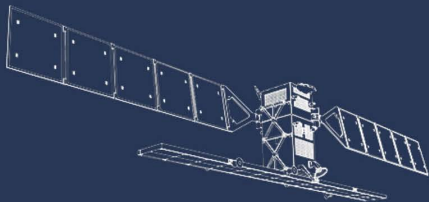


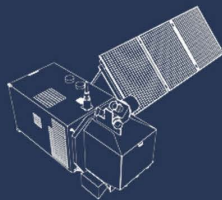


# TUTORIAL FOR EXERCISE 5

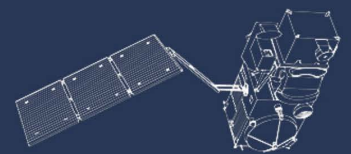
## Raw materials detections using Sentinel-2



sentinel-1



sentinel-2



sentinel-3

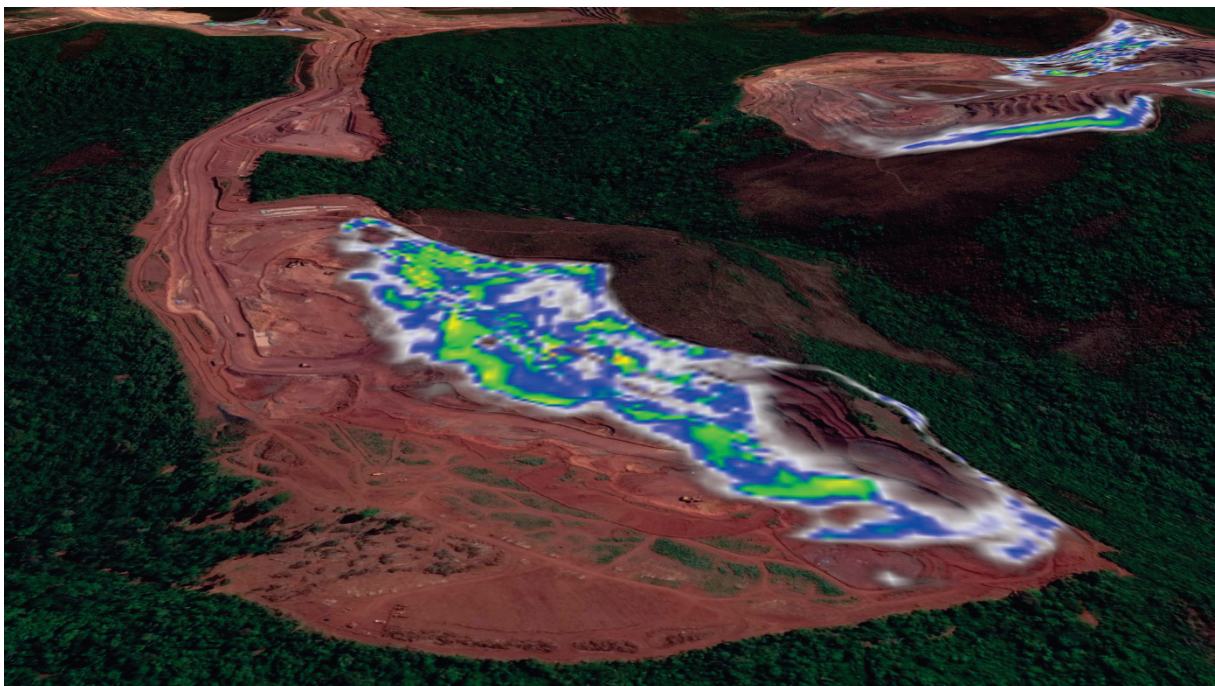
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# 1 Exercise outline

In this exercise, we will:

- learn how to differentiate spectra of iron bearing minerals
- extract the pixels of an outcrop of interest on Sentinel-2 image
- learn how to use different band-ratios to detect iron bearing minerals for this outcrop
- visualize the resulting classification and compare it with the field data
- learn how to use Spectral Angle Mapper
- detect the presence of iron bearing mineral within the outcrop using SAM



## 2 Iron bearing minerals detection

The Earth has a complex and variable surface whose topographic relief and material composition reflect the bedrock and unconsolidated materials beneath each part of the surface, as well as any changes that have affected them. Anyone who seeks to describe and explain the materials and structures of the Earth's surface must understand geomorphological principles and be able to recognise the surface manifestations of different materials and structures. Applications of RS in geological mapping focus on identifying these materials and structures and assessing their properties and characteristics. Geological mapping usually requires a considerable amount of field survey, but the mapping process can be greatly facilitated by the use of visual interpretation of images and their digital analysis.

