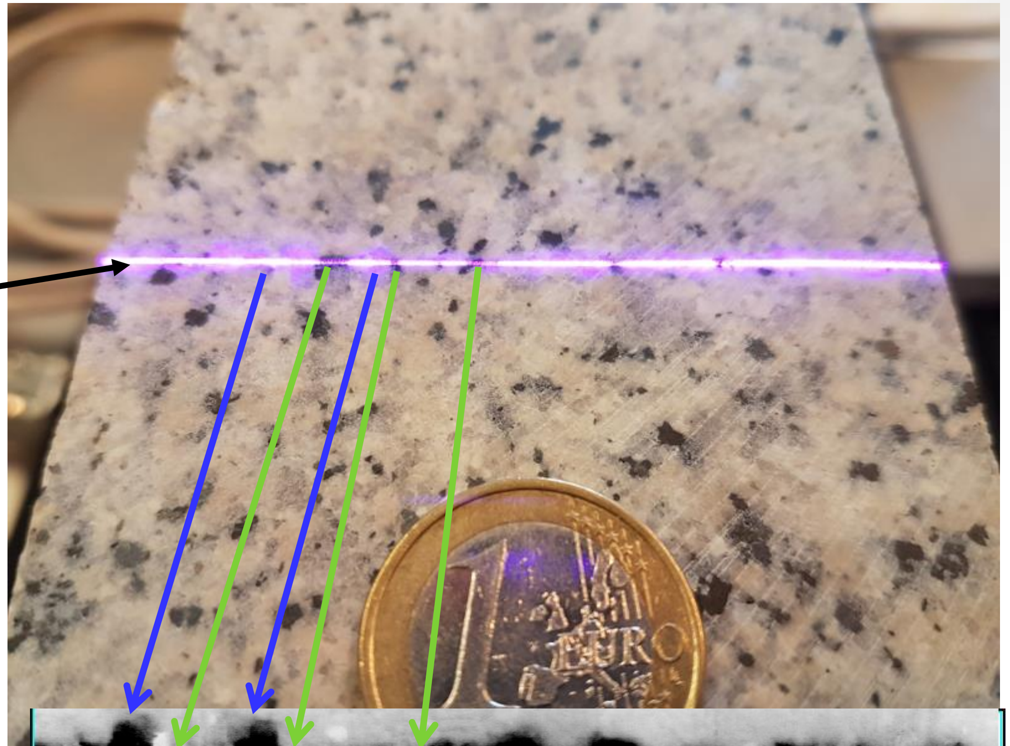
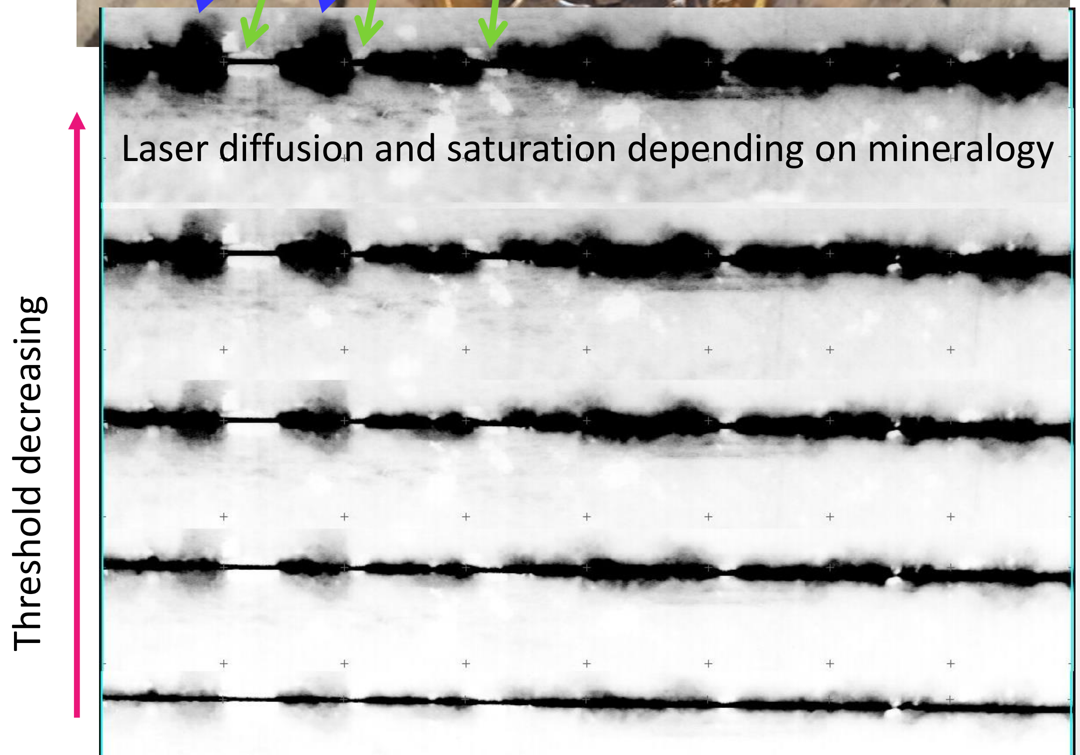
Example: flat surface of granite

