HELMHOLTZ INSTITUTE FREIBERG
FOR **RESOURCE TECHNOLOGY**

EGU General Assembly

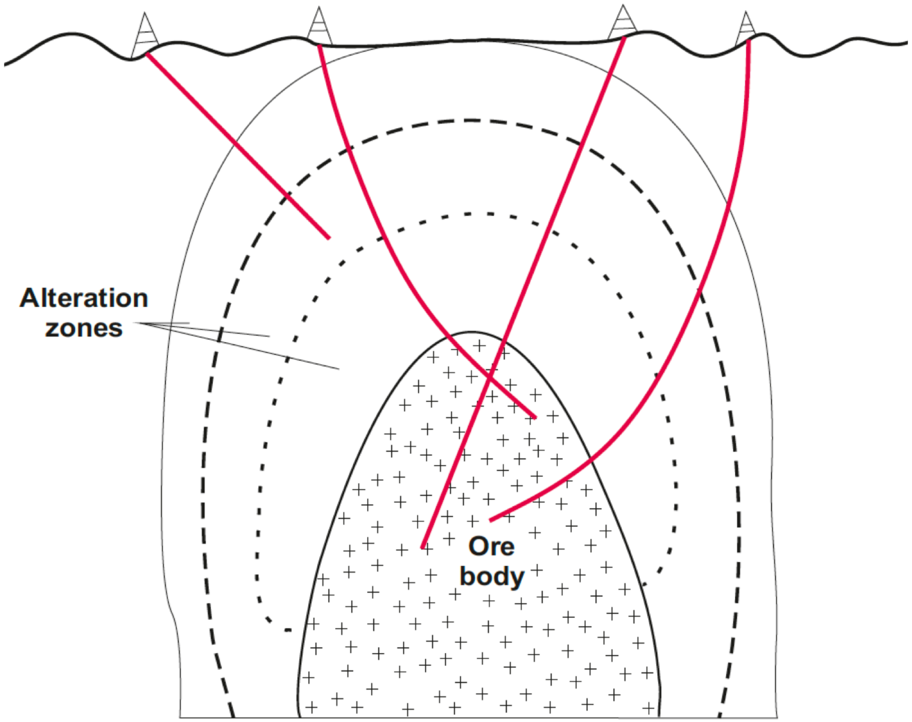
Fusion of VNIR-SWIR and LWIR hyperspectral data for mineral mapping in a machine learning framework

Cecilia Contreras, Mahdi Khodadadzadeh, Laura Tusa,
Sandra Lorenz and Richard Gloaguen

