

# Using Copernicus data within the Raw Materials lifecycle

## Mining Resources

Workshop on Copernicus Use for the Management  
of Natural Resources

Location: Antofagasta

Date: 6 September 2022



# *Using Copernicus data within the Raw Materials lifecycle*



ALMA MATER STUDIORUM  
UNIVERSITÀ DI BOLOGNA

**Sara Kasmaeeyazdi**

DICAM - Dept. Civil, Chemical, Environmental and Materials Engineering



## Context of this seminar:

- **Who are we?** Presenting the RawMatCop group
- **Why did we use Copernicus data ?** Objectives and advantages
- **Raw Materials lifecycle and use of Copernicus**
  - ✓ **Exploration of minerals and metals;**
  - ✓ **Excavation and Materials flow monitoring;**
  - ✓ **Ground stability and monitoring (open pit and dams)**
  - ✓ **Mining residues characterization**
  - ✓ **Environmental monitoring**



# Raw Materials Academy Group



**Dr. Mehdi Abdolmaleki**  
Post-Doc Researcher at  
Luleå University of  
Technology  
Expert in mineral exploration,  
satellite data, geochemistry.



**Dr. Louis Andreani**  
Post-Doc Researcher at  
Helmholtz Institute Freiberg  
Expert in satellite-based remote  
sensing applied to raw materials,  
tectonics and natural hazards.



**Dr. Elsy Ibrahim**  
RawMatCop Researcher  
2017-2019 at University of  
Liège  
Multidisciplinary remote sensing  
expert and freelance consultant



**Dr. Sara Kasmaeeyazdi**  
Mining Engineer and Post-  
Doc Researcher at University  
of Bologna  
Expert in in geostatistics and remote  
sensing in the fields of resources  
exploration and environment.



**Dr. Christian Köhler**  
RawMatCop Researcher  
2017-2019 at TU  
Bergakademie Freiberg  
Physicist with expertise in remote  
sensing for environmental  
monitoring



**Dr. Ignacio Marzán**  
Researcher at CSIC  
Multidisciplinary geophysicist  
focused on monitoring our  
interaction with the underground  
environment in natural resources  
searching.

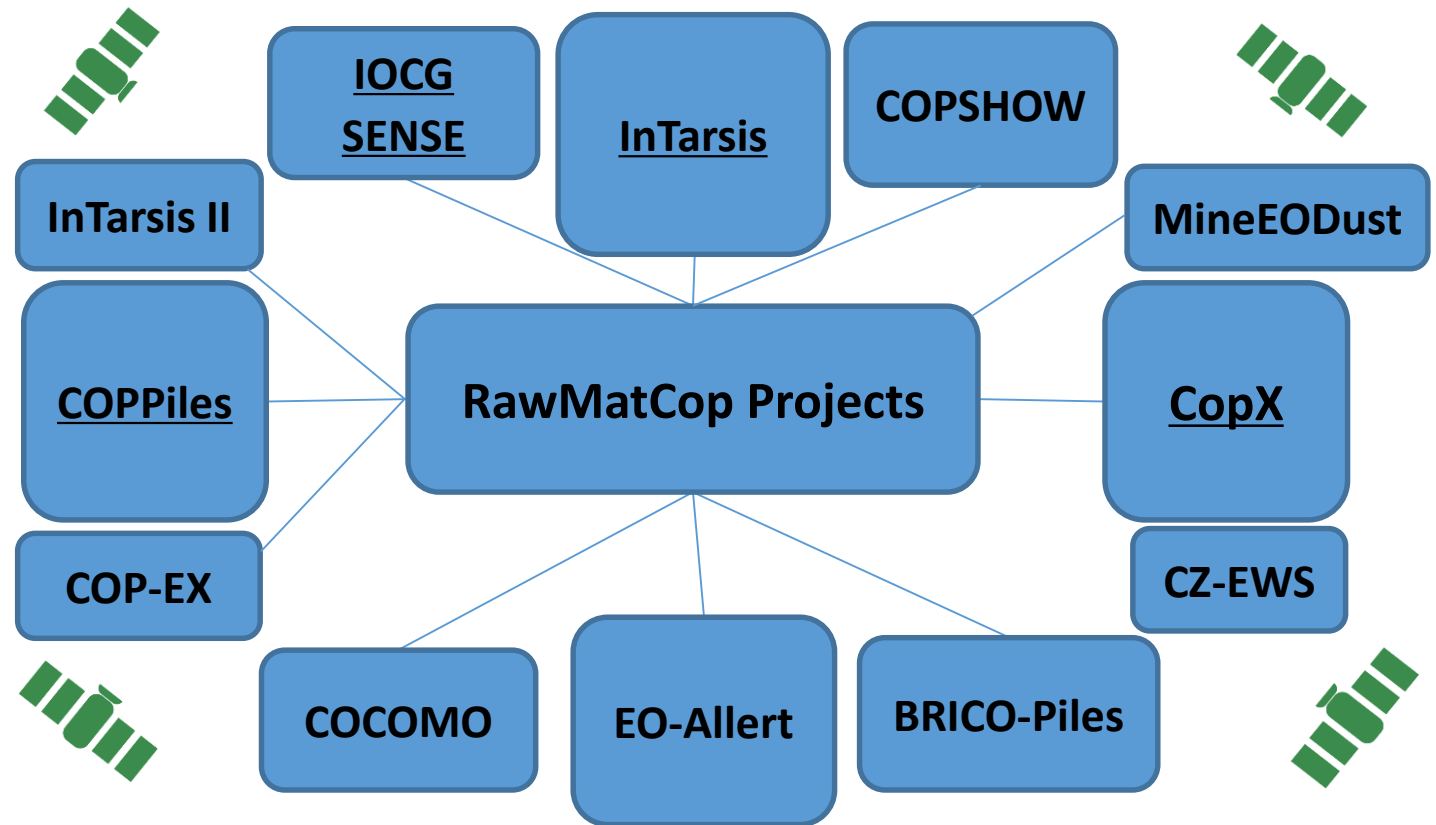
**6 Researcher from 6 institutes in Europe (Italy, Sweden, Spain, Belgium, Germany)**

# Raw Materials Academy Group



12 projects each for one year

Started from 2017-2021



<https://eitrawmaterials.eu/eit-rm-academy/rawmatcop/post-docs/ocs - EIT RawMaterials>

# Sara Kasmaeeyazdi

[www.unibo.it/sitoweb/sara.kasmaeeyazdi2](http://www.unibo.it/sitoweb/sara.kasmaeeyazdi2)



**EDUCATION:** PhD in Georesources (Geostatistics), UNIBO, (2014-2017), Thesis entitled “Geostatistical modeling of ore deposits with transitional boundaries”.

**Scientific Collaborations:** La Sapienza University (Rome), MINES ParisTeCH (France), Technology University of Lulea (Sweden)

2017  
2018

- Geostatistical modelling in different topics: Stockpiles, Geothermal Energy (**H2020**)

2018  
2019

- **Raw Mat Cop project:** Copernicus data in mining residues characterization, **EIT RawMaterials**

2019  
2021

- **INCO-Piles project:** International Consortium to recover Critical Raw Materials from stockpiles and tailings, **EIT RawMaterials**

2021  
NOW

- **Raw MAT Cop Alliance:** Alliance of RawMaterials lifecycle with Copernicus and Remote Sensing techniques, **EIT RawMaterials**



# Why do we use Copernicus data ?

Objectives and advantages



# Why Copernicus Data

- **Mining:** Is it still an old-fashioned sector?

Objective:

Solving mining challenges



<https://www.earthsystems.com/>





# Why Copernicus Data

- Environmental hazards

## Monitoring of mining wastes

An aerial view of mud and waste from the disaster caused by the collapse, in Minas Gerais, Brazil, on 26 January 2019. The tailing dam's sudden collapse caused a toxic torrent of mining waste to sweep across a rural pocket of Minas Gerais state.

Photograph: António Lacerda/EPA



# Why Copernicus Data

- Environmental hazards

Ground subsidence  
Caused by mining  
activities



Creator: White Jonathan L. , ©1910-2022 Colorado Geological  
Survey  
<https://coloradogeologicalsurvey.org>



ALMA MATER STUDIORUM  
UNIVERSITÀ DI BOLOGNA

# Why Copernicus Data

- Mining activities costly and damaging?



<https://www.ennomotive.com/>

- Large exploration areas;
- High number of sampling;



# Why Copernicus Data

- Mining activities costly and damaging?



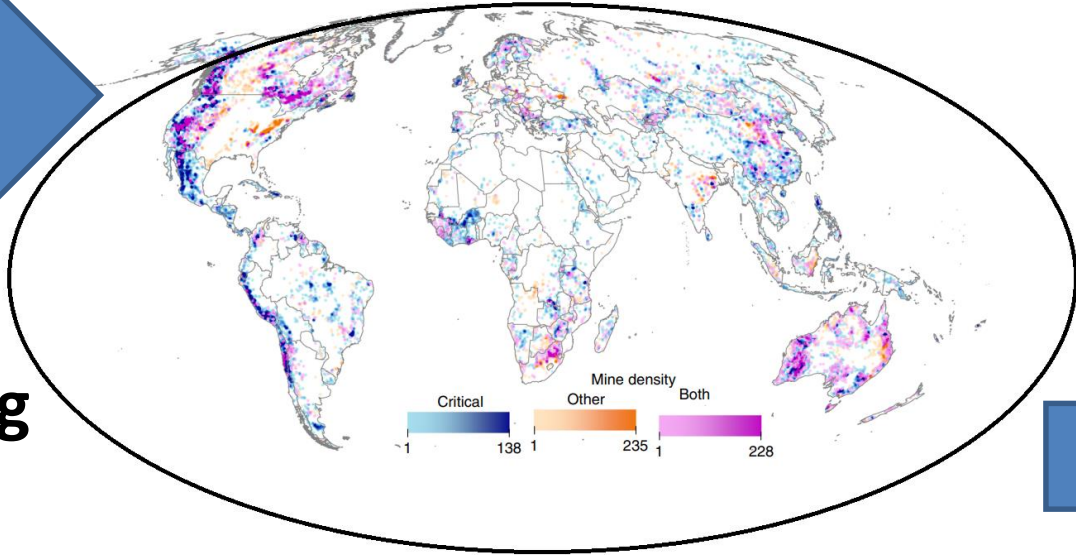
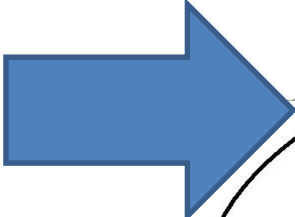
- Mixed-up materials and disordered pilings

Many waste rock piles hold hidden stores of valuable minerals. Shutterstock;  
<https://theconversation.com/>