Laser line (405nm) on a flat surface of a granite rock.

Granit is mainly composed by 2 transparent minerals (quartz and felspar) and highly reflected mineral (biotite, in black)

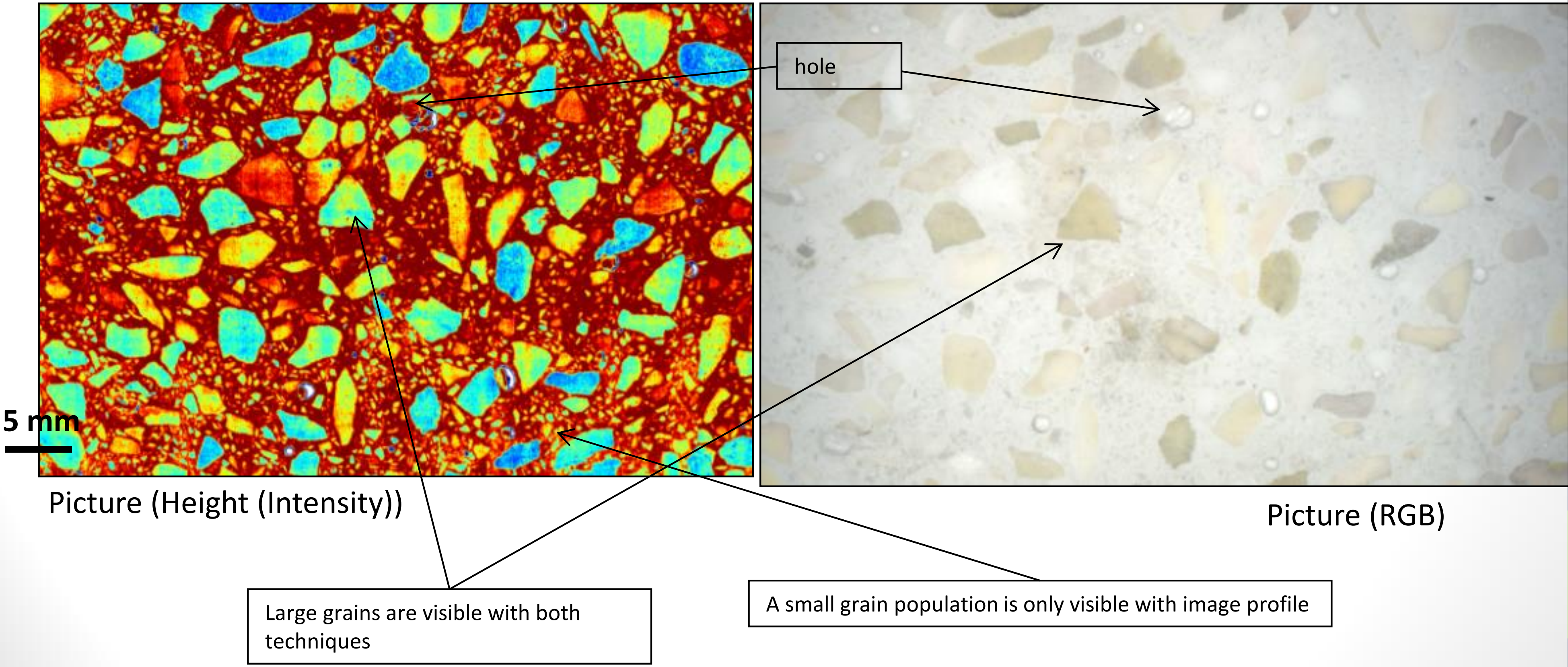
Compared to a simple lightening, the laser allows to enhance the optical properties of the mineral, and intensity quantification can be done.