EGU. European Geoscience Union
Vienna | Austria | 9th April 2019

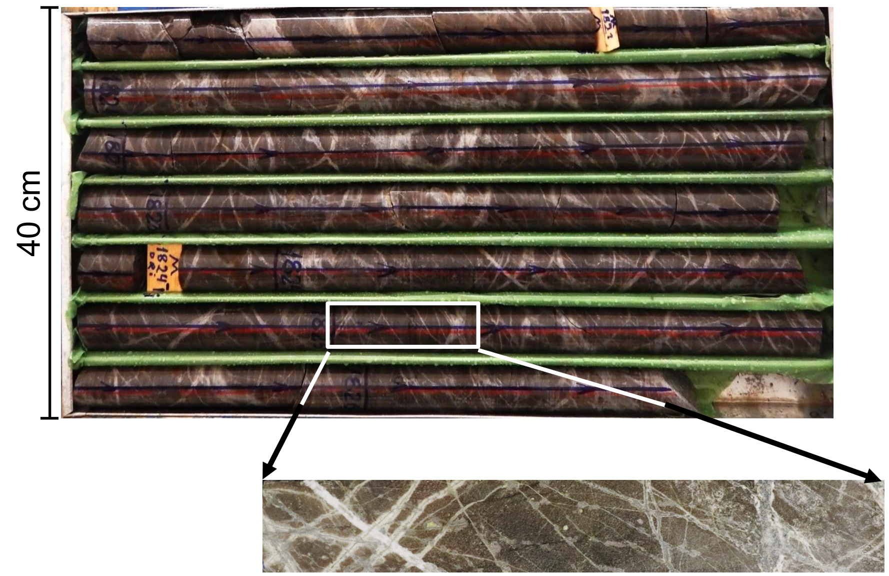
Motivation

Traditional approaches require core logging and geochemical measurements



Sketch of an alteration system showing drill holes in red

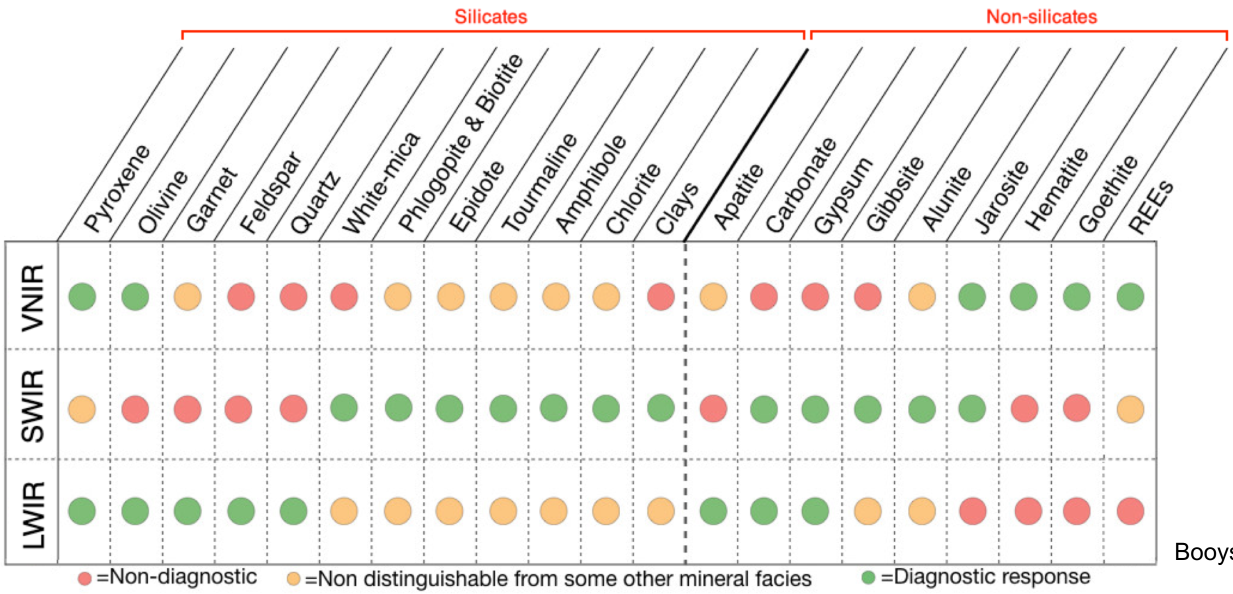
Drill core tray



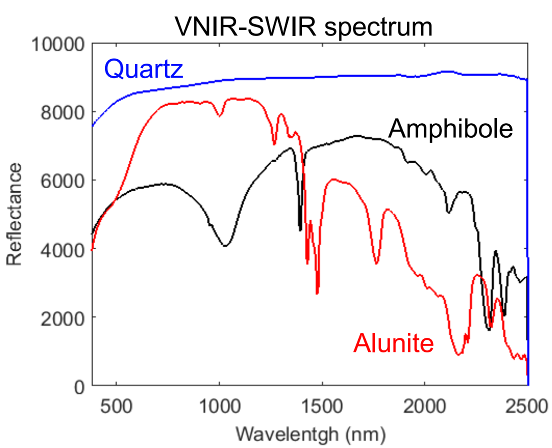
Cecilia Contreras
Helmholtz Institute Freiberg for Resource Technology

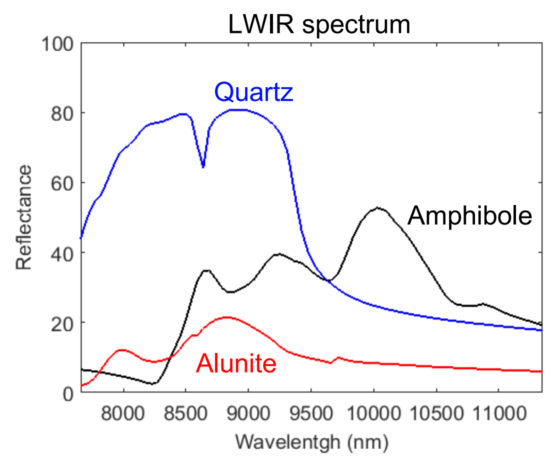
Motivation

- Hyperspectral data have a huge potential to rapidly acquire data
- Integrating VNIR-SWIR and LWIR data favours the identification of minerals