One of the important roles of RS in this field is the use of satellite imagery as a logistical aid for geological field mapping, especially in remote regions. Satellite imagery provides an efficient and relatively inexpensive way of obtaining information about an area compared to ground-based field surveys. The images are used to locate areas where rocks are exposed at the surface and are thus accessible to study and monitor key geological units. The images also allow important differences between landforms to be identified, linking them to the geological processes that have shaped them.

Hyperspectral sensors can obtain reflectance values with a quality similar to laboratory measurements and can therefore provide unique spectral data at high spectral resolution. This allows accurate identification and mapping of minerals and rocks using a variety of hyperspectral sensors while determining the point, local and regional distribution of minerals for a range of geological and soil science investigations.

## 2.1. Study area and image download

Download image:

S2B\_MSIL2A\_20210803T134209\_N0301\_R124\_T22MEU\_20210803T173901

from Copernicus Open Access Hub

[<https://scihub.copernicus.eu/dhus/#/home>]

The study area is a part of the Serra Norte Mining Complex - surface mine situated in Para, Brazil.

The mine produced an estimated 106.092 mtpa of iron ore in 2020.

S2B\_MSIL2A\_20210803T134209\_N0301\_R124\_T22MEU\_20210803T173901

Outline [https://scihub.copernicus.eu/dhus/odata/v1/Products\('c03aa15e-8bcb-457e-bc56-48c7c2bbe9e9'\)\\$value](https://scihub.copernicus.eu/dhus/odata/v1/Products('c03aa15e-8bcb-457e-bc56-48c7c2bbe9e9')$value)

Footprint

Quicklook

Attributes

Summary

Date: 2021-08-03T13:42:09.024Z

Filename: S2B\_MSIL2A\_20210803T134209\_N0301\_R124\_T22MEU\_20210803T173901 SAFE