Mapping grains

- Comparison between profilometry and RGB images on an heterogeneous sample.
- There are more information in the image profile intensity than in RGB image
  - 3 surface families:
    - Large grain
    - Small grain



Picture (Height (Intensity))

Picture (RGB)

Mapping grains

Observation : Picture (z) allows to identify clearly porosity and cracks

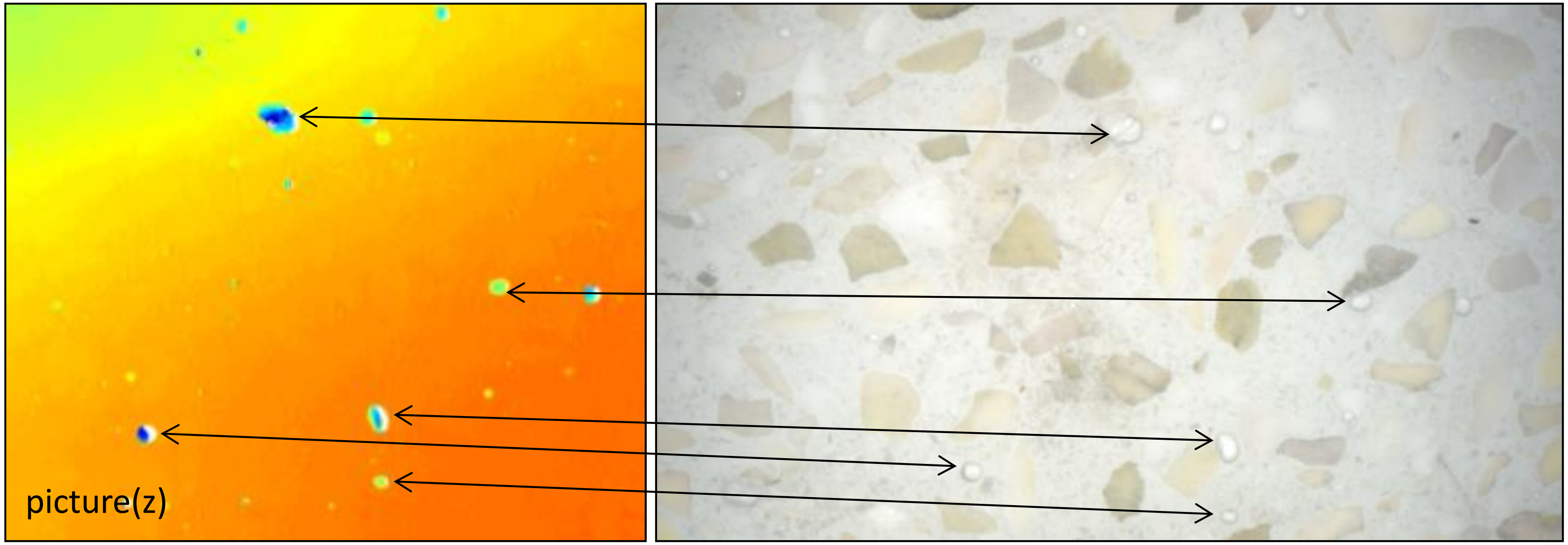
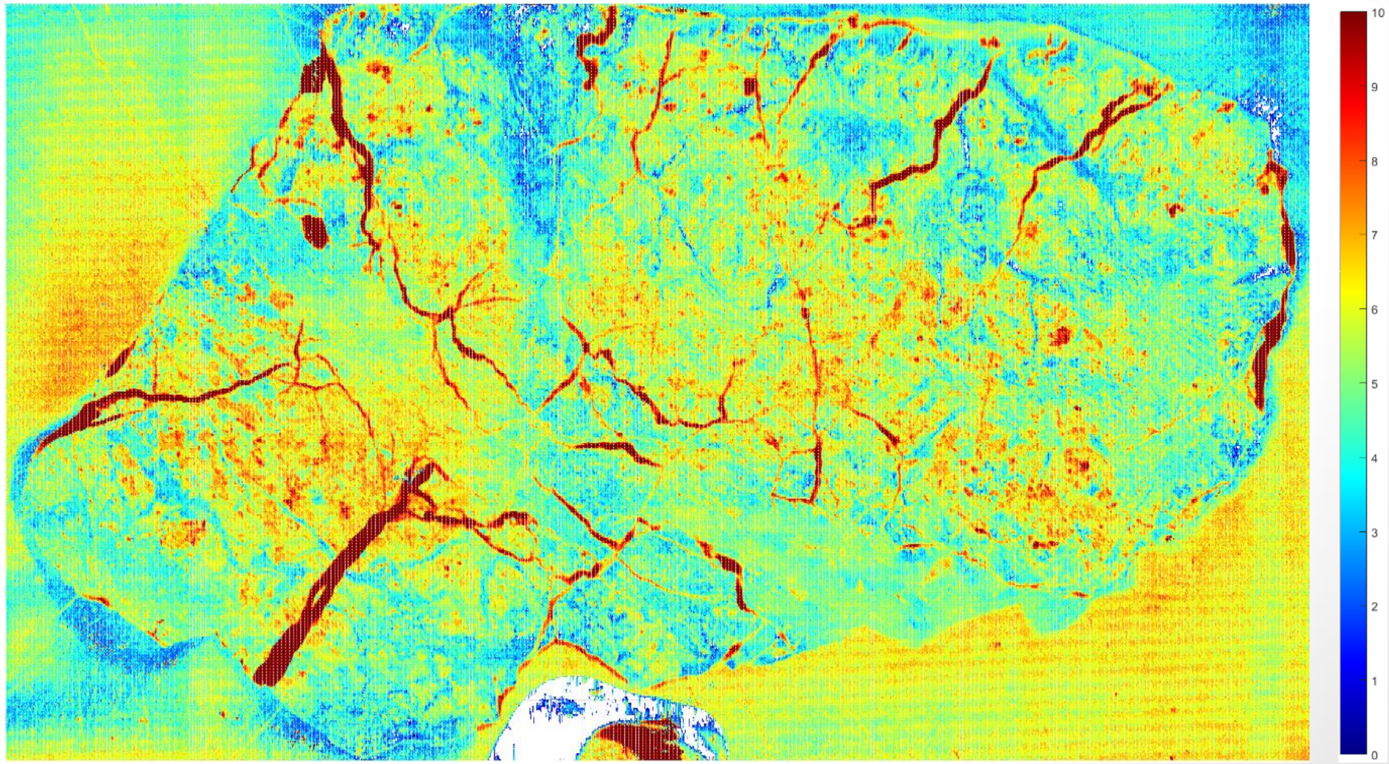