Booysen et al. 2019

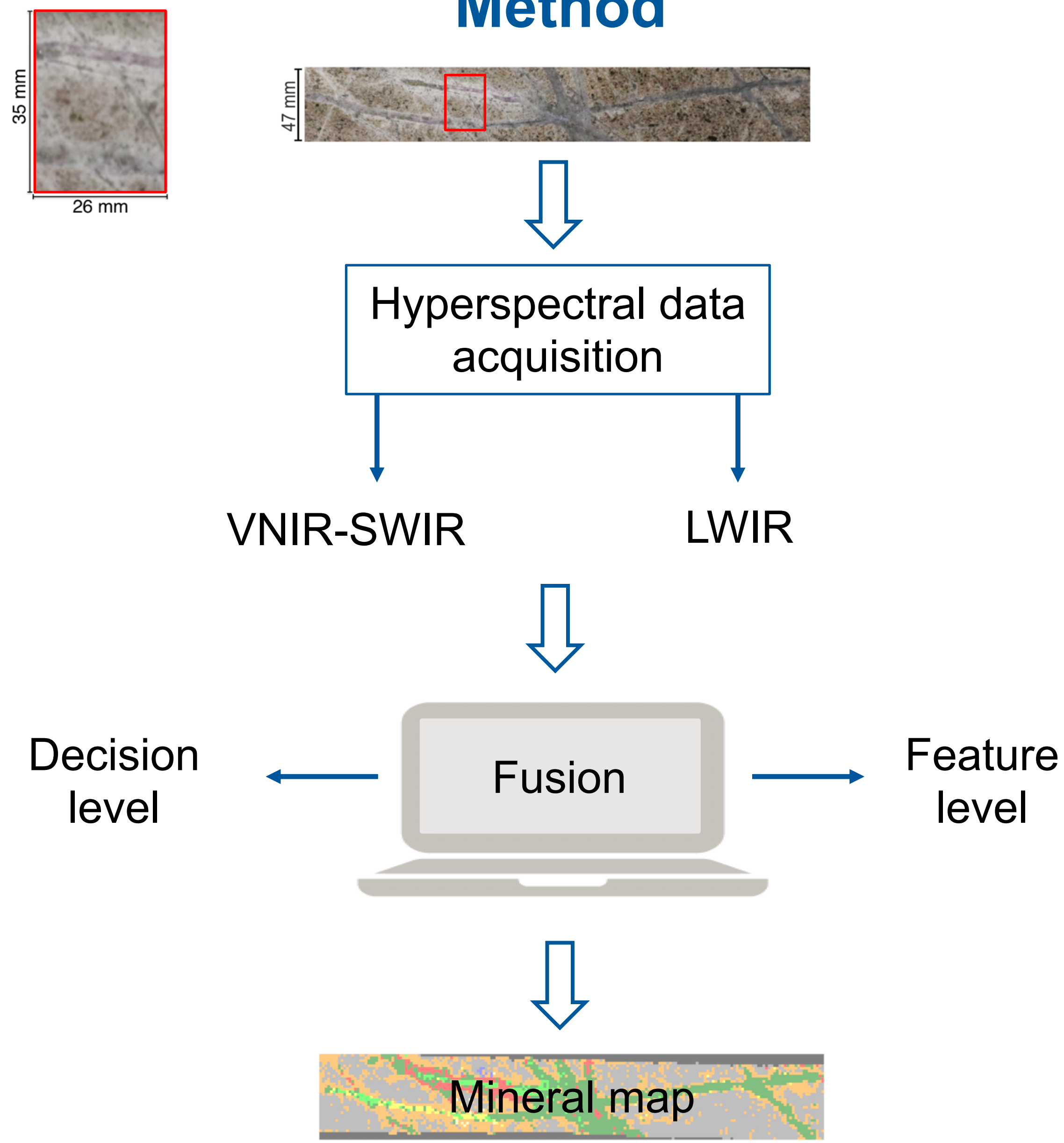




Spectra coming from the USGS and JPL spectral libraries

Cecilia Contreras
Helmholtz Institute Freiberg for Resource Technology

Method



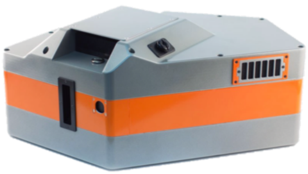
VNIR: Visible-near infrared | SWIR: Short-wave infrared | LWIR: Long-wave infrared

Cecilia Contreras
Helmholtz Institute Freiberg for Resource Technology

Data acquisition

VNIR-SWIR hyperspectral

SisuRock drillcore scanner



Specim AisaFENIX

- Spectral range: 380–2500 nm, 623 bands
- Spectral resolution: 3.5 nm VNIR, 12 nm SWIR
- Spatial resolution: 1.5mm/pixel

LWIR hyperspectral

Telops Hyper-Cam

- Spectral range: 7700–11800 nm, 90 bands
- Spectral resolution: 36-76 nm
- Spatial resolution: 0.60mm/pixel

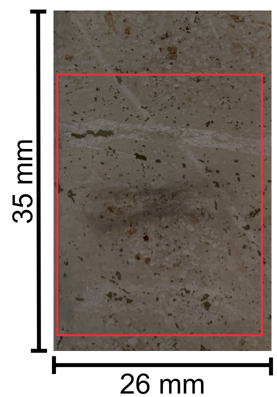
VNIR: Visible-near infrared | SWIR: Short-wave infrared | LWIR: Long-wave infrared