Identifier: S2B\_MSIL2A\_20210803T134209\_N0301\_R124\_T22MEU\_20210803T173901

Instrument: S2B

Satellite: Sentinel-2

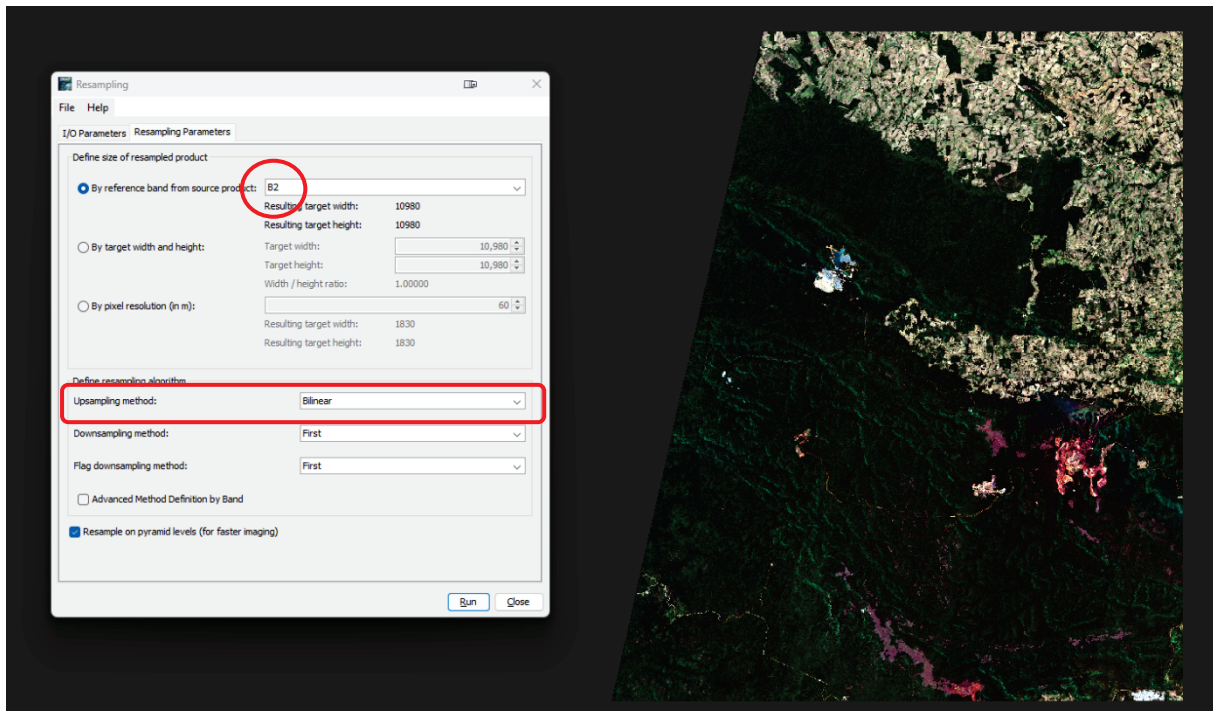
Size: 888.45 MB

Serra Norte Mining Complex

## 2.2. Image pre-processing

### Resampling

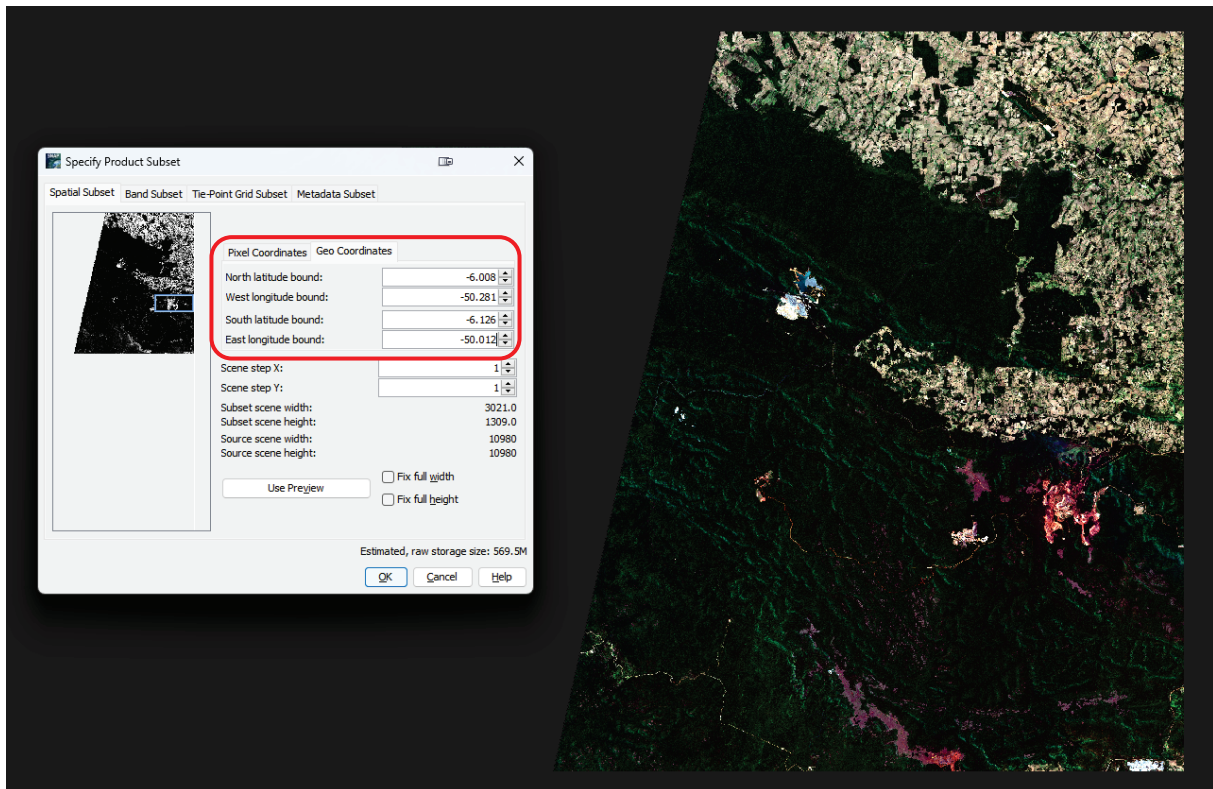
Firstly, we will resample the image to 10 m pixel size using bilinear upsampling.



### Subset

Secondly, we will create a subset for the outcrop using the following Geo coordinates:

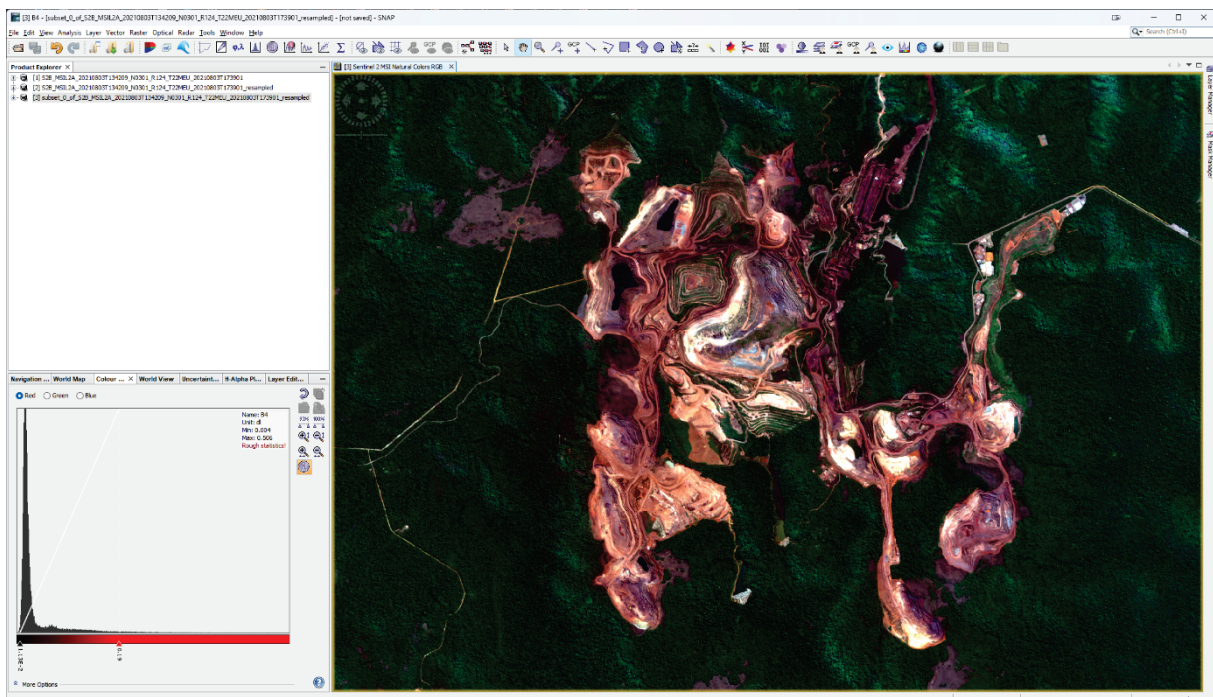
|   |         |
|---|---------|
| N | -6.008  |
| W | -50.281 |
| S | -6.126  |
| E | -50.012 |



RGB composite

Then, we will open the MSI Natural Colours RGB composite of the generated subset.

To assess our work and to evaluate the difference between spectra of various layers – we will use pins for two locations with known iron content.



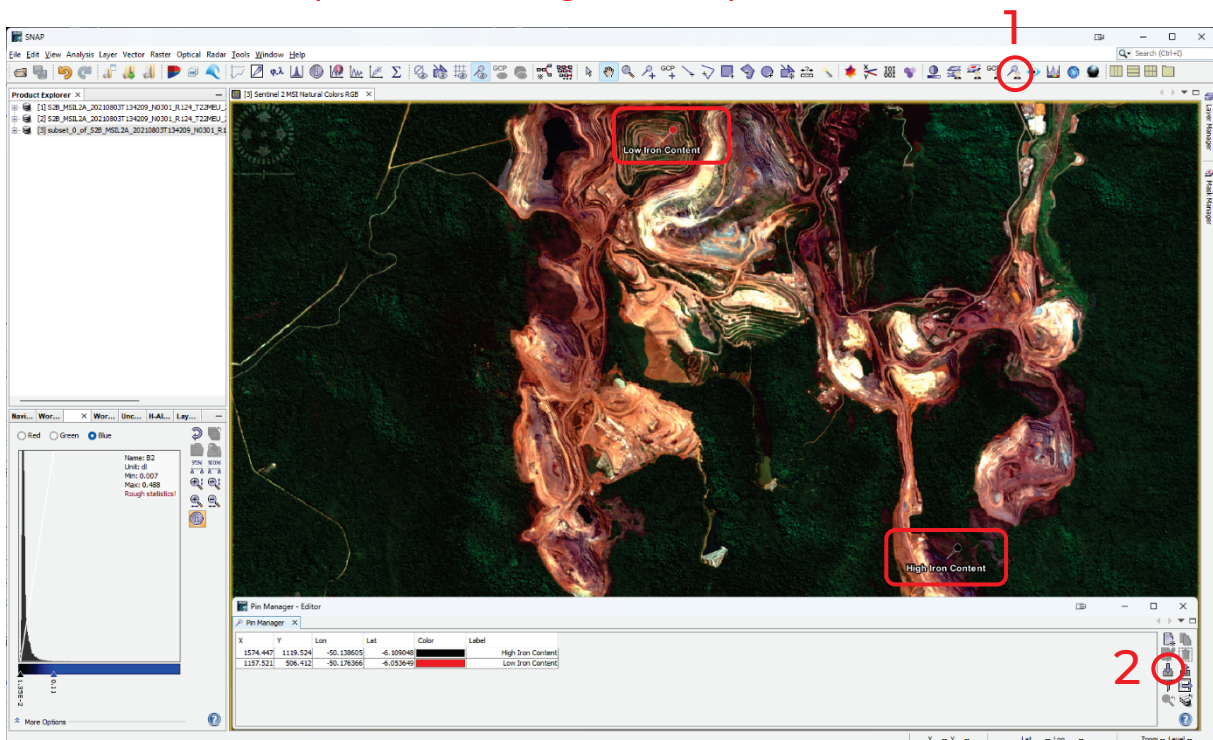
## 2.3. Spectra of iron bearing minerals