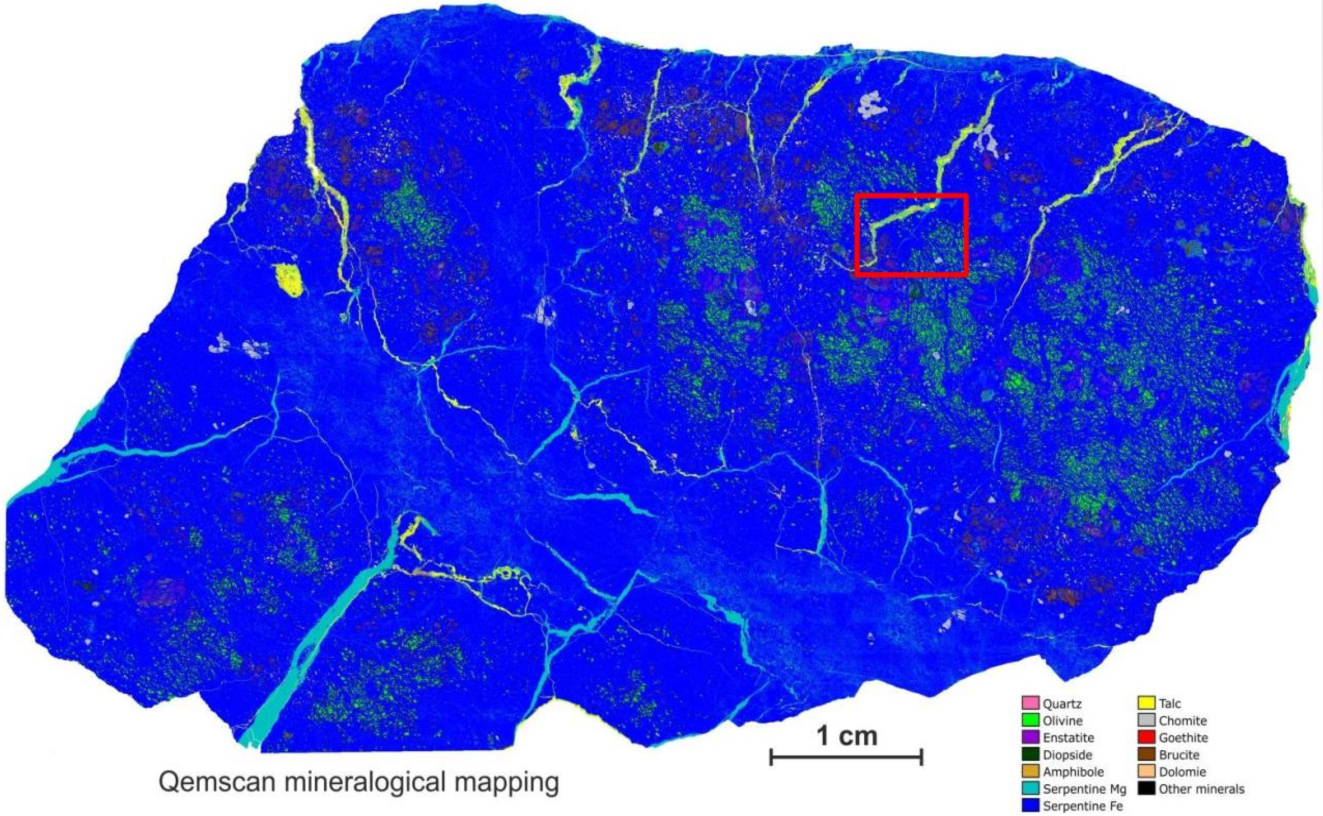
Image analysis of picture (z) will allows to measure roughness.