Cecilia Contreras
Helmholtz Institute Freiberg for Resource Technology

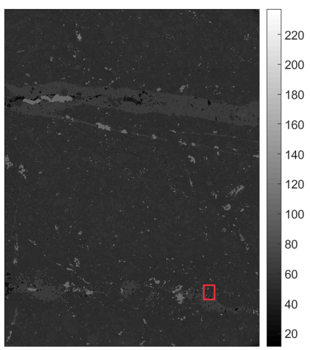
Data acquisition

High resolution mineralogical data – Validation dataset

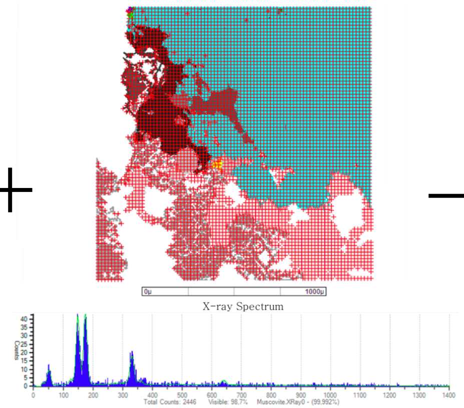
RGB of drill core sample



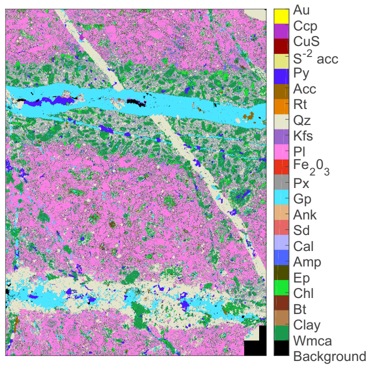
Thin section



BSE image



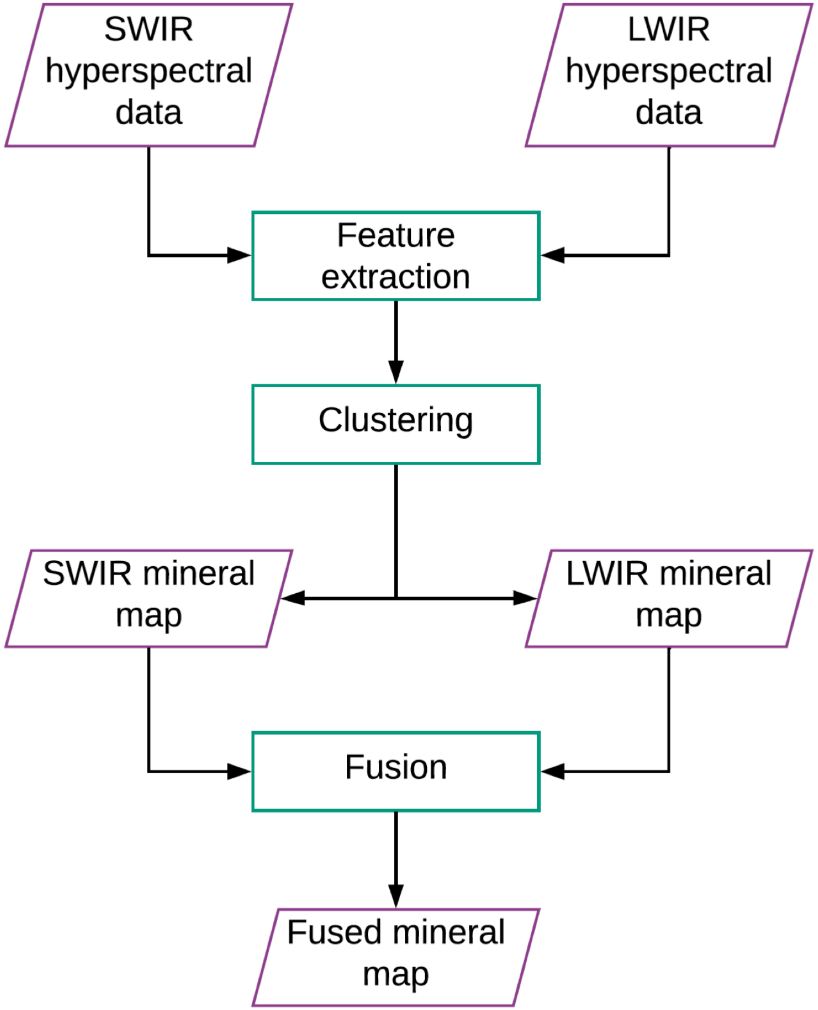
X-ray mapping



MLA image

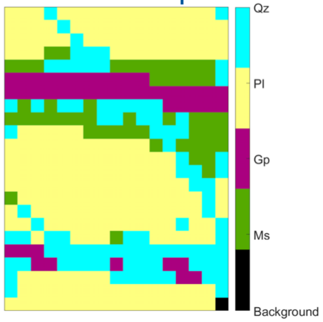
- Scanning Electron Microscopy (SEM) Mineral Liberation Analysis (MLA)
- Back-scattered electron (BSE) signals from scanning electron microscope
- MLA high resolution mineral maps (3 µm/pixel) by BSE and X-ray mapping

Data fusion: Decision level

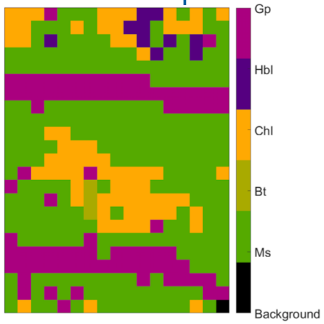


- Feature extraction: Principal component analysis (PCA)
- Clustering: K-means (Elbow method for the number of clusters)
- Fusion:

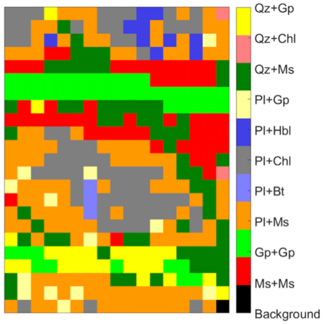