# Why Copernicus Data

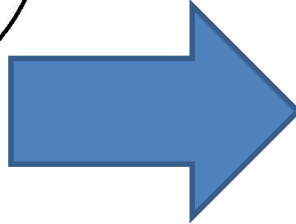
Mining challenges



costly and damaging activities

Hazards

Innovative tools and techniques



Clean and sustainable solutions

# Why Copernicus Data

## Clean and sustainable solutions in mining

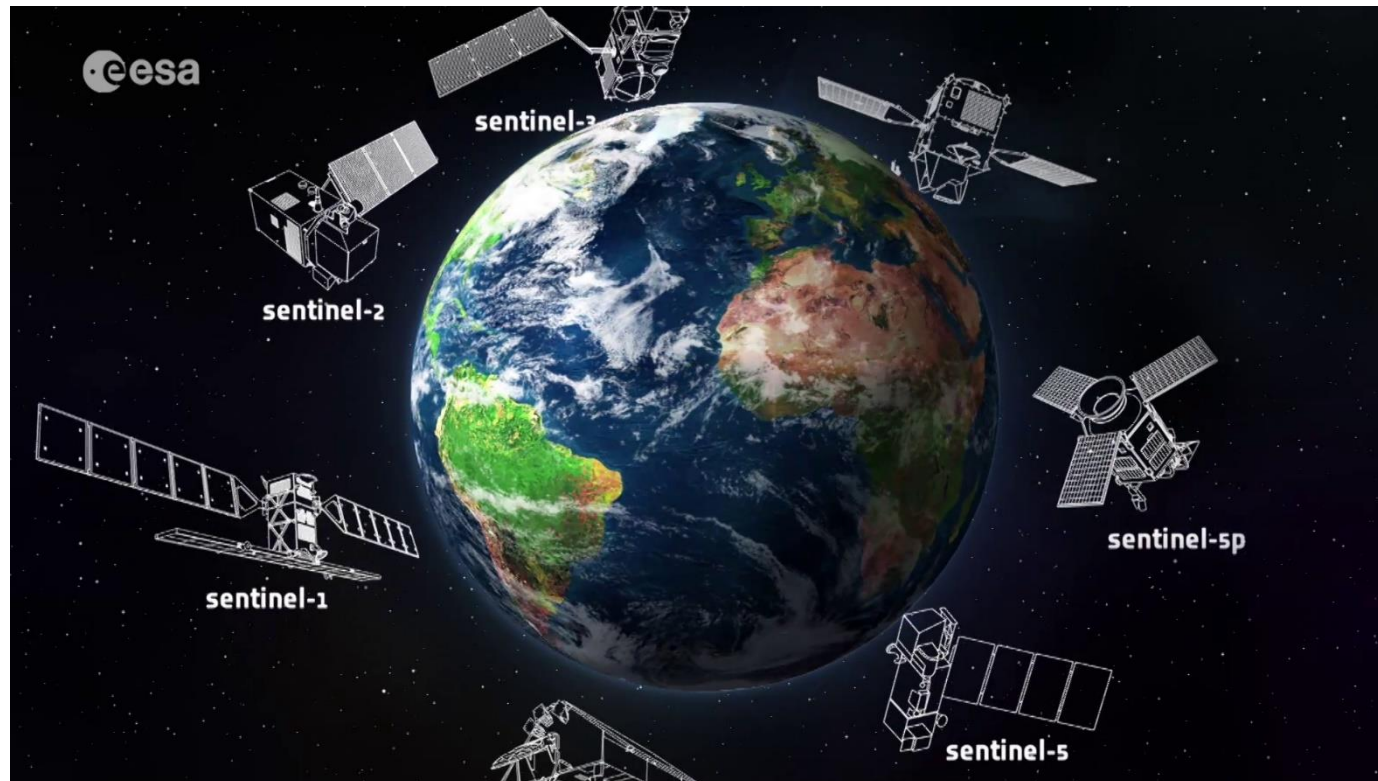


- ✓ **Smart monitoring of mining activities;**
- ✓ **Focused area of exploration and smarter techniques;**
- ✓ **Less samples and optimized sample grid;**
- ✓ **Open-pit stability monitoring and materials flow;**
- ✓ **Stockpiling and wastes managements.**



# Copernicus Data

**Copernicus Programme** Copernicus is the European Union's Earth Observation (EO) and monitoring programme.

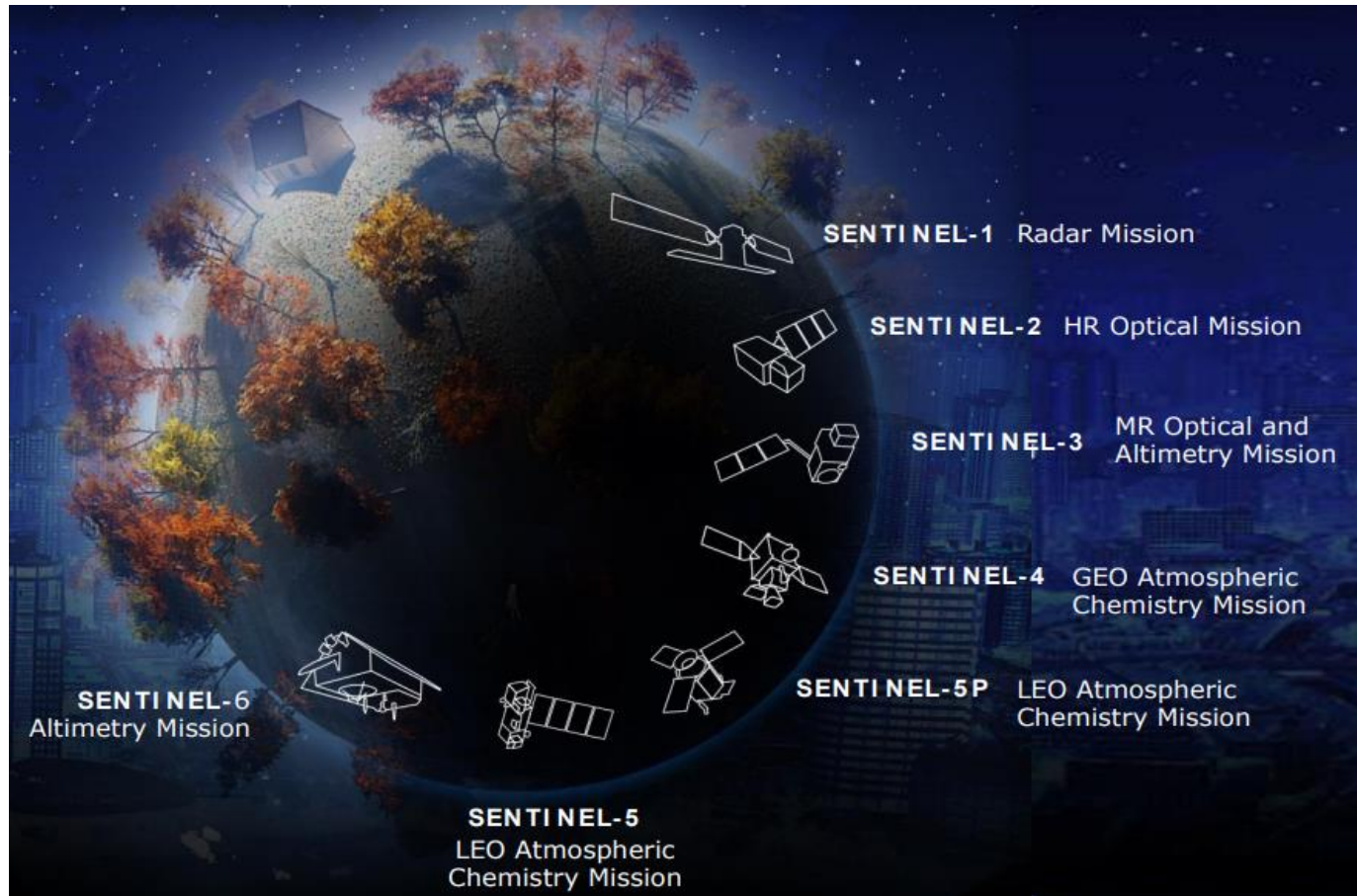


**Copernicus is managed by the European Commission with the ESA, EU Member States and EU Agencies.**



# Copernicus Data

Copernicus and its satellites generate publicly-available, open-access and free Earth Observation data daily via the Copernicus services.



The programme is composed of Sentinel missions, focusing on a specific aspect of EO including atmospheric, oceanic, and land monitoring.

The Sentinels provide a unique set of observation data.



# Copernicus Data

<https://www.copernicus.eu/>

Sentinels		Year
Sentinel-1	a polar-orbiting, all-weather, day-and-night radar imaging mission for land and ocean services	2014 2016
Sentinel-2	a polar-orbiting, multispectral high-resolution imaging mission for land monitoring to provide, for example, imagery of vegetation, soil and water cover, inland waterways and coastal areas	2015 2017
Sentinel-3	a multi-instrument mission to measure sea-surface topography, sea- and land-surface temperature, ocean colour and land colour with high-end accuracy and reliability	2016 2018
Sentinel-4	a payload devoted to atmospheric monitoring that will be embarked upon a Meteosat Third Generation-Sounder (MTG-S) satellite in geostationary orbit	2019
Sentinel-5	a payload that will monitor the atmosphere from polar orbit aboard a MetOp Second Generation satellite	2021
Sentinel 5P	a missions being developed to reduce data gaps between Envisat, in particular the Sciamachy instrument, and the launch of Sentinel-5	2017 2021
Sentinel-6	carries a radar altimeter to measure global sea-surface height, primarily for operational oceanography and for climate studies	2023



<https://marine.copernicus.eu/>



ALMA MATER STUDIORUM  
UNIVERSITÀ DI BOLOGNA

# Raw Materials lifecycle & Copernicus



## RawMatCop Academy

The RawMatCop Programme aimed to develop skills, expertise and applications of Copernicus data to the raw materials sector.



## Research activities covered topics on:

- ✓ Exploration of minerals and metals;
- ✓ Excavation and Materials flow monitoring;
- ✓ Ground Stability and monitoring
- ✓ Mining residues characterization
- ✓ Environmental monitoring

<https://www.youtube.com/watch?v=jpN73fMkvQo&t=2s>

# Raw Materials lifecycle & Copernicus

## Exploration



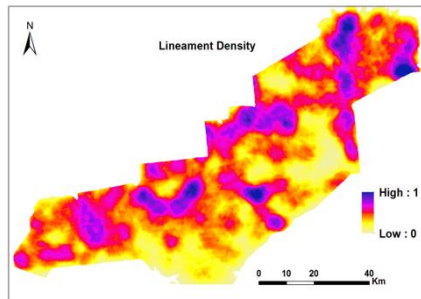
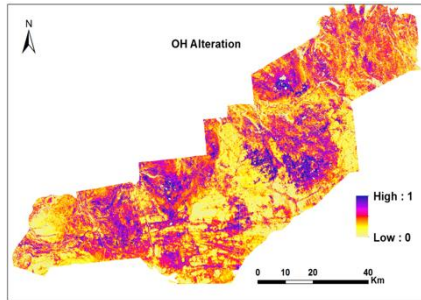
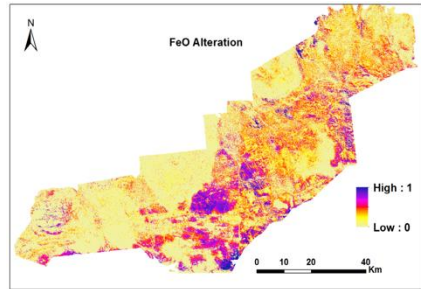
**Dr. Mehdi Abdolmaleki**  
Post-Doc Researcher at  
Luleå University of  
Technology

Expert in mineral exploration,  
satellite data, geochemistry.