### Importing pins with known data

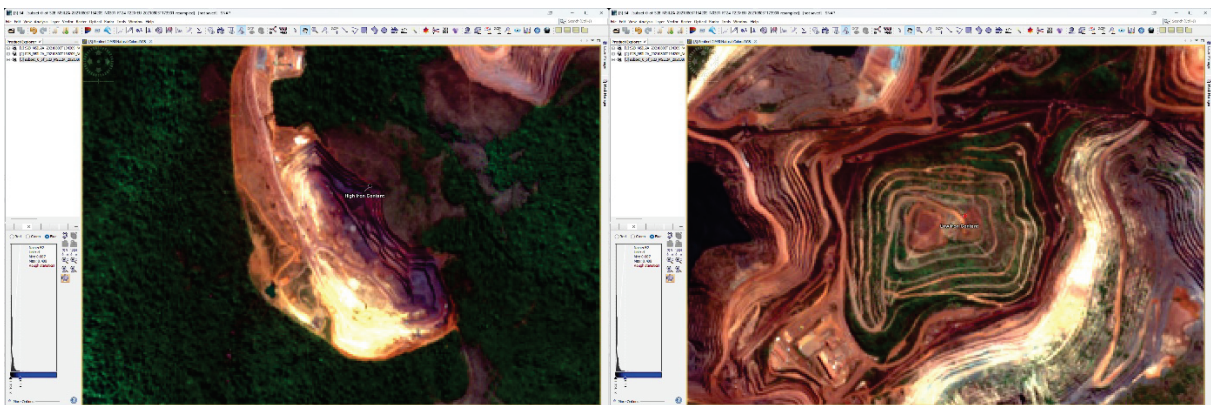
Firstly, we will open those pins for two locations. To do this:

1. open the pin manager;
2. import the provided pins for *High Iron Content* and *Low Iron Content*.

*pin\_IronBearingMinerals.placemark*



We can visually compare these two locations; how they differ in RGB natural colours.





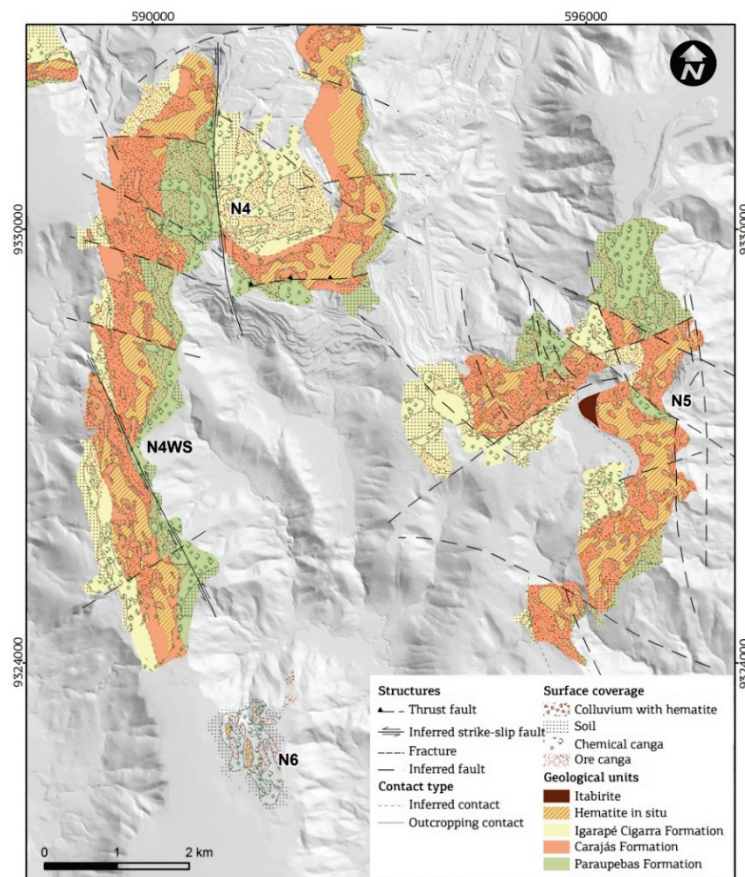
These pins corresponds to the location of newly opened quarrying containing minerals with high iron content;

and to the location of the older part with mined material – containing low iron content minerals.