Mineral map 1



Mineral map 2

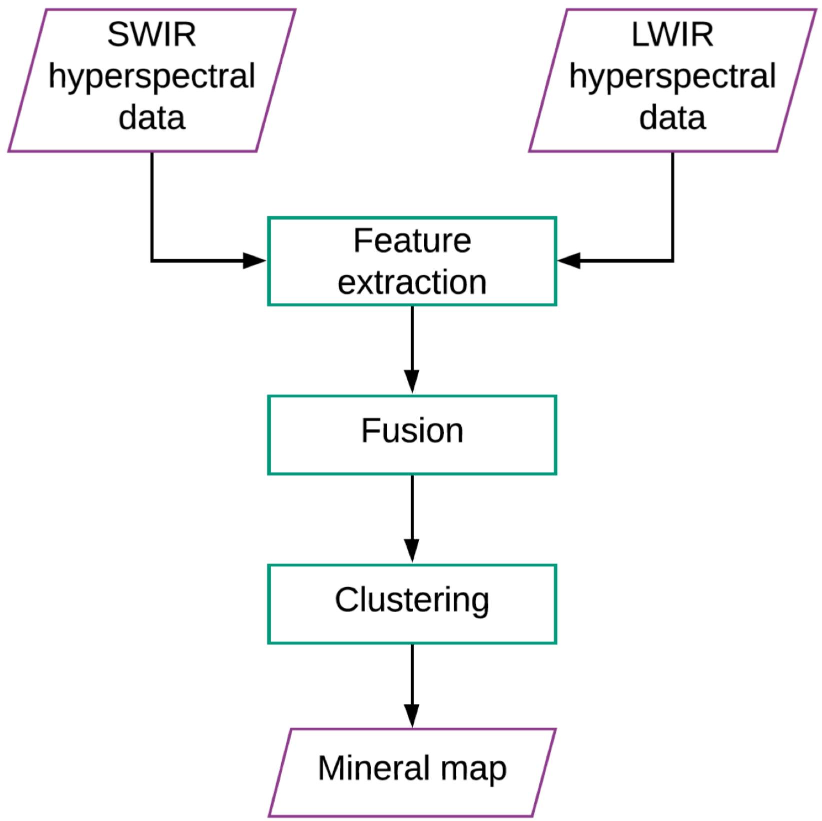


Fused mineral map



Cecilia Contreras
Helmholtz Institute Freiberg for Resource Technology

Data fusion: Feature level



- Feature extraction: Principal component analysis (PCA) and Canonical correlation analysis (CCA)

- Fusion:

Dataset 1

$$\mathbf{X} = \mathbf{X_1}, \ldots, \mathbf{X_n}$$

Features extracted 1

$$\mathbf{FE_X} = [\mathbf{FE_{X1}}, \ldots, \mathbf{FE_{Xn}}]$$

Dataset 2

$$\mathbf{Y} = \mathbf{Y_1}, \ldots, \mathbf{Y_n}$$

Features extracted 2

$$\mathbf{FE_Y} = [\mathbf{FE_{Y1}}, \ldots, \mathbf{FE_{Yn}}]$$

Concatenation

$$\mathbf{F_{FE}} = [\mathbf{FE_{X1}}, \ldots, \mathbf{FE_{Xn}}, \mathbf{FE_{Y1}}, \ldots, \mathbf{FE_{Y}}]$$

- Clustering: K-means

Cecilia Contreras
Helmholtz Institute Freiberg for Resource Technology

Data fusion: Feature level

Canonical Correlation Analysis (CCA)