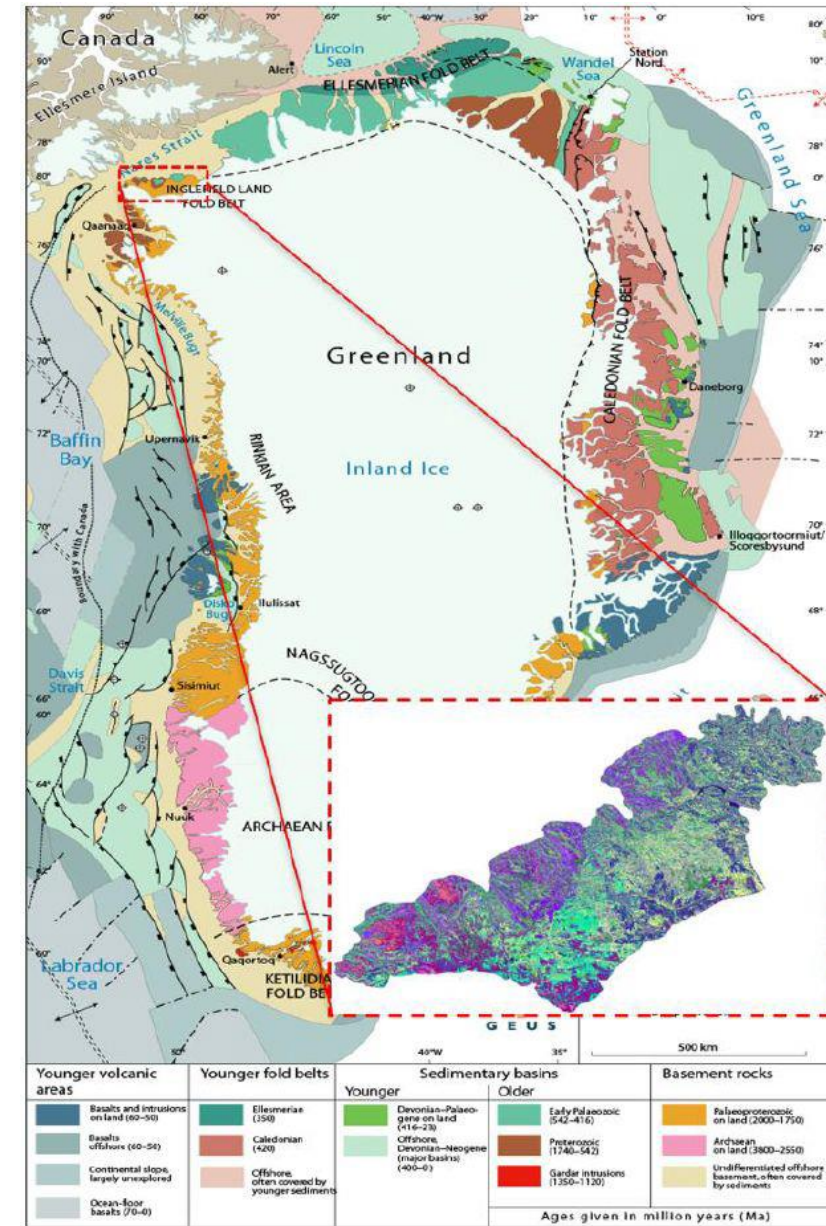
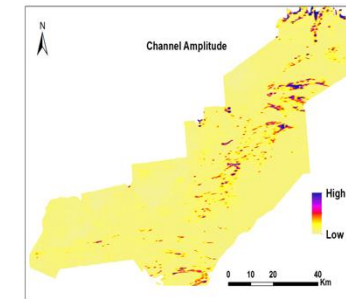
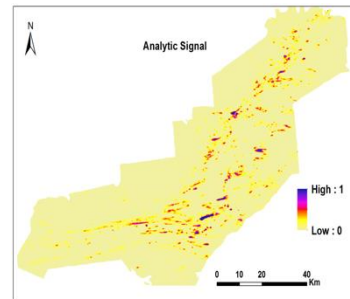
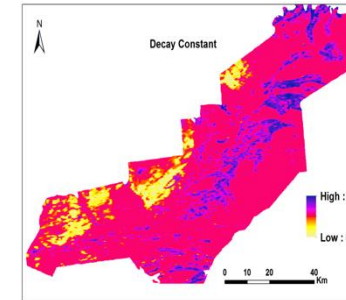
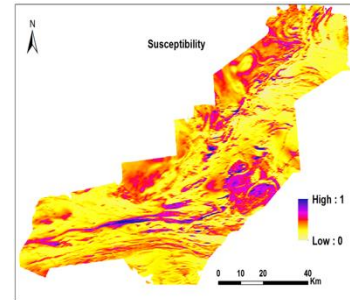
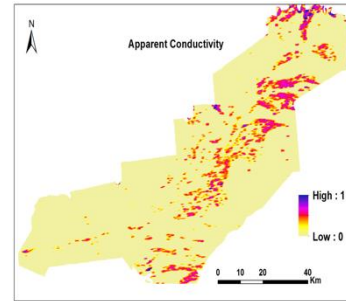
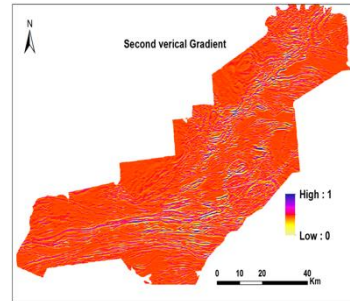
**IOCG-SENSE (2018-2019)** Integration of space-borne remote sensing data with geophysical and geological data for exploration of IOCG mineralization

**COPSHOW (2019-2021)** Development of showcase examples, tools and courses for promoting Copernicus data

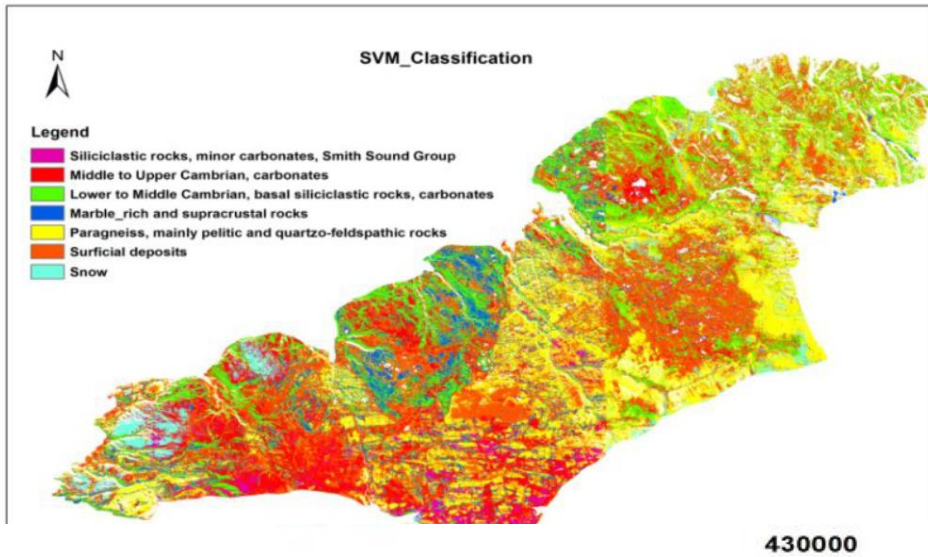
## Sentinel-2 satellite



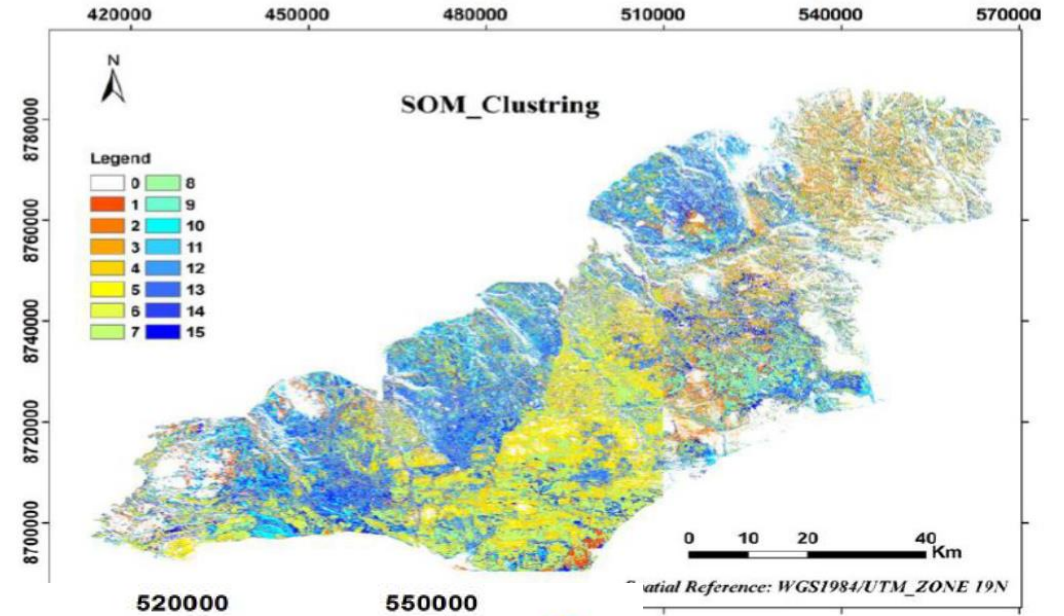
## Airborne Geophysics



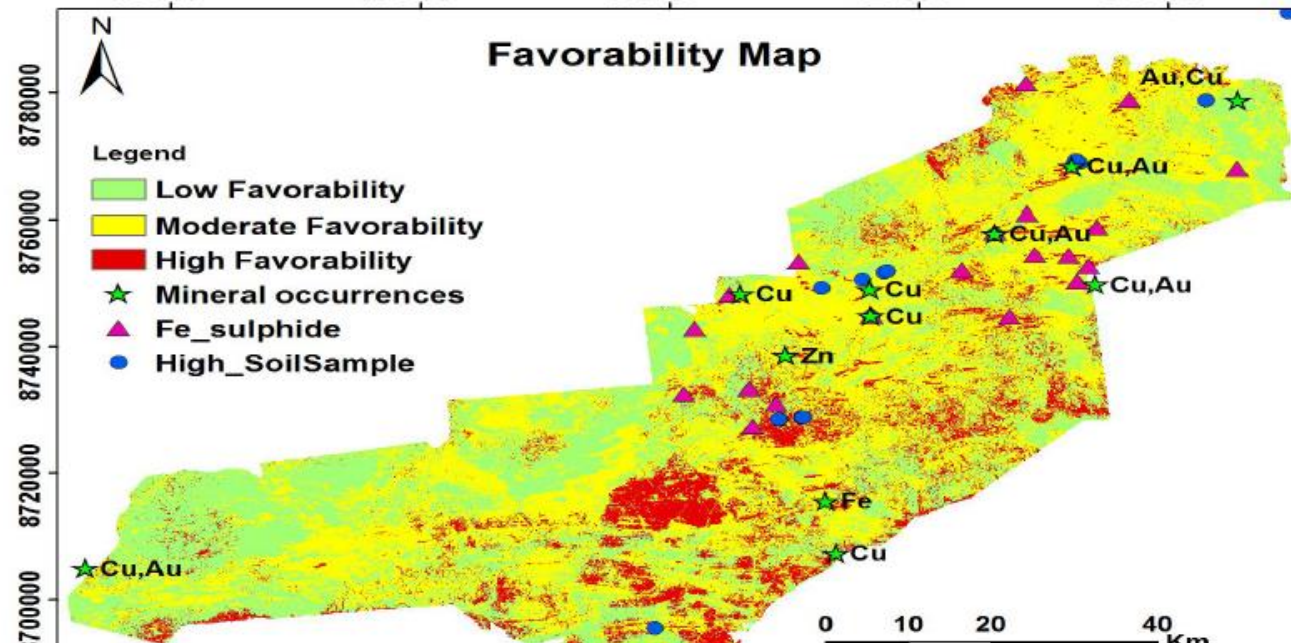
## Support Vector Machines (SVM)