Serpentined sample (saprolite level on peridotite bed rock):

Width

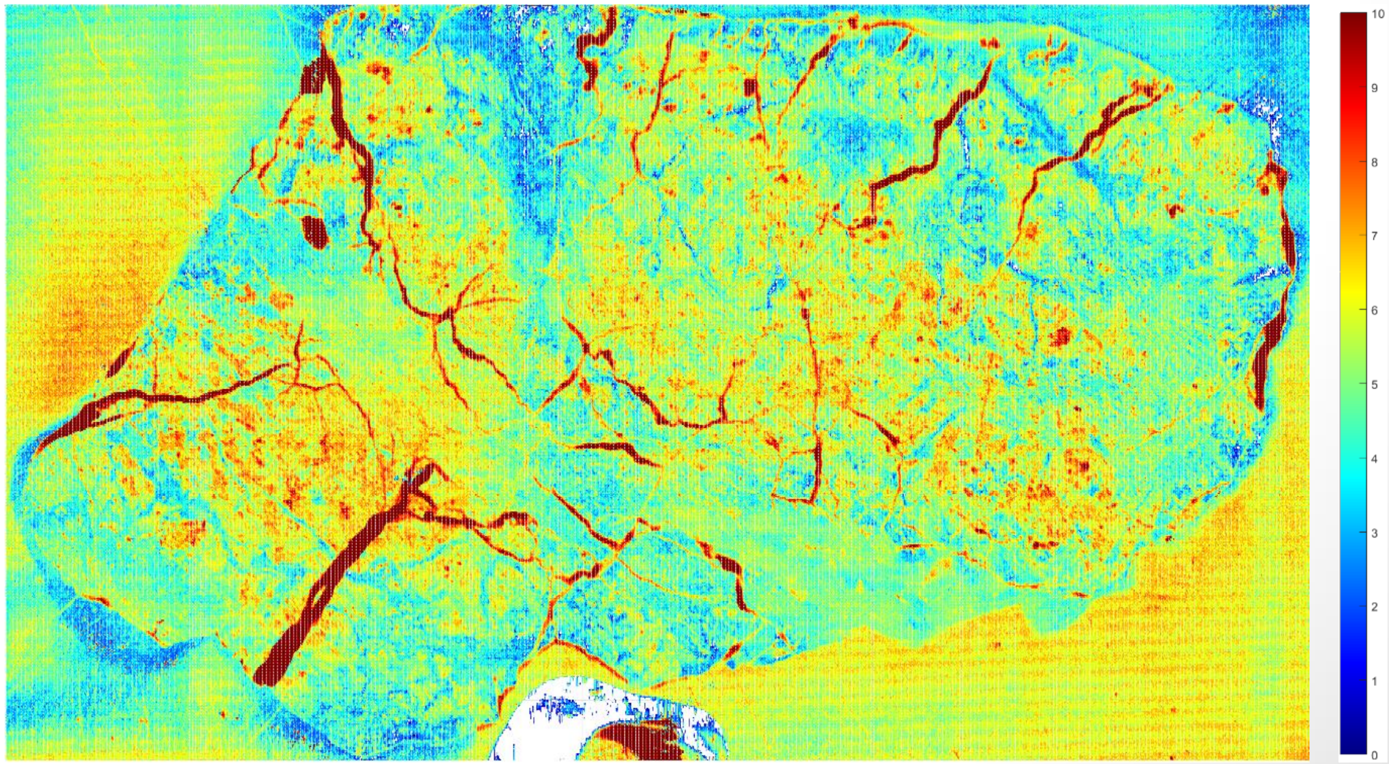


Serpentined sample (saprolite level on peridotite bed rock):