Characterize the relationship between two sets of multidimensional variables

Dataset 1
$$X \in \Re^{p \times n}$$

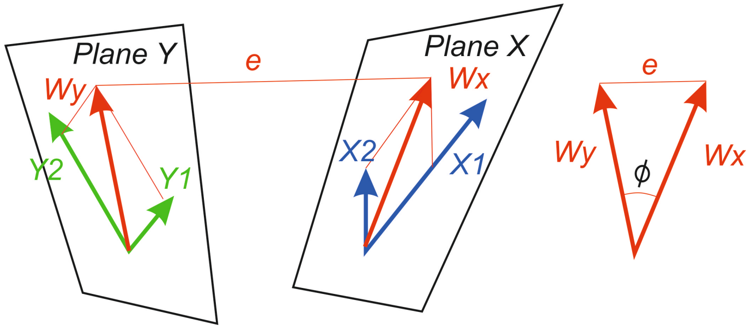
Dataset 2
$$Y \in \Re^{q \times n}$$

Linear combinations

$$X^* = W_x^T X \qquad Y^* = W_y^T Y$$

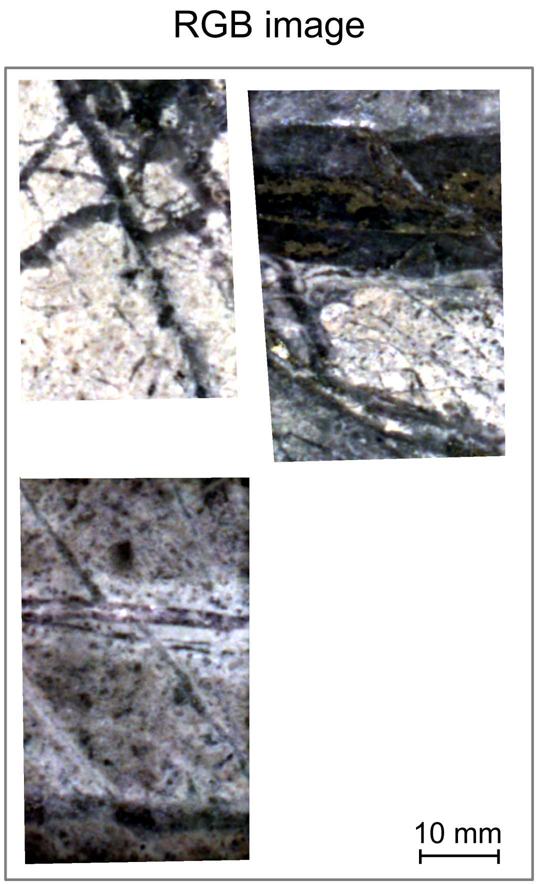
maximize $$corr(X^*, Y^*) = \frac{cov(X^*, Y^*)}{var(X^*).var(Y^*)}$$

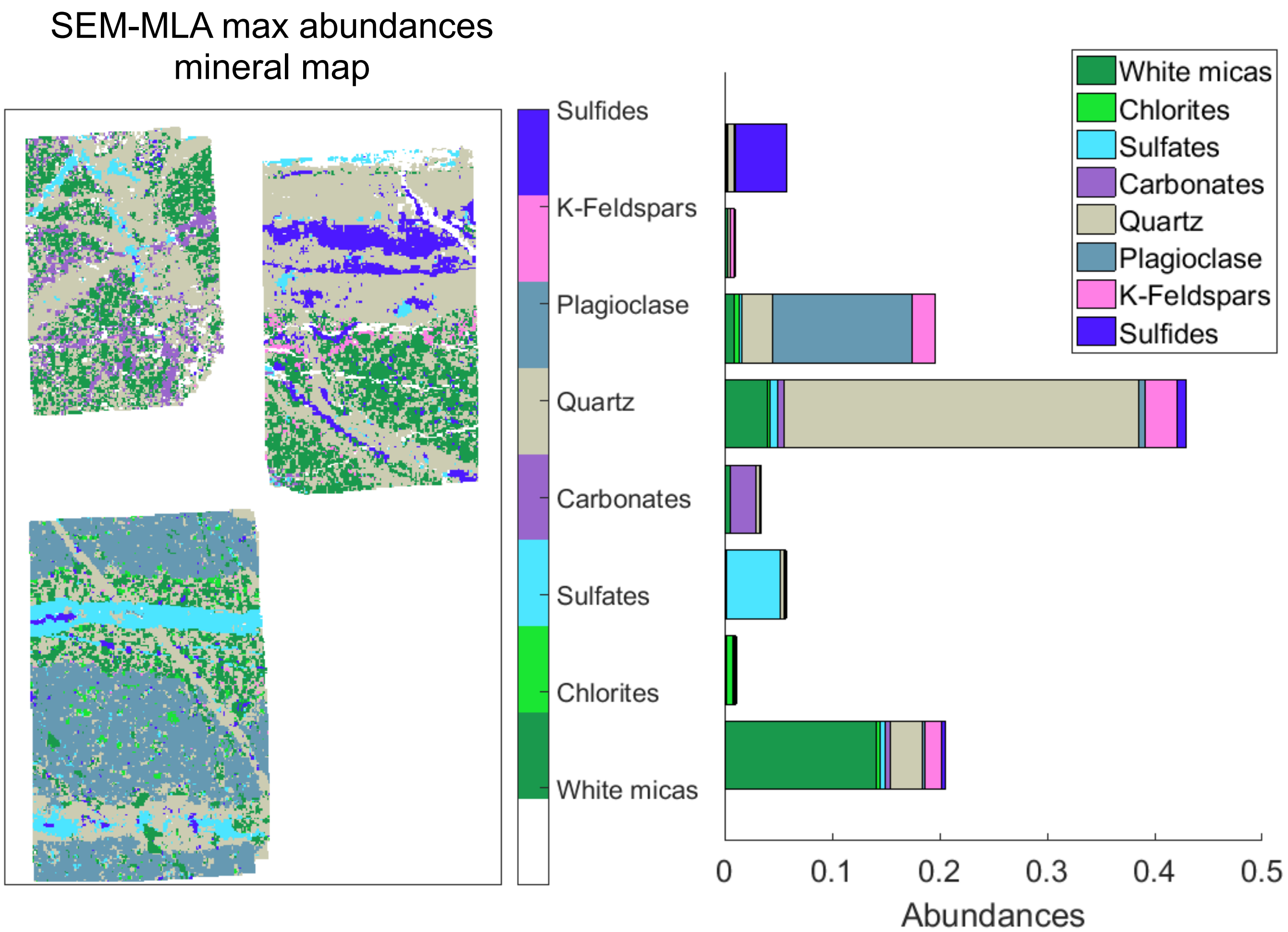
$$var(X^*) = var(Y^*) = 1$$



M. Haghighat et al., Fully automatic face normalization and single sample face recognition in unconstrained environments. Expert Systems With Applications 47 (2016) 23–34.