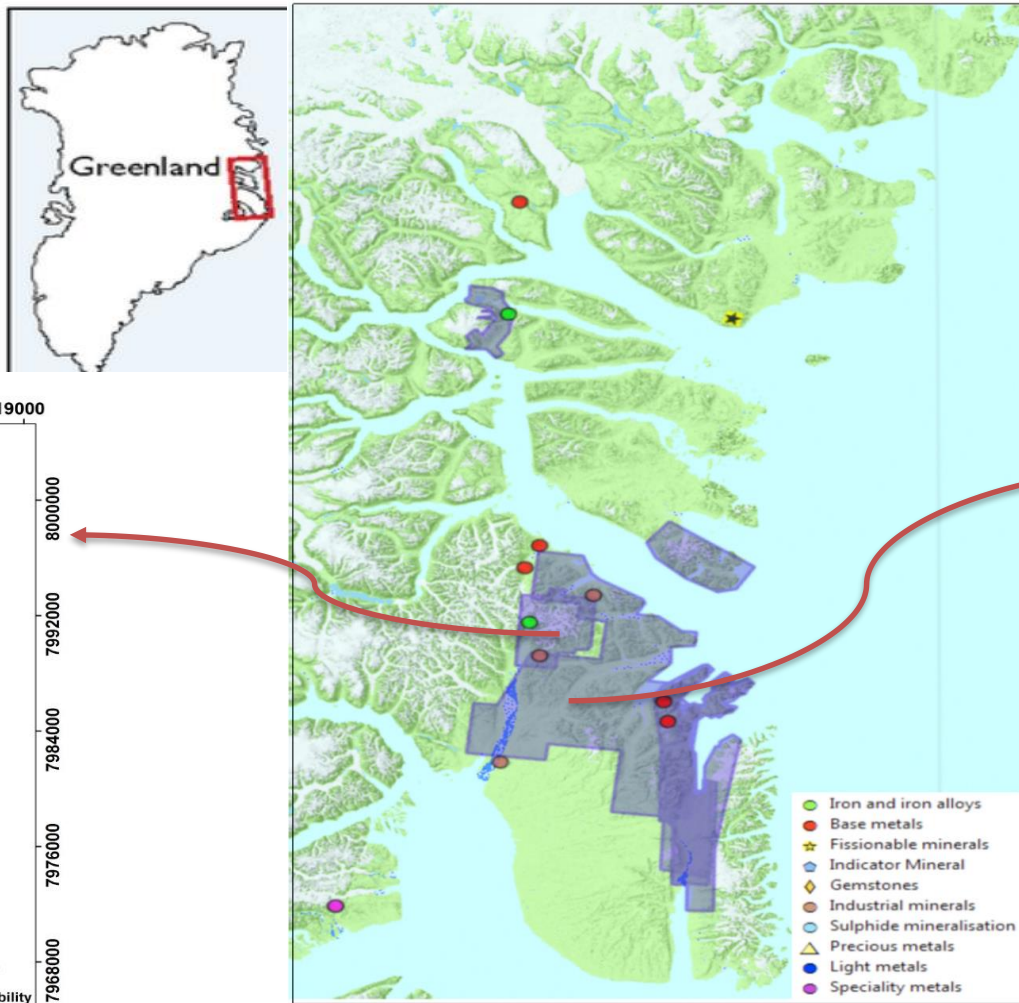


## Self-Organizing Maps (SOM)

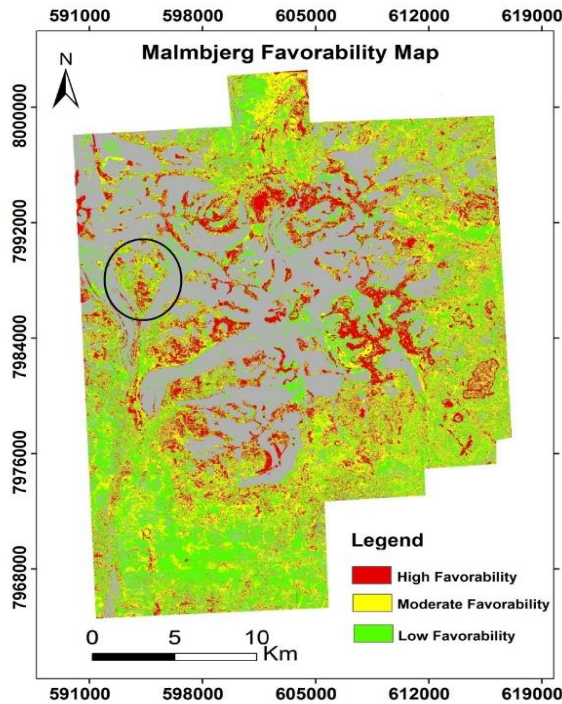


## Fuzzy Analytic Hierarchy Process (FAHP)

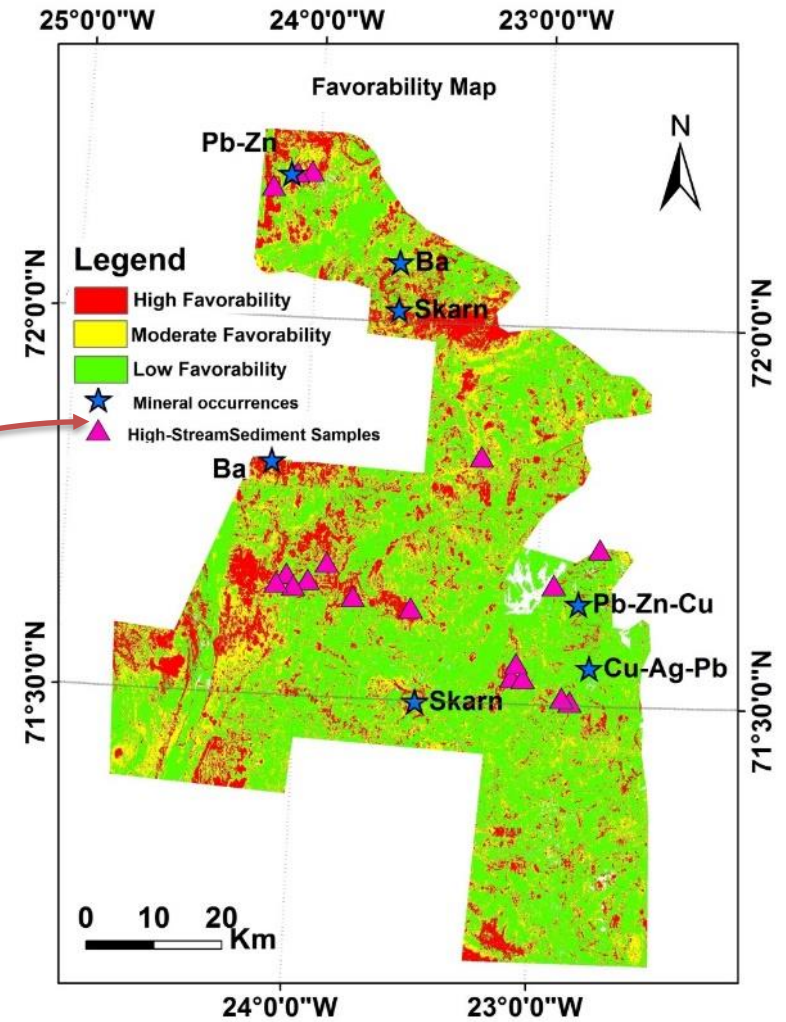




Map of detailed airborne geophysical surveys and known mineral occurrences



Molybdenum Malmbjerg deposit and surrounding area



Central East Greenland

# Raw Materials lifecycle & Copernicus



## Exploration, outcrop Mapping and mining Monitoring

MINEODust  
(2017-2018)

Spatiotemporal mapping of dust dispersion  
around mining sites using remote sensing

CopX  
(2019-2020)

Geospatial mining transparency through  
Copernicus and MapX



**Dr. Elsy Ibrahim**  
RawMatCop Researcher  
2017-2019 at University of  
Liège

Multidisciplinary remote sensing  
expert and freelance consultant



ALMA MATER STUDIORUM  
UNIVERSITÀ DI BOLOGNA

# MinEOdust (2017-2018)

## Highlights:

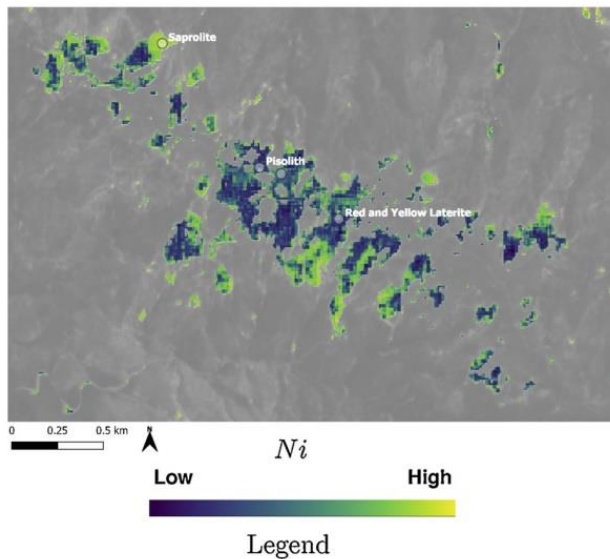
Mapping mineral chemistry of a lateritic outcrop in new Caledonia using Sentinel-2 and field reflectance spectra from drill holes.

More info: <https://doi.org/10.1016/j.jag.2018.08.004>

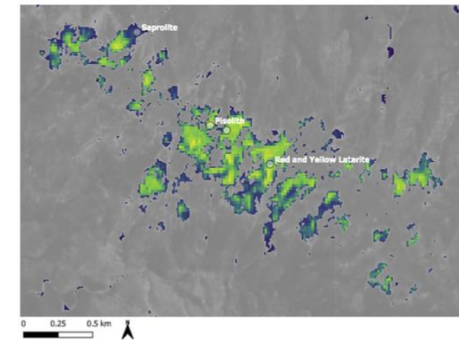
Relative Fe<sub>2</sub>O<sub>3</sub> content obtained using regression and the ferric oxide index approaches.



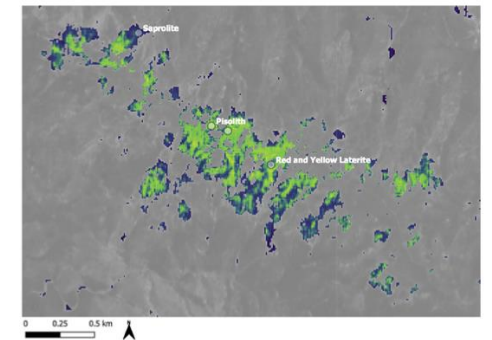
Mapping outcrop characteristics



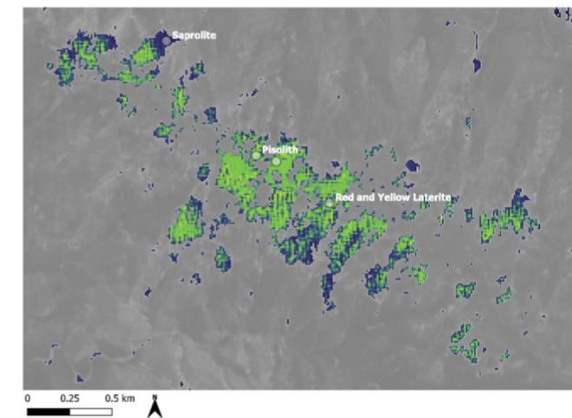
The project was in collaboration with



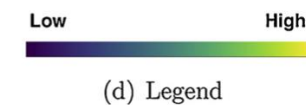
(a) Ferric Oxide index with band 8a



(b) Ferric Oxide index with band 8



(c) Regression equation



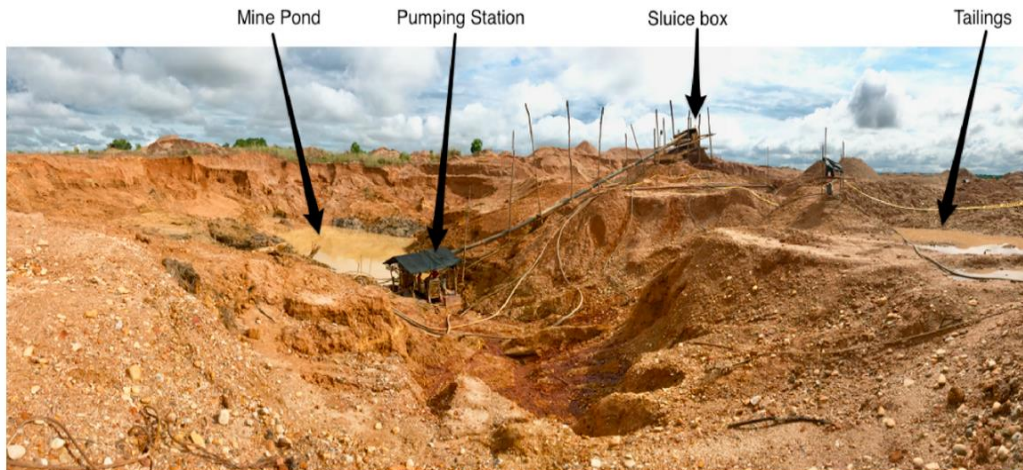


COPX (2019-2020)  
EO-Allert (2020 – 2021)

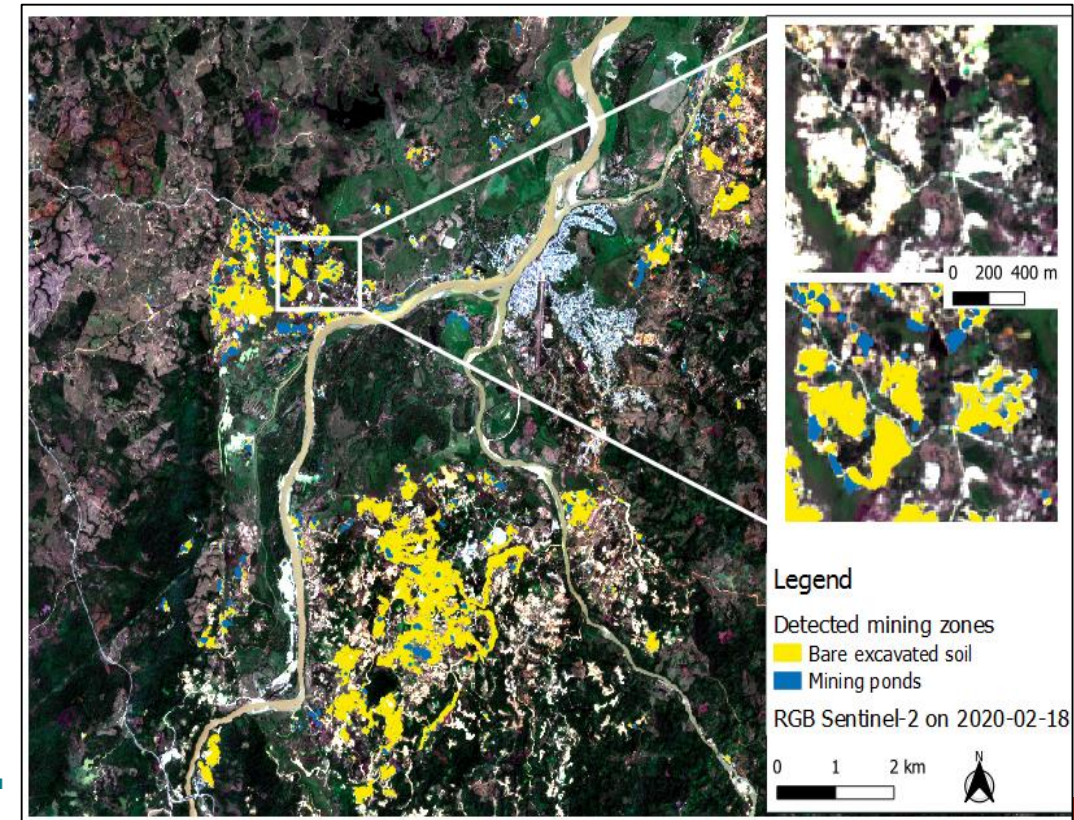
### Highlights:

Small-scale surface mining of gold placers: Detection, mapping, and temporal analysis through the use of free satellite imagery.