To have a general overview of a geology of this outcrop and the Serra Norte Mining Complex, we refer to the paper:

*DOI: 10.1590/2317-4889201620160023*

*Ducart, D. F., Silva, A. M., Toledo, C. L. B., & Assis, L. M. de. (2016). Mapping iron oxides with Landsat-8/OLI and EO-1/Hyperion imagery from the Serra Norte iron deposits in the Carajás Mineral Province, Brazil. Brazilian Journal of Geology, 46(3), 331–349.*

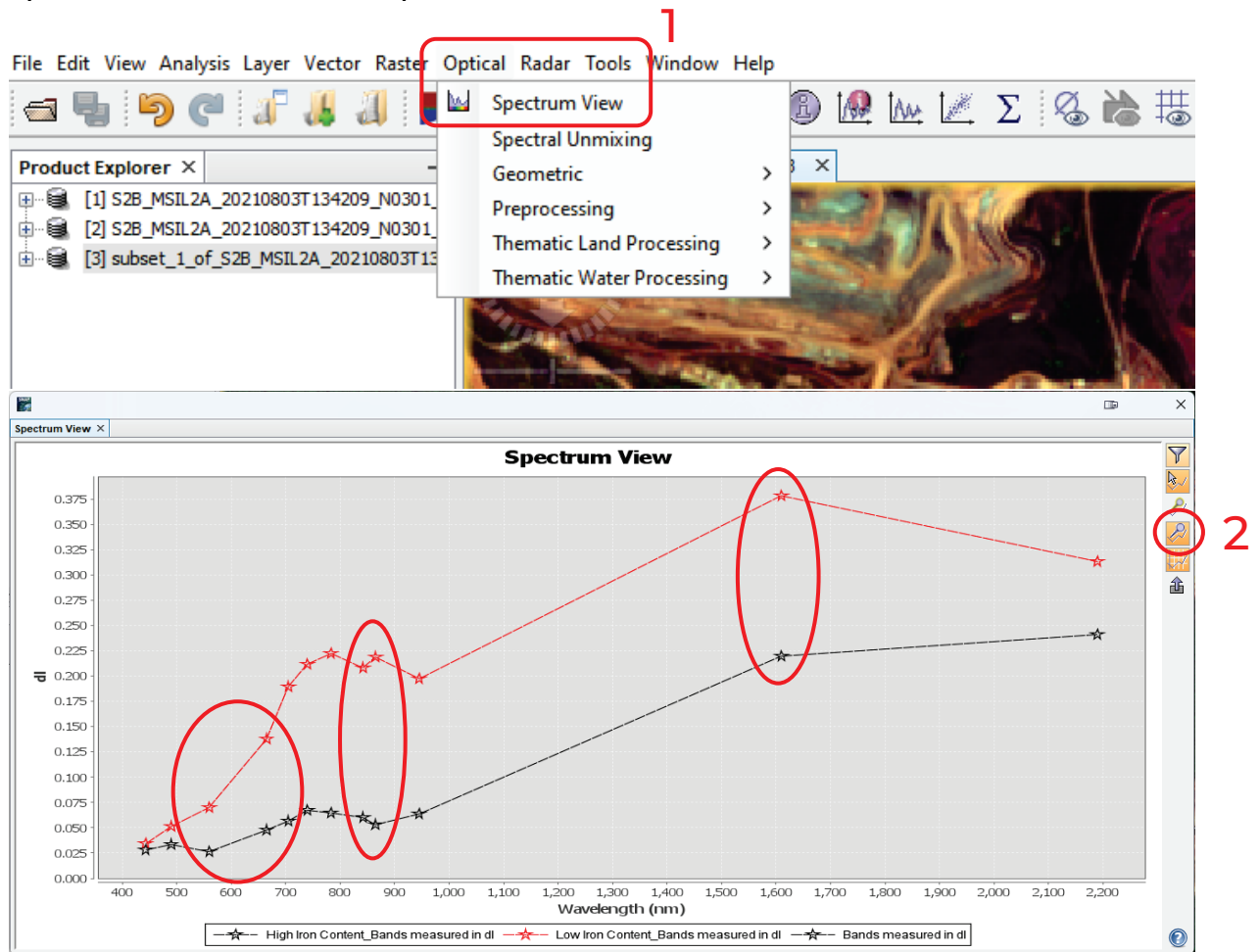


Spectrum view

To differentiate spectra of iron bearing minerals, we will use the tool Spectrum View for the two provided pins.

Both spectra belongs to the non-vegetated area, but still we can see that they are quite different from each other.

Therefore, to detect iron bearing minerals, we will use these differences in spectral curves and compute various band ratios.