Data set



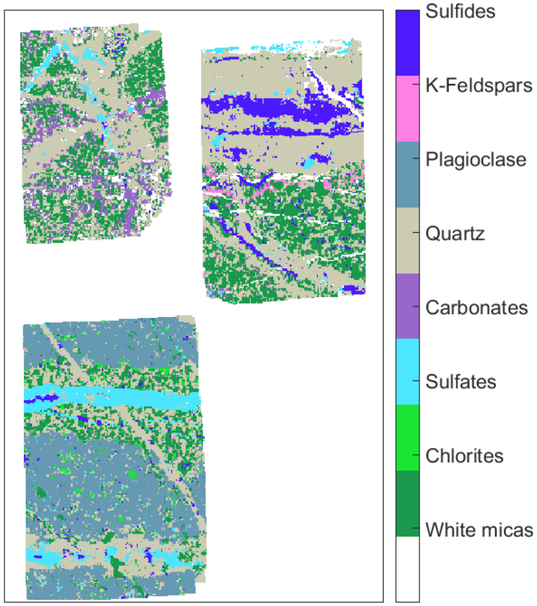


SEM-MLA: Scanning electron microscopy - mineral liberation analysis

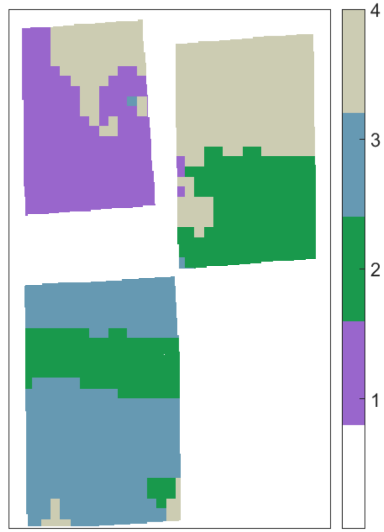
Results: Decision level

Elbow method:
SWIR: 4 Clusters
LWIR: 3 Clusters

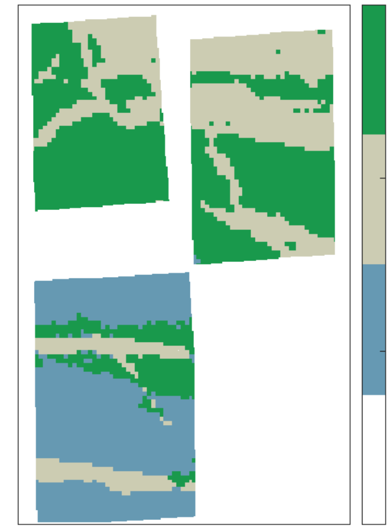
SEM-MLA max abundances mineral map



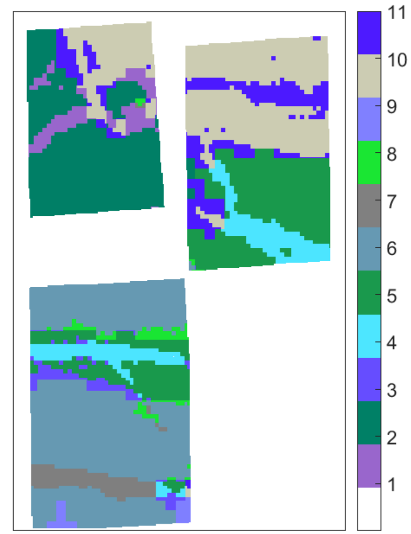
SWIR + K-means mineral map



LWIR + K-means mineral map



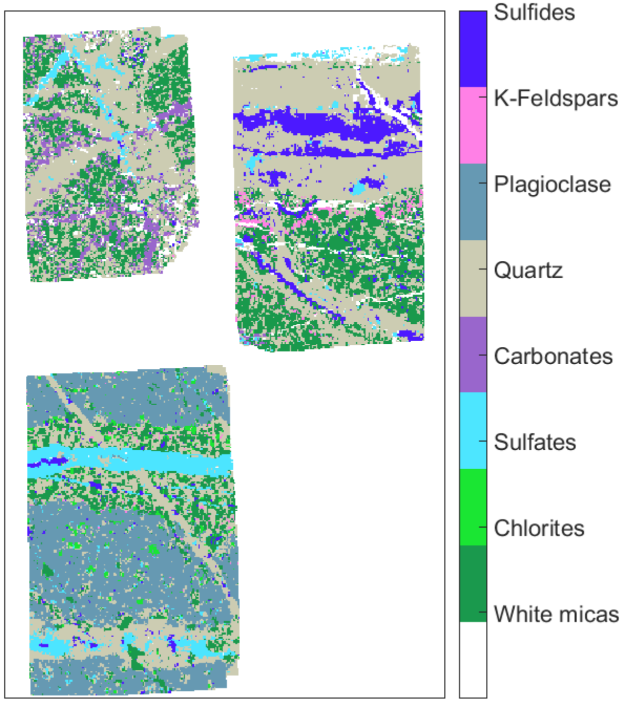
Fused mineral map



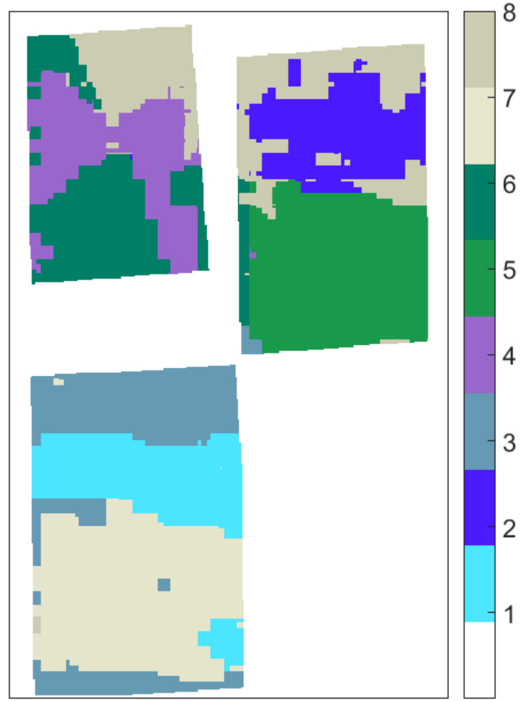
Cecilia Contreras
Helmholtz Institute Freiberg for Resource Technology

Results: Feature level

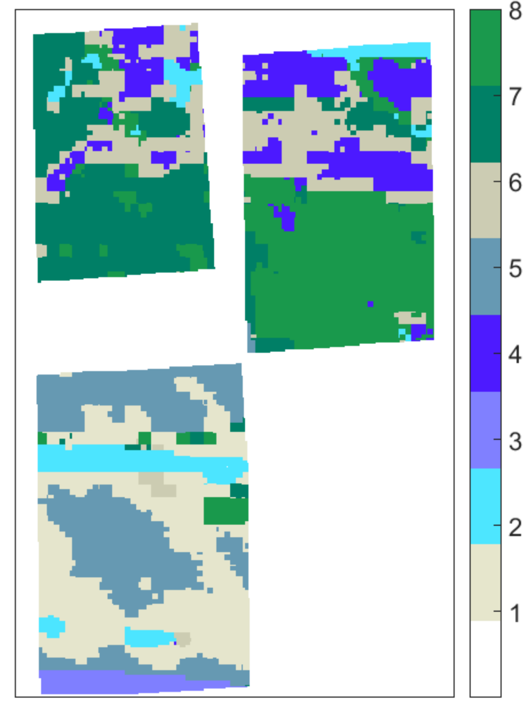
SEM-MLA max abundances mineral map



Fused PCA + K-means mineral map



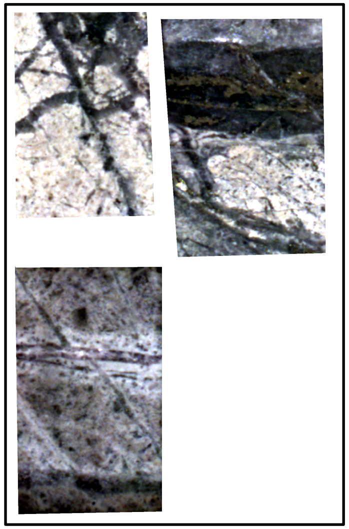
Fused CCA + K-means mineral map



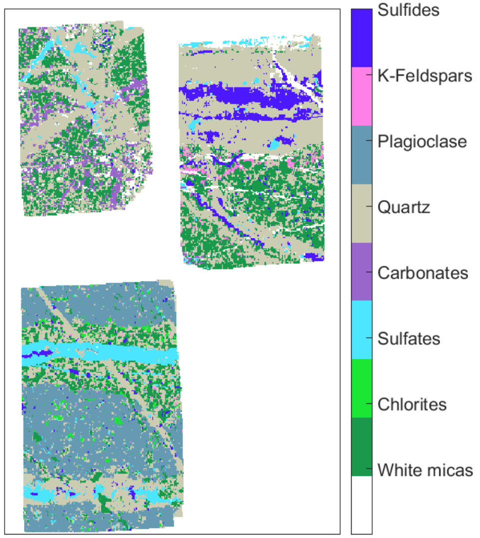
PCA: Principal component analysis | CCA: Canonical correlation analysis