Qemscan mineralogical mapping

Width



Contents

- Introduction
- Laser triangulation profilometer
- Preliminary results
- Conclusions and perspectives

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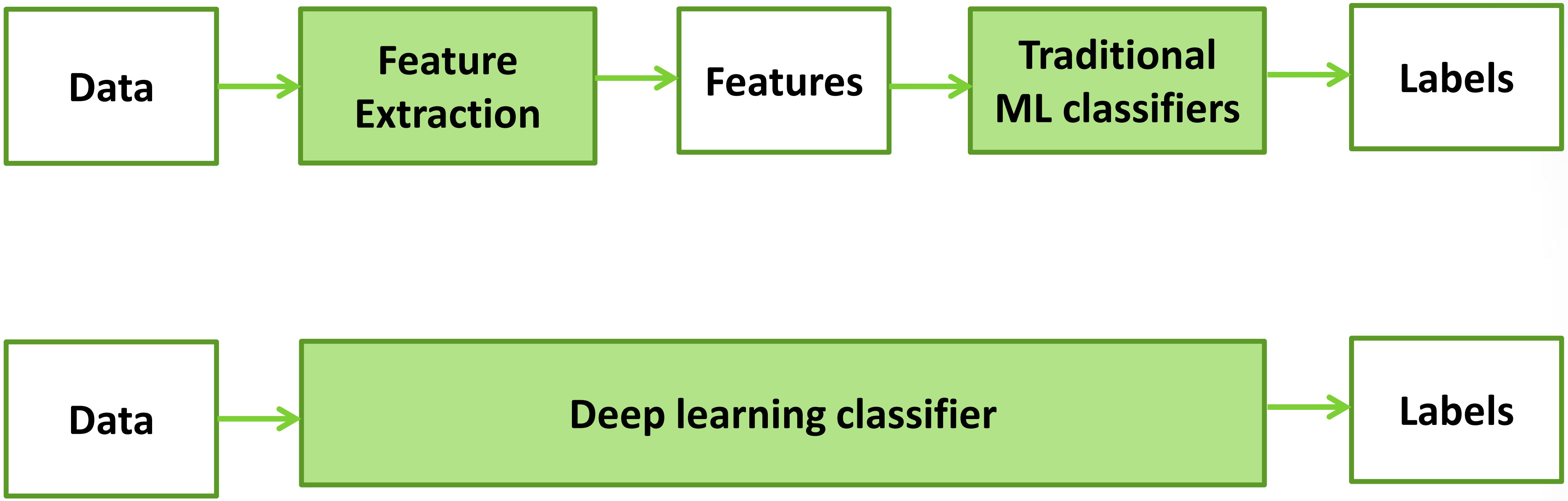
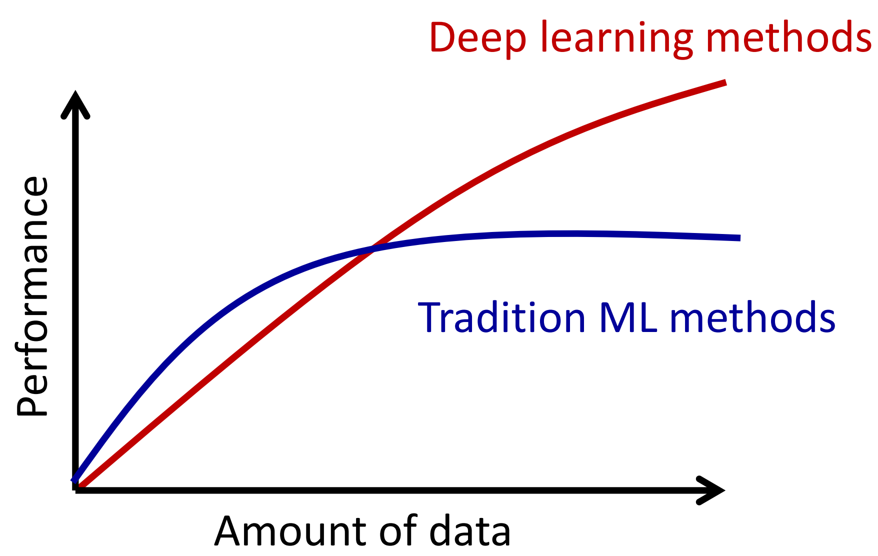
Conclusions and perspectives

- Profilometry imaging brings a volumetric dimension that cannot be done with classical RGB.
- Morphologic parameters can be quantified better than classical RGB.
- Mineralogical contour is improved.