More info: <https://doi.org/10.1016/j.jag.2020.102194>



The project was in collaboration with



# Raw Materials lifecycle & Copernicus



## Exploration and Mining Extraction



**Dr. Louis Andreani**  
Post-Doc Researcher at  
Helmholtz Institute Freiberg  
Expert in satellite-based remote  
sensing applied to raw materials,  
tectonics and natural hazards.

**COP-EX  
(2016-2017)**

**Integration of Copernicus data in a multi-scale and multi-source exploration scheme**

**MineStream  
(2019-2020)**

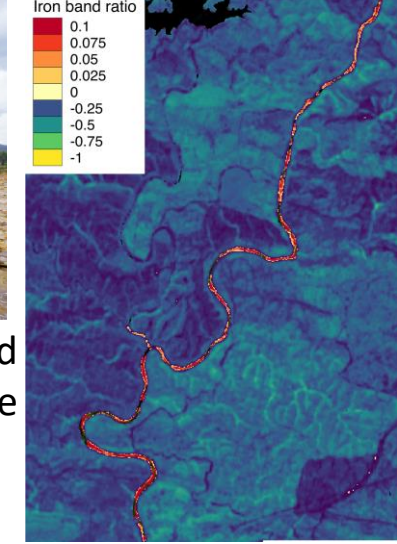
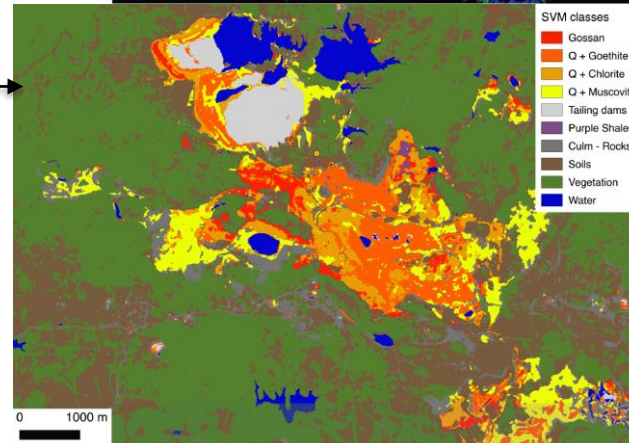
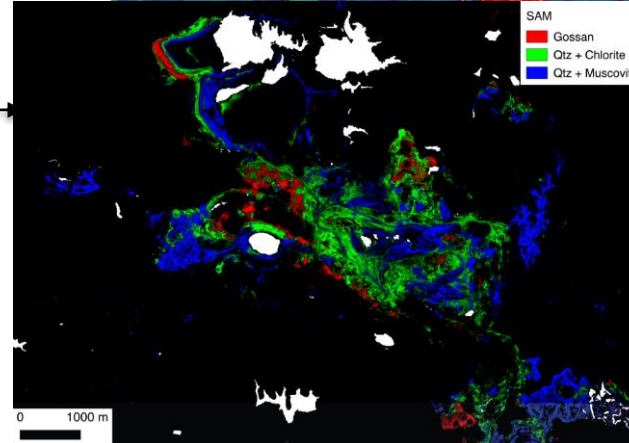
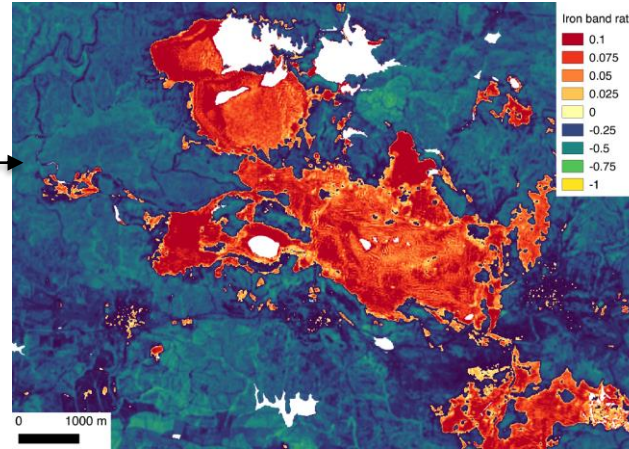
**From blasting to tailings: integration of remote sensing and in-situ data for monitoring material streams in mining environments**

# Cop-EX (2016-2017)

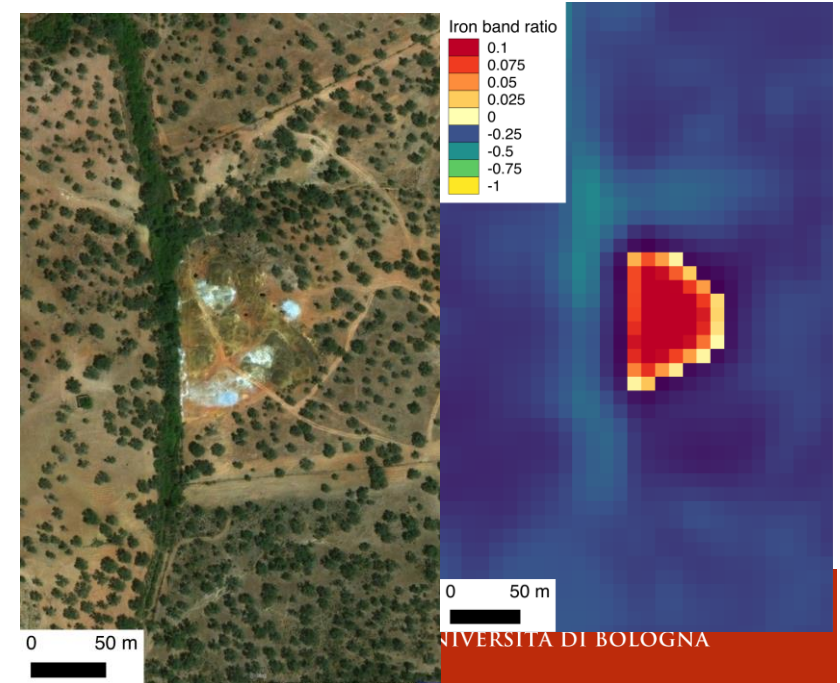
Band Ratios

Spectral Angle Mapper

Machine Learning



Detection of prospects



Sentinel-2 scene



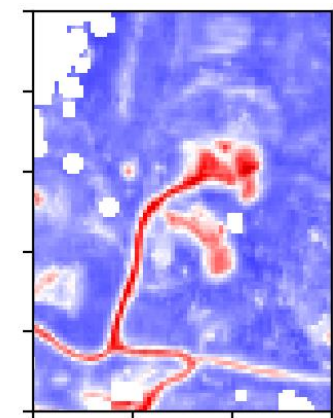
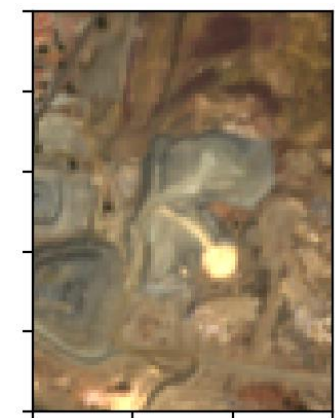
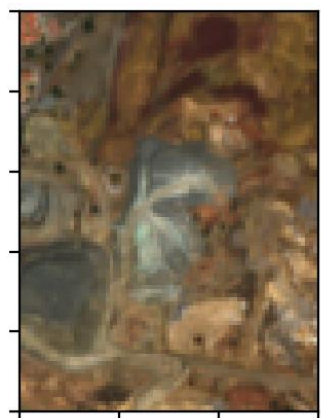
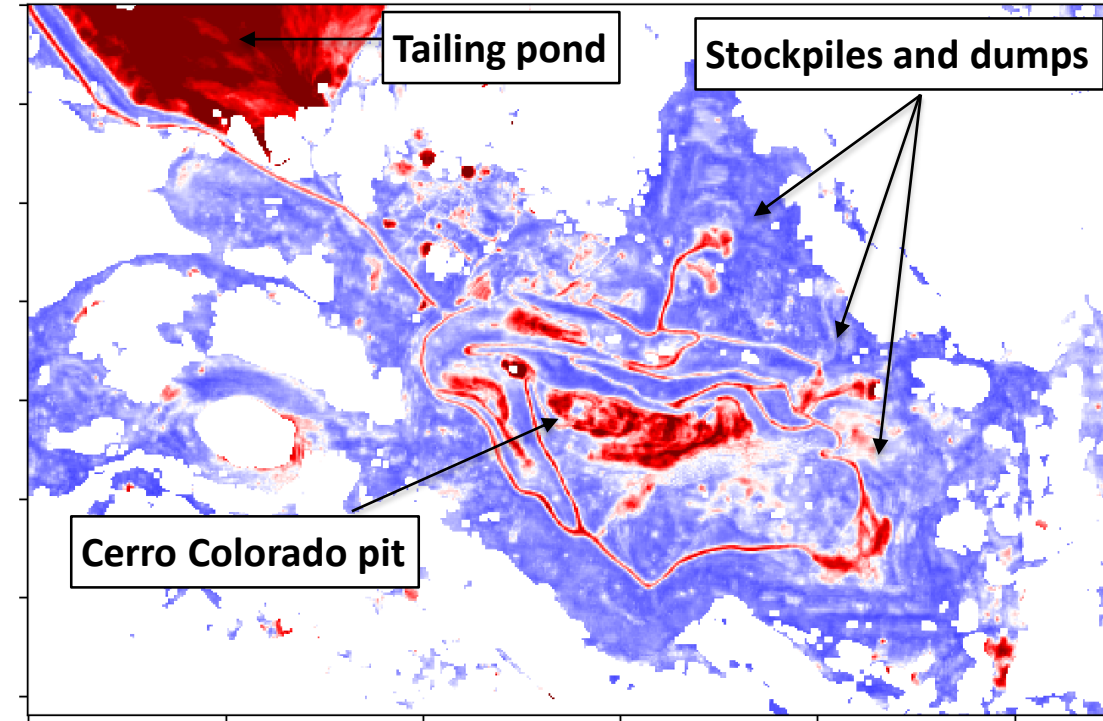
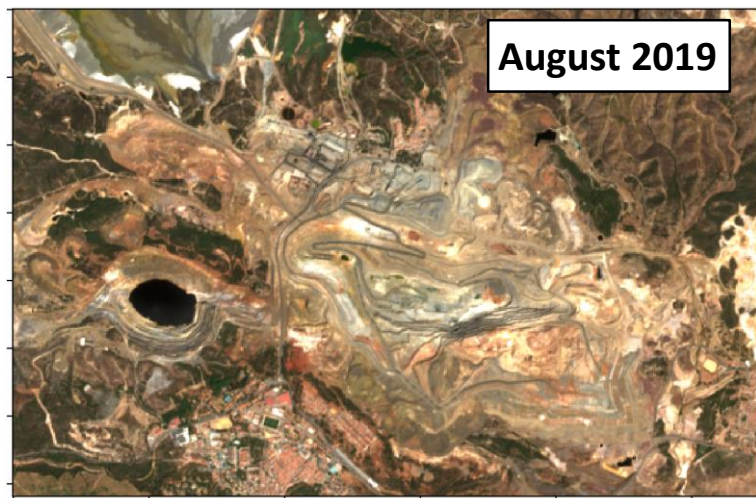
## Objective:

Mapping of iron-bearing minerals and alteration minerals using Sentinel-2

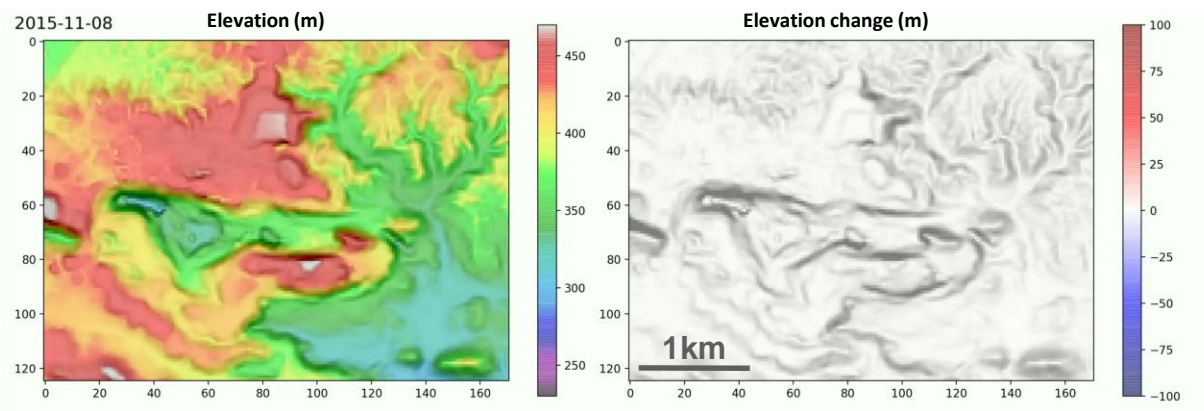
Case study: Iberian Pyrite Belt - Riotinto mine

# Change detection based on S2 spectra and S1 coherence

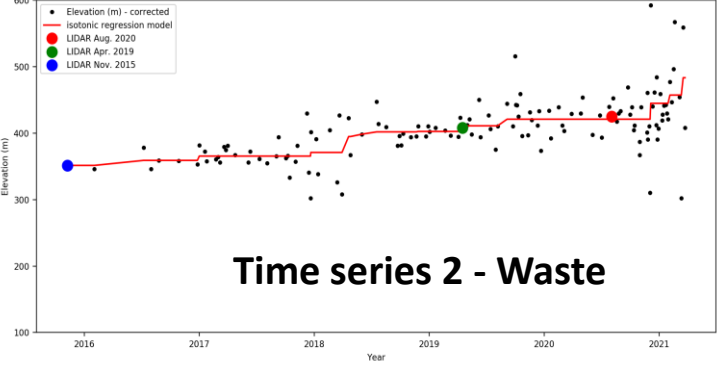
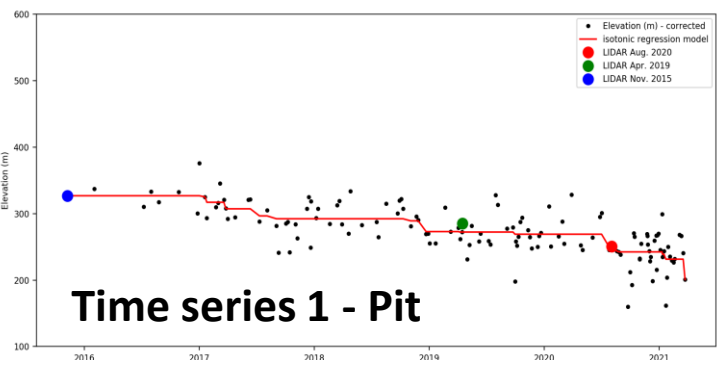
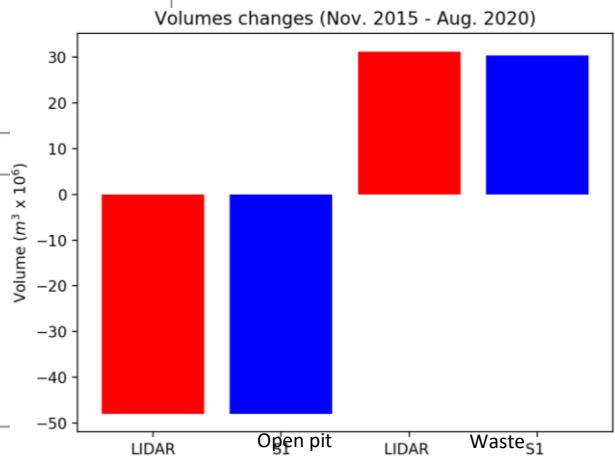
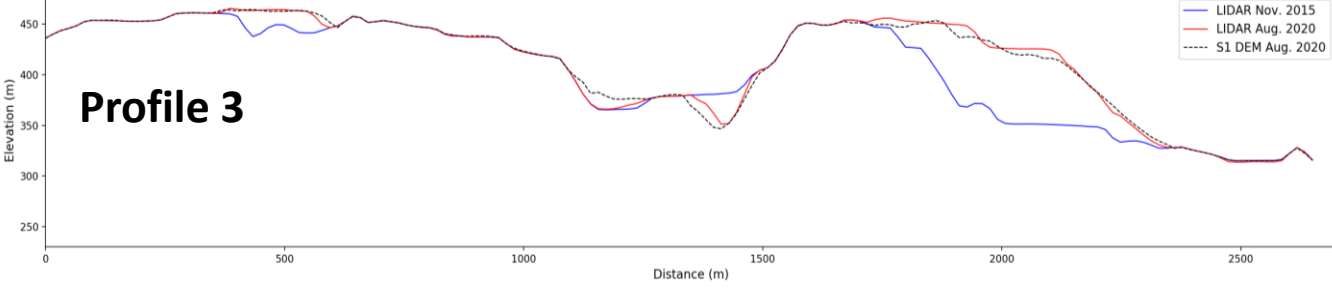
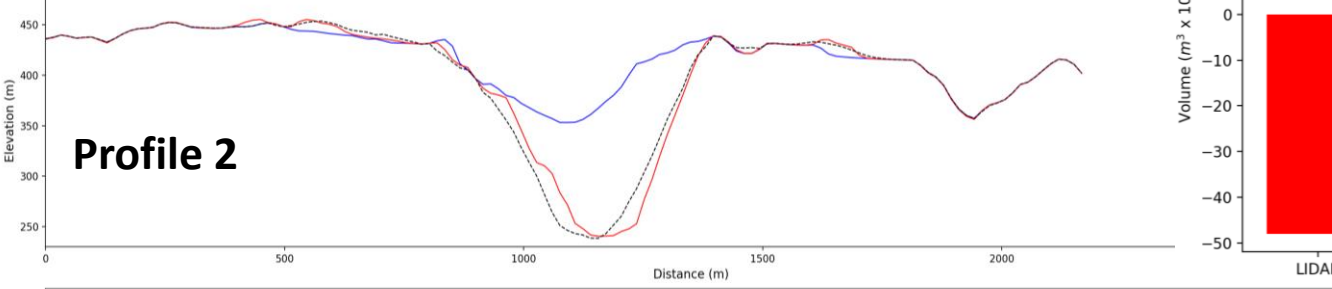
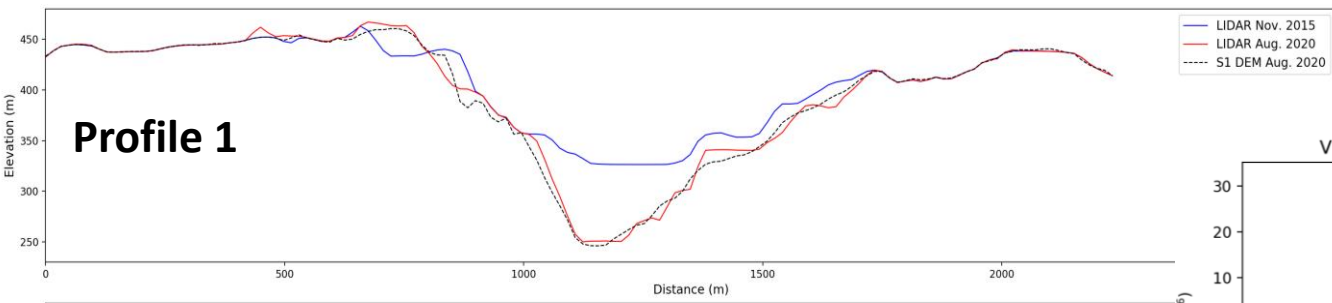
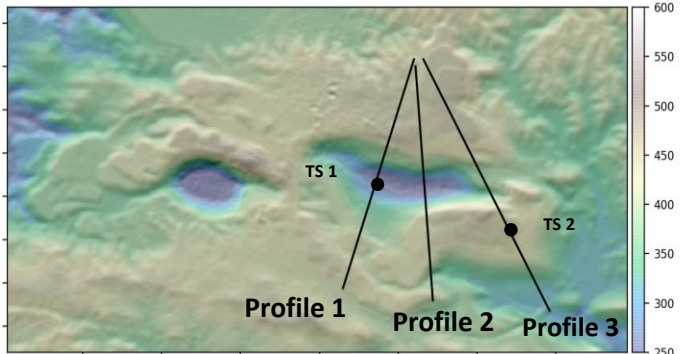
## Riotinto Mine - May to August 2019



## Topographic changes based on time series analysis of DEMs generated from Sentinel-1



### Riotinto Mine



# Raw Materials lifecycle & Copernicus



## Ground Stability and Mining monitoring

**CZ-EWS**  
(2017-2018)

**Earth's Critical Zone Early Warning System (CZ-EWS) by integrating SAR and seismic data in a mining context (Minas Riotinto, SW Iberia)**

**InTarsis**  
(2018-2019)

**A ground monitoring system combining Sentinel-1 and seismic**

**InTarsis II**  
(2019-2021)

**Using Sentinel-1 to improve mining monitoring capacities in Andalucía, Spain**

**Dr. Ignacio Marzán**  
Researcher at CSIC

Multidisciplinary geophysicist  
focused on monitoring our  
interaction with the underground  
environment in natural resources  
searching.

# CZ-EWS: Early Warning System integrating SAR and seismic data in Riotinto mine

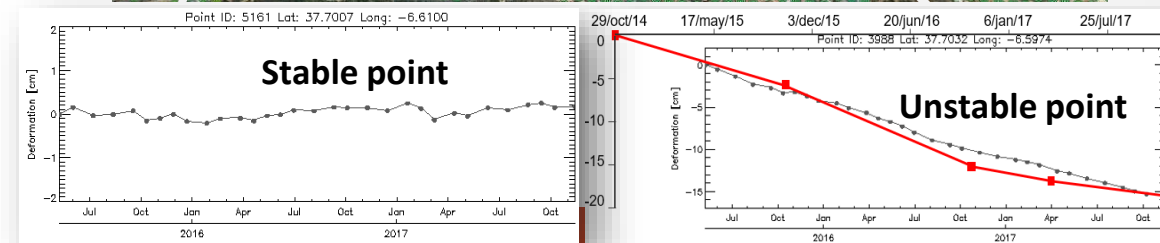
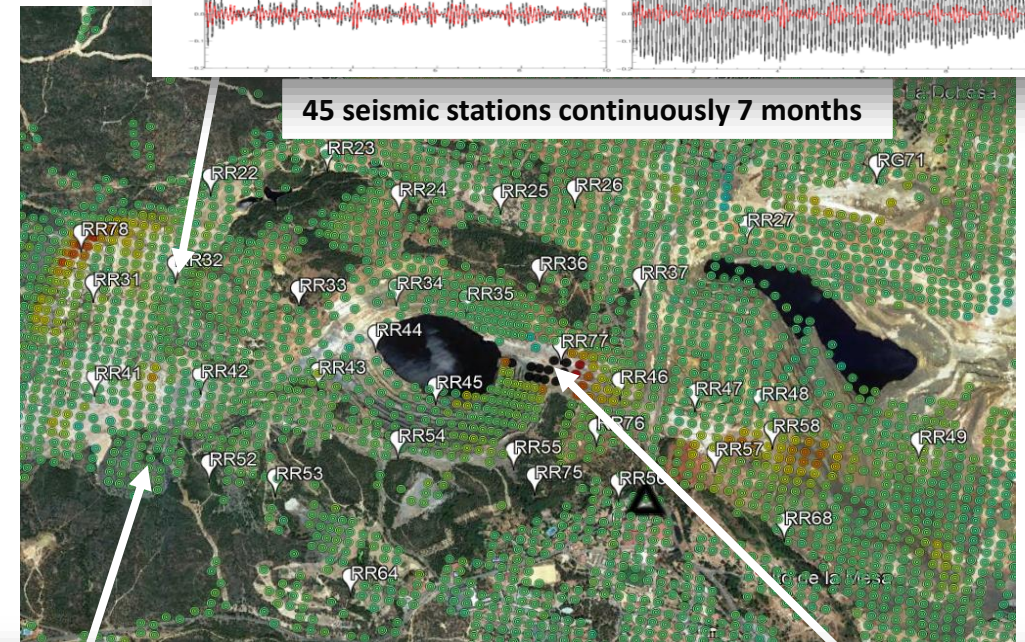
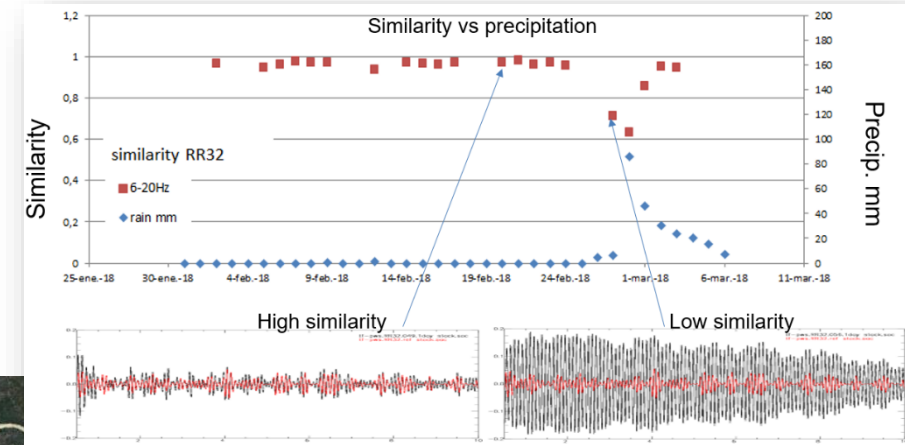
## Objectives:

- To reduce ground stability hazards related to mining activities through a monitoring system that combines SAR and passive seismic data.
- Ground deformation map of in Riotinto mine.