Comparison

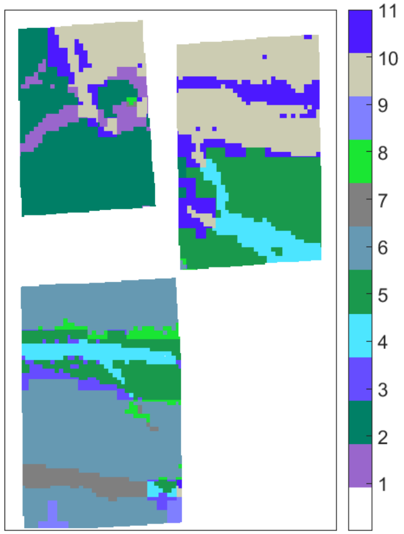
RGB image



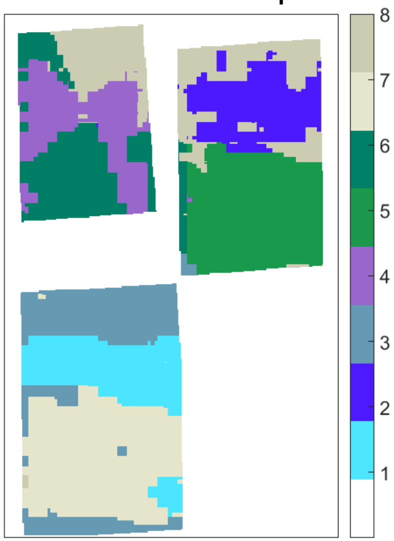
SEM-MLA max
abundances mineral map



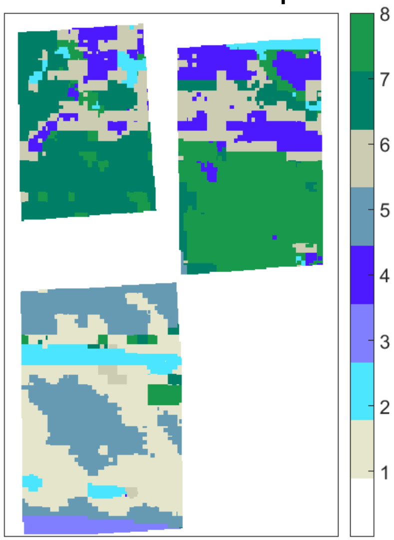
Decision fusion
mineral map



Fused PCA + K-means
mineral map



Fused CCA + K-means
mineral map



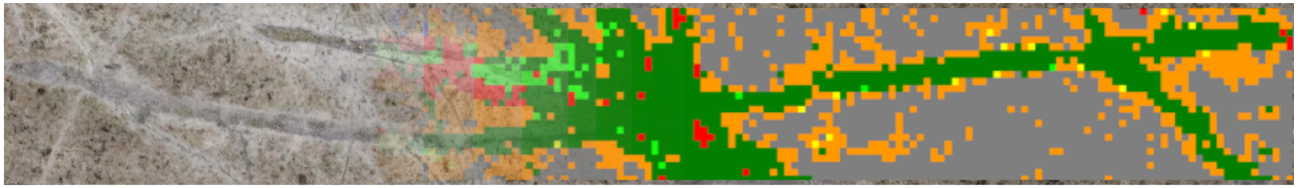
Cecilia Contreras
Helmholtz Institute Freiberg for Resource Technology

Summary and conclusions

- VNIR-SWIR and LWIR fusion at both, feature and decision levels:
  - For the decision level we used PCA and K-means followed by the fusion of the labels in the SWIR and LWIR mineral maps
  - For the feature level we fused the PCA and CCA extracted features and performed K-means on the stacked feature vectors to produce the final mineral maps

- Validation has been done based on a visual analysis using SEM-MLA mineral maps

- Decision level approach produced the most consistent and descriptive mineral map



Drill core mineral mapping

Cecilia Contreras
Helmholtz Institute Freiberg for Resource Technology

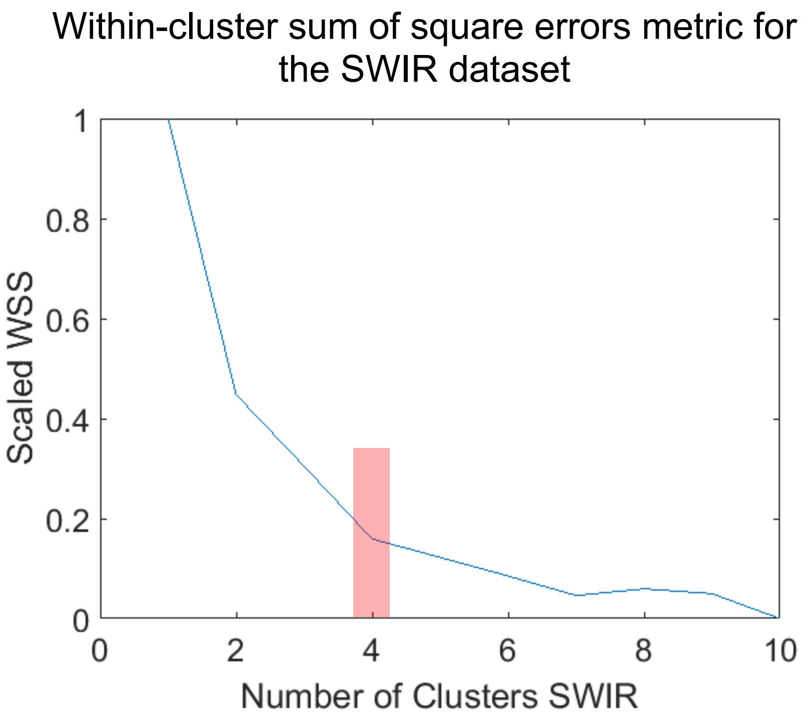
Thanks for your attention !!!

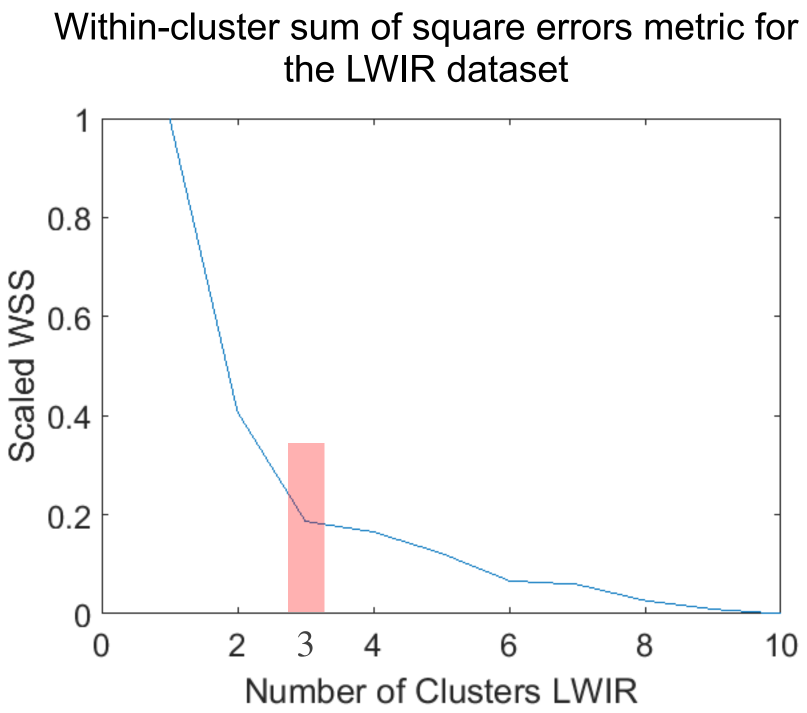
PhD student. Isabel Cecilia Contreras
E-mail: i.contreras@hzdr.de
Tlf: +49 351 260 4493

Río Tinto mine, Spain. Photo by: Leila Ajjabou

Results: Decision level

Elbow method for the estimation of the appropriate number of clusters





Cecilia Contreras
Helmholtz Institute Freiberg for Resource Technology