- Data processing routines are under construction.
- Texture analysis will be done using RGB images
- Hyperspectral imaging (in progress):
  - Collecting endmembers (buidling hyperspectral library)
  - Evaluating hyperspectral classification and unmixing techniques on data acquired from harzburgite, dunite and bauxite samples

Conclusions and perspectives



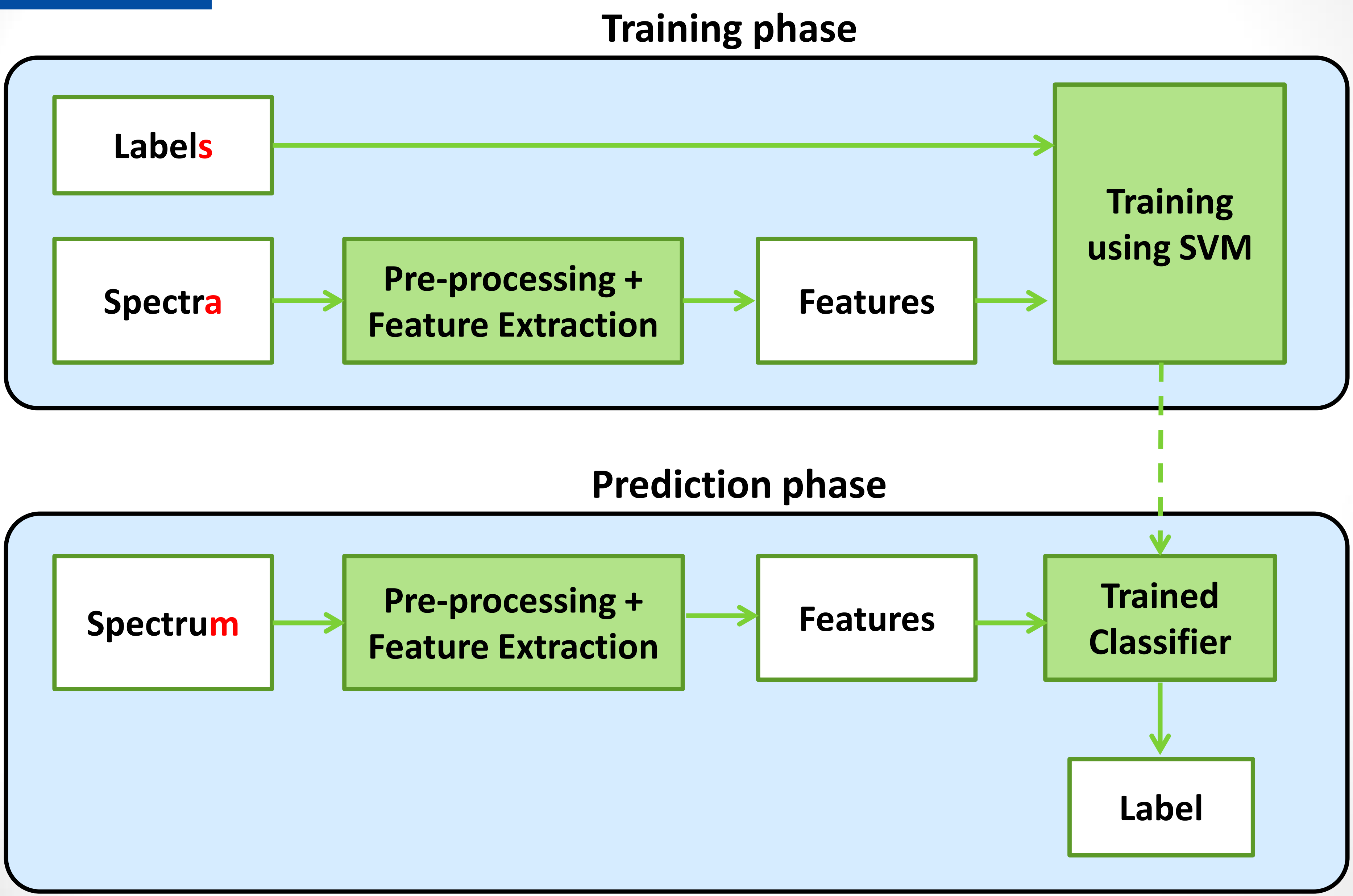


Thank you for your attention!