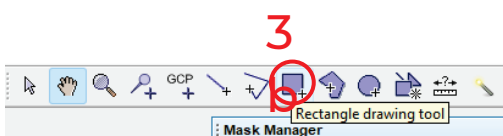
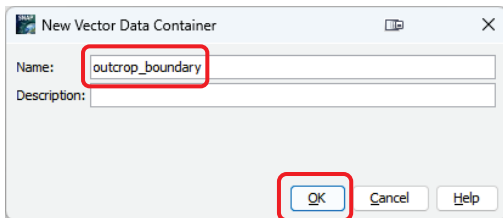
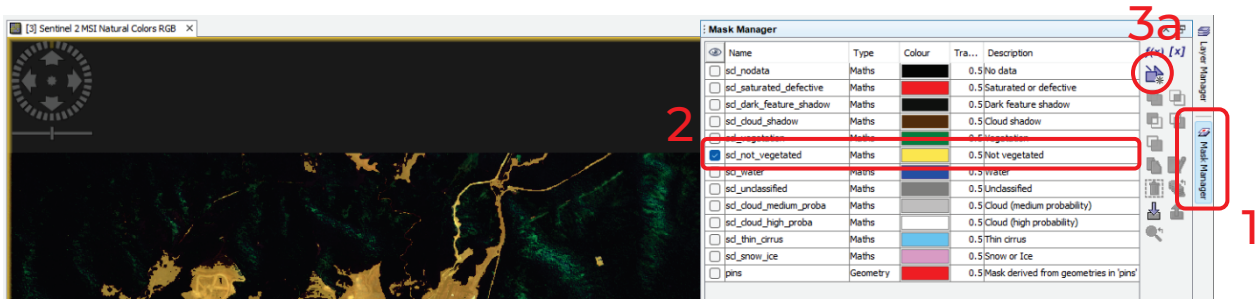


## 2.4. Extracting the outcrop

Since we are interested only in the bare soil within the outcrop, we will extract pixels for the non-vegetated part.

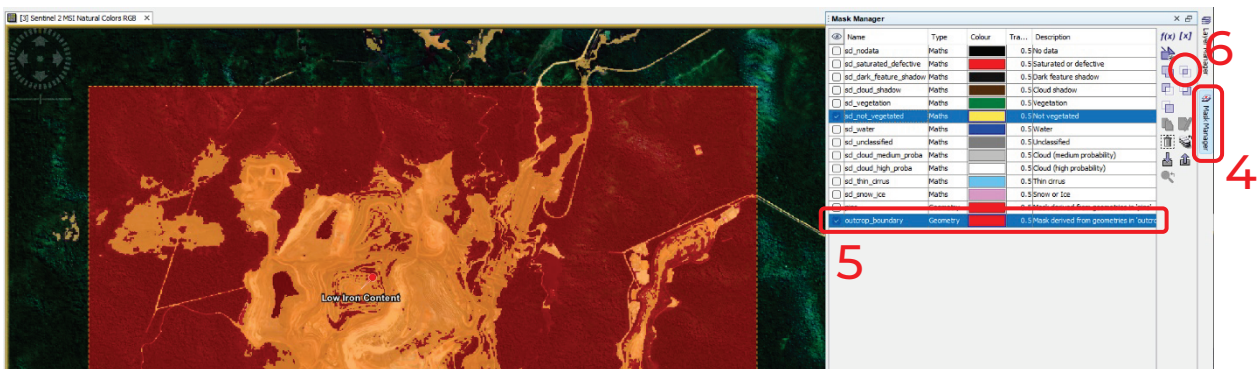
To do this:

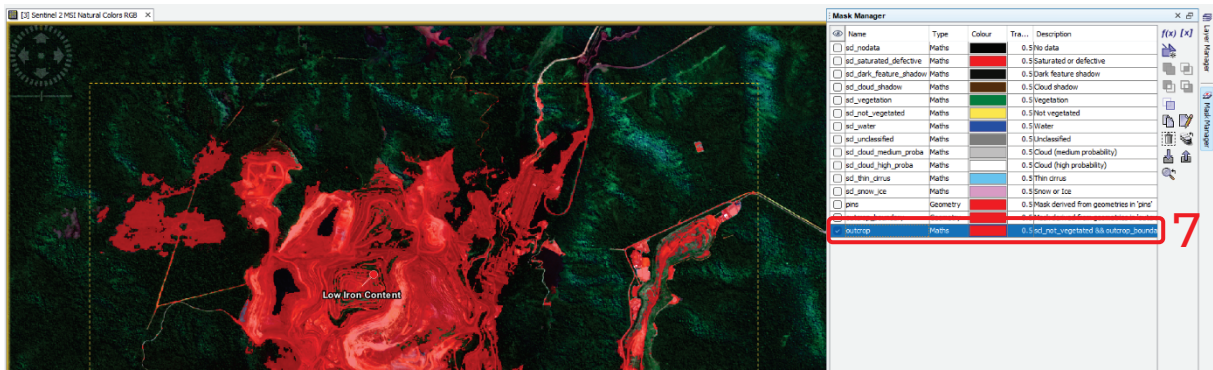
1. open the mask manager;
2. select *scl\_non\_vegetated* mask;
3. create a bounding box around the outcrop:
  - a) *new vector data container*,
  - b) *rectangle drawing tool*,
  - c) draw a rectangle.



Then, we will use the intersection between this bounding box and the other mask:

4. go to mask manager;
5. activate geometry for outcrop boundary and select both – mask and geometry;
6. use tool *Creates the intersection of the selected masks*;
7. the result is a new mask – rename it to outcrop and deselect other masks.