## Outcomes:

- Deformation map of the study area was completed for the period May 2015 to Nov 2017.
- 4 main zones of deformation were characterized.
- Good correlation with GPS measurements in the abandoned open pit
- 45 seismic stations, 7 months continuous recording showed promising results for autocorrelation mapping that could anticipate ground failures.

R32 Temporal variations of soil mechanical properties due to rain



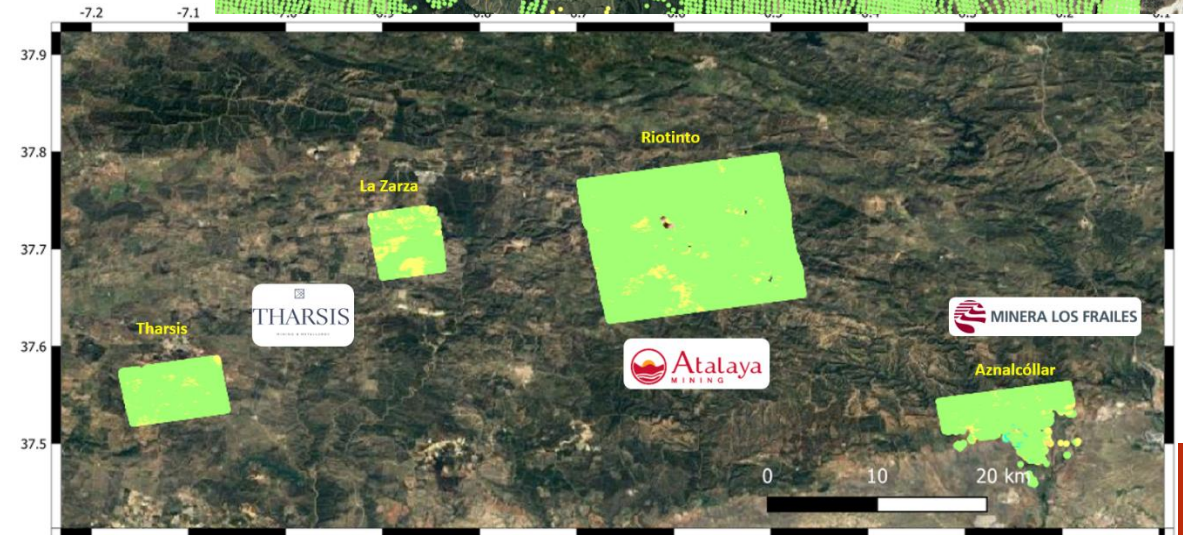
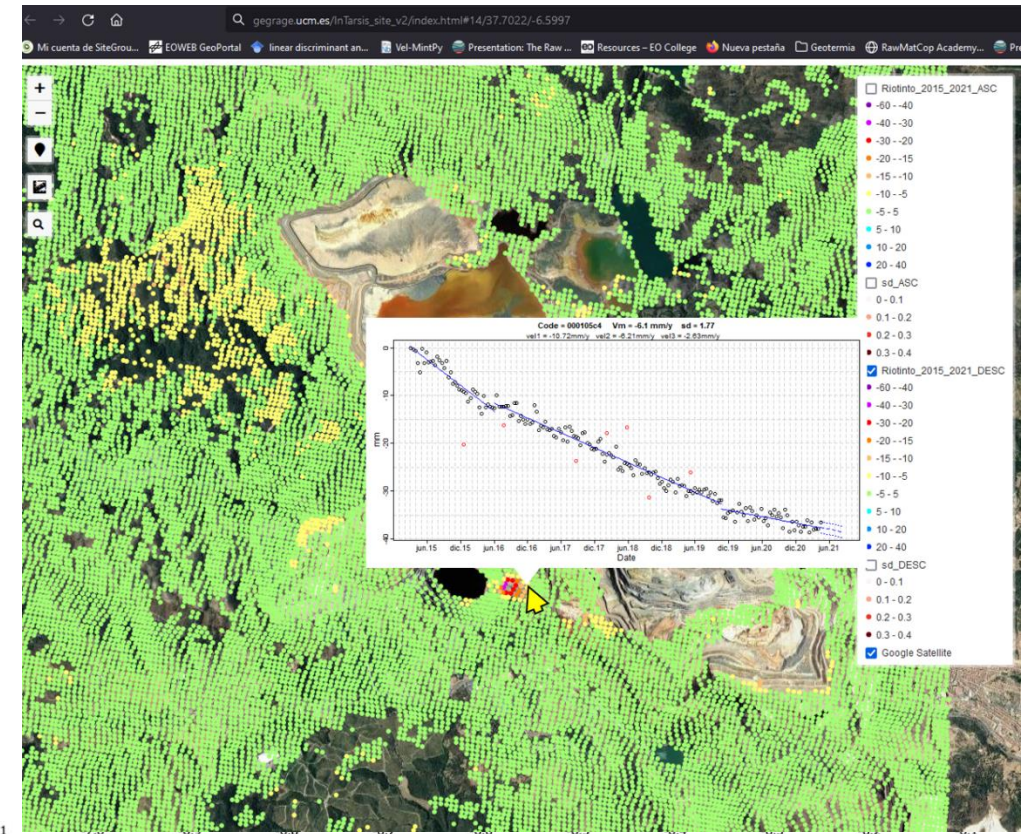
# InTarsis I-II (2019-2021) Web tool to improve ground stability monitoring capabilities of mining stakeholders

## Objectives:

- To contribute to a safe and sustainable mineral supply by improving the monitoring capacity of mining stakeholders
- To devise InTarsis, a web tool that serves digested Sentinel-1 ground deformation data at the end-user level.
- To apply InTarsis to 4 mining target in the Iberian Pyrite Belt
- To train our mining partners in the use of Sentinel-1

## Outcomes:

- The InTarsis tool is working and is being tested together with our partners.
- The 4 mining targets were monitored (updates every 12 days, from 2017-2021)
- New instable areas were detected.
- Partners got access to the web service.





# Raw Materials lifecycle & Copernicus



## Mining Residuals (tailings and stockpiles)

COP-piles  
(2018-2019)

Sampling optimization in stockpiles/tailings, for grade mapping of raw material using geostatistical analysis and Earth observation data

BRICO-piles  
(2019-2021)

Characterization of bauxite residuals in abandoned sites for contamination monitoring and raw material recovery using Copernicus data



**Dr. Sara Kasmaeeyzdi**  
Mining Engineer and Post-  
Doc Researcher at University  
of Bologna

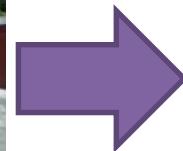
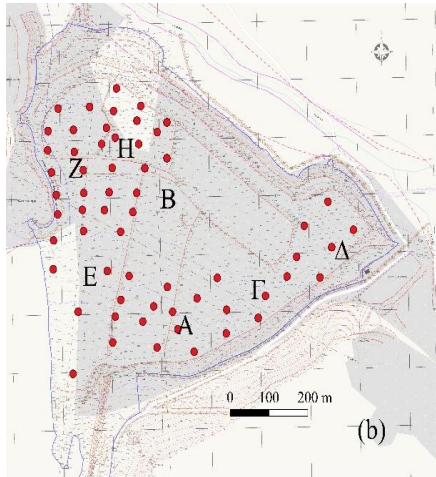
Expert in in geostatistics and remote  
sensing in the fields of resources  
exploration and environment.

# COP-Piles (2018) Sampling optimization in stockpiles/tailings, for grade mapping of raw material using geostatistical analysis and Earth observation data (ENEA, NTUA, MYTILINEOS S.A)



## Active Bauxite Residues

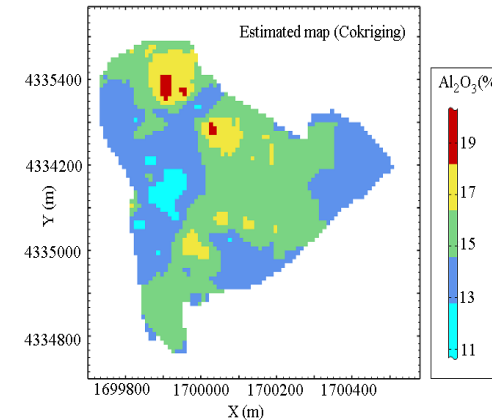
Daily data concentrations (Fe, Al, Ti, V)



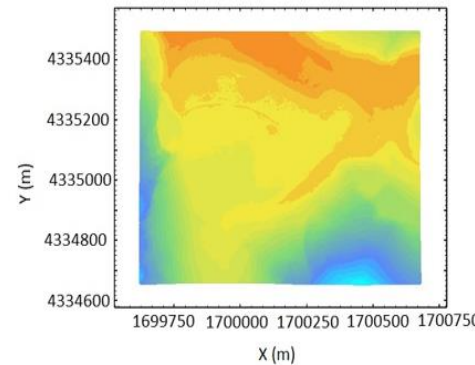
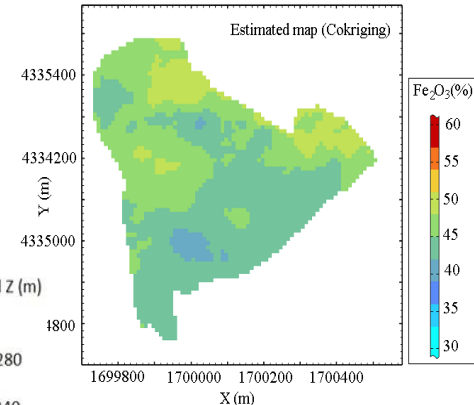
stereo images of PLEIADES (23-5-2019)



Sentinel-2 image in 23-06-2019



Grade maps for  $Fe_2O_3$  and  $Al_2O_3$



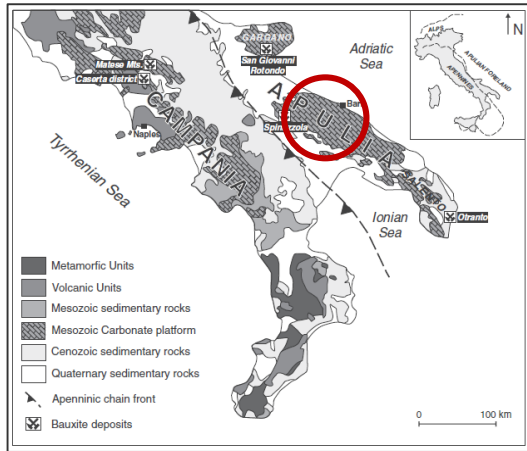
Topography map and Volume calculation

## Objective:

- mapping Aluminium, Iron and Vanadium variability within the bauxite residuals.
- Optimization of sampling with market and environmental scenarios.