VNIR/SWIR camera parameters

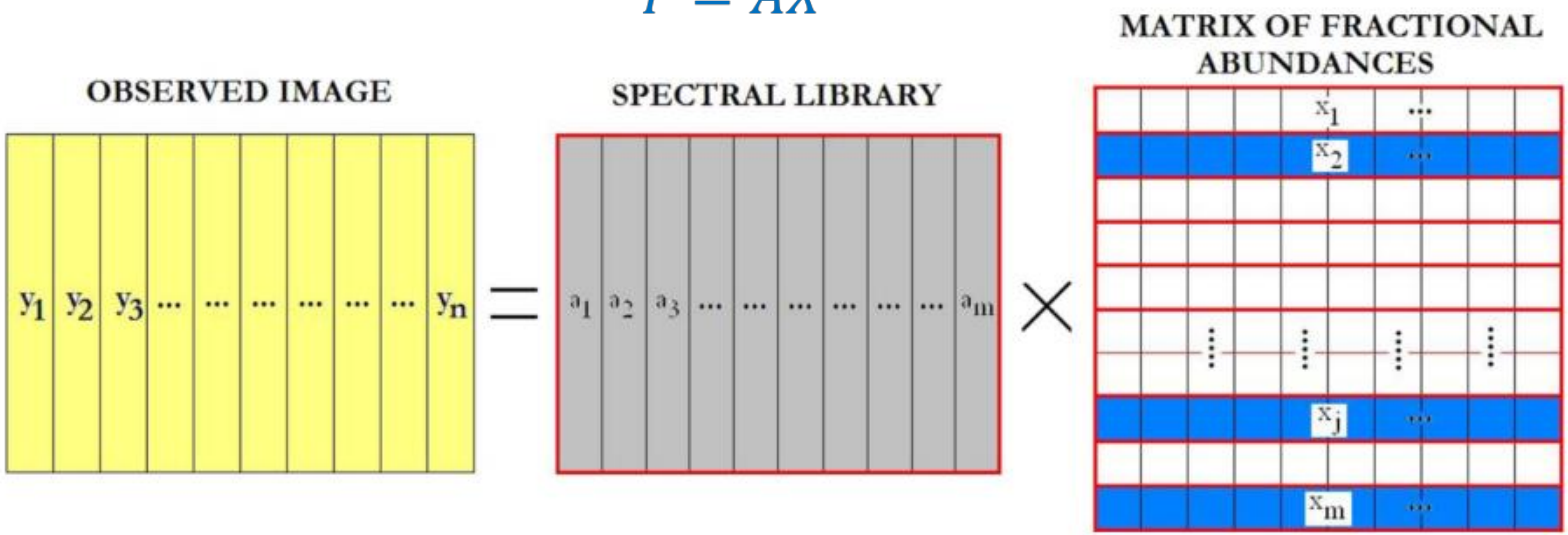
Parameters	FX10 VNIR	SWIR OLES30
Spectral range (nm)	400 - 1000	1000 - 2500
Spectral bands	224	288
Spectral FWHM (nm)	5.5	12
Spatial sampling	1024	384
Field of View (degree)	38	17
Maximum frame rate (fps)	330	450
Exposure time range (ms)	0.1 – 20	0.1 – 20
Aperture	1.7	2
Focal length (mm)	15	30
Measurement distance (m)	0.118	0.316
Field of View (mm)	81.26	94.45
Spatial resolution (um)	79.36	245.97
Depth of Field (mm)	1.91	9.64

Spectral classification



Sparse unmixing methods

$$Y = AX$$



Y L x n

A L x m

X m x n

$$\min_X \|AX - Y\|_F^2 + \lambda \|X\|_{2,1}$$

subject to: X≥ 0, **1**X = 1

Iordache *et al.*, IEEE Trans, 2014

Unmixing methods

X(m x n)

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

$$\min_X \|AX - Y\|_F^{\,2} + \lambda \|X\|_{2,1}$$

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

SUnSAL
(Sparse unmixing by variable splitting and augmented Lagrangian):

$$\min_X \|AX - Y\|_F^{\,2} + \lambda \|X\|_{1,1}$$

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

FCLS
(Fully contrained least squares):

$$\min_X \|AX - Y\|_F^{\,2}$$

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

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