# BRICO-Piles (2019) Characterization of bauxite residuals in abandoned sites for contamination monitoring and raw material recovery using Copernicus data (EIT RawMaterials Regional Hub Puglia)



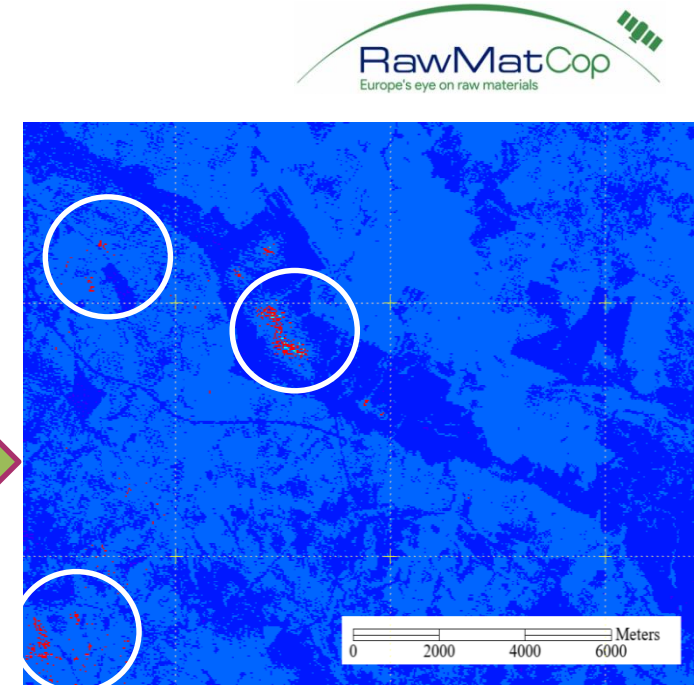
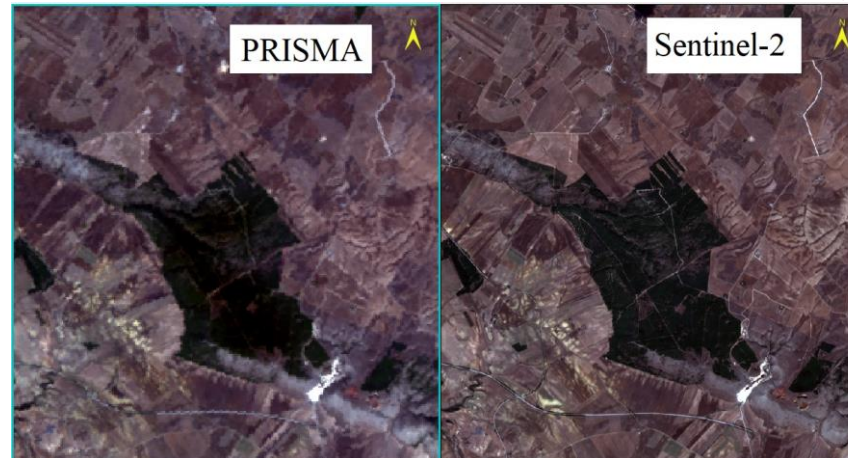
bauxite residues in Puglia region (Italy)

## Abandoned Bauxite Residues

Spectro-radiometry surveys and Sampling



Satellite Images



Possible bauxite areas detected by iron-oxides band-ratio (PRISMA Image- 20-09-2020)

## Objective:

- Detection of exploitable materials (bauxite potential points);
- Expansion of hyperspectral imaging services for raw materials sector



# Raw Materials lifecycle & Copernicus



## Environmental Monitoring



CoCoMo  
(2018-2019)

Copernicus for contamination monitoring and decision support in active mining and rehabilitation

**Dr. Christian Köhler**

RawMatCop Researcher

2017-2019 at TU

Bergakademie Freiberg

Physicist with expertise in remote

sensing for environmental

monitoring

# CoCoMo (2018-2019) Copernicus for Contamination Monitoring and Decision Support in Active Mining and Rehabilitation (Jörg Benndorf, TU Bergakademie Freiberg)



## The objectives of the project are:

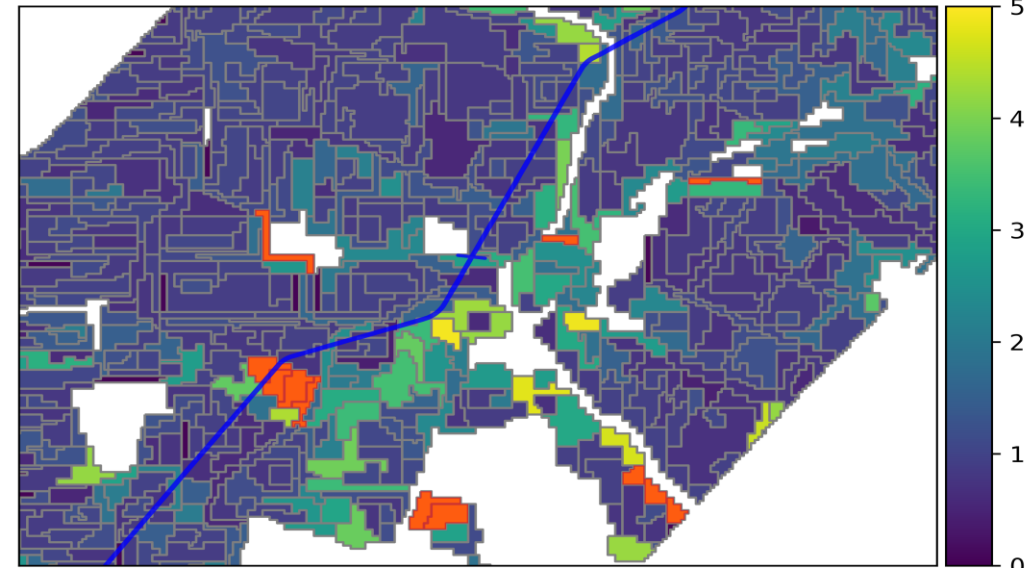
- Integrate multi-scale (Copernicus Sentinel, UAV, ground-based), multi- and hyperspectral spatio-temporal data into one comprehensive data product.
- Assess the potential of multidimensional spatio-temporal data for environmental contamination monitoring
- Development of workflows and algorithms for early, nearly real-time identification of potentially contaminated areas

## The impacts are:

- Strengthen the use of Copernicus data
- Increase of social acceptance and safety of mining operations

## Exemplary application of results: Early warning system for oil pipelines

Mahalanobis distance



Color coded threat level (violet=low, yellow=high) for potentially contaminated areas along oil pipeline (blue). Red areas exceed threshold and are reported as contamination warning.



# Sum up and outcomes of researches:



- The developed tools have the potential to reduce monitoring costs, to increase public awareness as well as to improve openness and transparency of the environmental impacts and remediation of mining activities.
- Sentinel-2 can be used to identify and monitor areas affected by acid mine drainage, allow for short-term or “real-time” monitoring.
- Using Copernicus data helps in suitable planning in the issuing of mining titles and licenses and efficient and well-designed interventions to stop illegal activities (monitoring the impacts the landscape, degrades the land, and contaminated the food chain with heavy metals).

# Sum up and outcomes of researches:

- Helping the Mineral exploration steps in hard reaching and challenging logistical areas: The Copernicus data may make exploration more efficient by identifying areas of particular interest and higher prospectivity.
- Monitoring of stability cost-effectiveness, great coverage, and a good resolution combined with a short time baseline thanks to Sentinel 1.
- Developement of workflows and algorithms for real-time identification of potentially contaminated areas, resulted by mining activities.





ELSEVIER

Contents lists available at ScienceDirect

## Resources Policy

journal homepage: [www.elsevier.com/locate/resourpol](http://www.elsevier.com/locate/resourpol)



### Copernicus data to boost raw material source management: Illustrations from the RawMatCop programme

Sara Kasmaeyazdi<sup>a,\*</sup>, Mehdi Abdolmaleki<sup>b</sup>, Elsy Ibrahim<sup>c</sup>, Jingyi Jiang<sup>c</sup>, Ignacio Marzan<sup>d</sup>, Irene Benito Rodríguez<sup>e</sup>

<sup>a</sup> Civil, Environmental, Chemical and materials Engineering (DICAM) University of Bologna, Italy

<sup>b</sup> Civil, Environmental and Natural Resources (SBN/GVM), Luleå University of Technology, Sweden

<sup>c</sup> Minerals Engineering, Materials & Environment (GeMME), Université de Liège, 4000, Liège, Belgium

<sup>d</sup> Georesources Barcelona, ICTJA-CISC, Spain

<sup>e</sup> RawMaterials Copernicus (RawMatCop) Programme, EIT RawMaterials, Berlin, Germany

#### ARTICLE INFO

##### Keywords:

Critical raw materials  
Copernicus  
Sentinel  
Mining residuals  
Exploration  
Mineral resources  
Ground instability  
Small-scale mining

#### ABSTRACT

Earth Observation (EO) data can become an essential tool in the transformation of a raw materials sector that aims to reconfigure its model of operation. The high demand for the mineral resources necessary for the transition to a carbon neutral and circular economy conflicts with the increasing difficulties of finding new deposits. As the sector heads towards embracing circularity and reducing the environmental impacts, a clear focus has been set on developing appropriate tools to boost the efficiency of mineral resource management, both technologically and economically. In this scenario, the Sentinel satellites of the European Copernicus program come into play. Despite being satellites considered medium resolution, they provide great temporal and spatial coverage in a continuous record, which makes them tools with great potential for the raw materials sector. However, the lack of applications in the raw materials sector suggests that these technological advances have remained underrated by sectoral actors. The RawMatCop program was designed to bridge this gap. This program, co-funded by the European Commission and EIT RawMaterials, aims to develop applications and promote the use of Copernicus data in the raw materials sector to contribute to a safe and sustainable supply of mineral resources. The presented applications can be grouped into three categories covering the whole mining cycle from exploration to exploitation and post-mining. Two of the presented case studies cover the study of primary sources including exploration of Iron Oxide Copper Gold mineralisations to identify high-potential mining areas and mapping of informal gold mining and its environmental impacts. Another project focused on secondary sources tackled data applications for grade mapping and sample optimisation in mining residues. And the fourth project focused on monitoring ground stability related to mining activity. The results demonstrate the high cost-effectiveness of Sentinel 1 and 2 in extending ground-based measurements to larger areas, especially when these are hard-to-reach areas. Finally, the presented projects examine the industrial and social impacts of technological innovations, as well as contribute to the achievement of prominent European Union policy objectives and the United Nations Sustainable Development Goals.

For more details please  
read our published group  
paper



ALMA MATER STUDIORUM  
UNIVERSITÀ DI BOLOGNA



# ✓ Raw Mat Cop (2017-2021)



## 2 physical short course:

- ✓ University of Liege (Belgium-2017)
- ✓ University of Bologna (Italy-2018)

## On-line course:

More than 5 on-line short courses since 2018



Each day started with a key-speker, an expert of using RS in mining

# Raw Mat Cop Short courses



## Course topics

- ✓ Introduction to Copernicus and Earth Observation data
- ✓ Basics of imaging technology, optical and active remote sensing in raw materials
- ✓ Optimised ways to monitor environmental impact and increase safety
- ✓ Copernicus' tools to tackle the industrial and societal challenges of raw materials in Europe



## Case studies & exercises

- ✓ Mineral exploration and mapping of deposits
- ✓ Monitoring of mining activities including waste management
- ✓ Environmental impact monitoring
- ✓ Water detection

<https://www.youtube-nocookie.com/embed/Kh50fe6hRds?rel=0>

# ✓ Raw Mat Cop Alliance (2022-2024)



Follow up the Raw Mat Cop: Project has started in July 2022.

- ✓ 3 advanced course will be held in 2023 and 2024;
- ✓ Continuing the groups' activities on developments of advanced methods contribute to a safe and sustainable supply of mineral resources.





**Thank You for your attention**

**PhD Student S.Kasmaee**

**Please contact me: [sara.kasmaeeyazdi2@unibo.it](mailto:sara.kasmaeeyazdi2@unibo.it)**

**[www.unibo.it/sitoweb/sara.kasmaeeyazdi2](http://www.unibo.it/sitoweb/sara.kasmaeeyazdi2)**



ALMA MATER STUDIORUM  
UNIVERSITÀ DI BOLOGNA



ALMA MATER STUDIORUM  
UNIVERSITÀ DI BOLOGNA

Dipartimento di Ingegneria Civile, Chimica, Ambientale e dei Materiali

[www.unibo.it](http://www.unibo.it)