We can compare the final mask to see how well or bad it covers the outcrop area.



## 2.5. Band ratios

*For a more comfortable work, you can close SNAP and open only with the pre-processed subset image.*

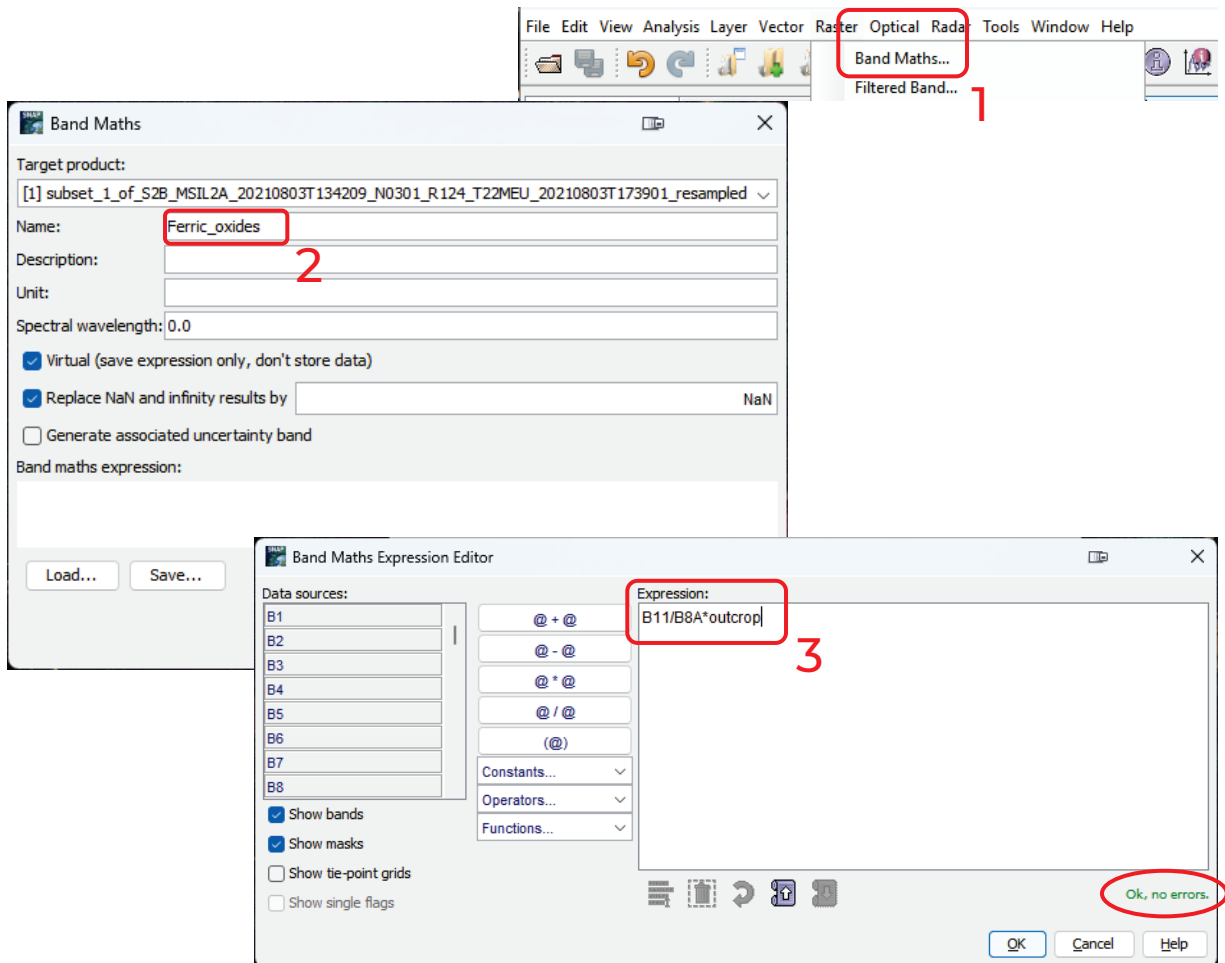
To detect iron bearing minerals, we will use different band ratios. The first one:

$$\text{Ferric oxides (Fe}^{3+}\text{)} = \frac{B11}{B8A}$$

To apply it only for our extracted outcrop area, we will use the following band math:

$$\text{B11/B8A*outcrop}$$

For the reference to this band ratio for iron bearing minerals see:  
 Ge, W., Cheng, Q., Jing, L., Wang, F., Zhao, M., & Ding, H. (2020). Assessment of the Capability of Sentinel-2 Imagery for Iron-Bearing Minerals Mapping: A Case Study in the Cuprite Area, Nevada. *Remote Sensing*, 12(18), 3028. DOI: 10.3390/rs12183028



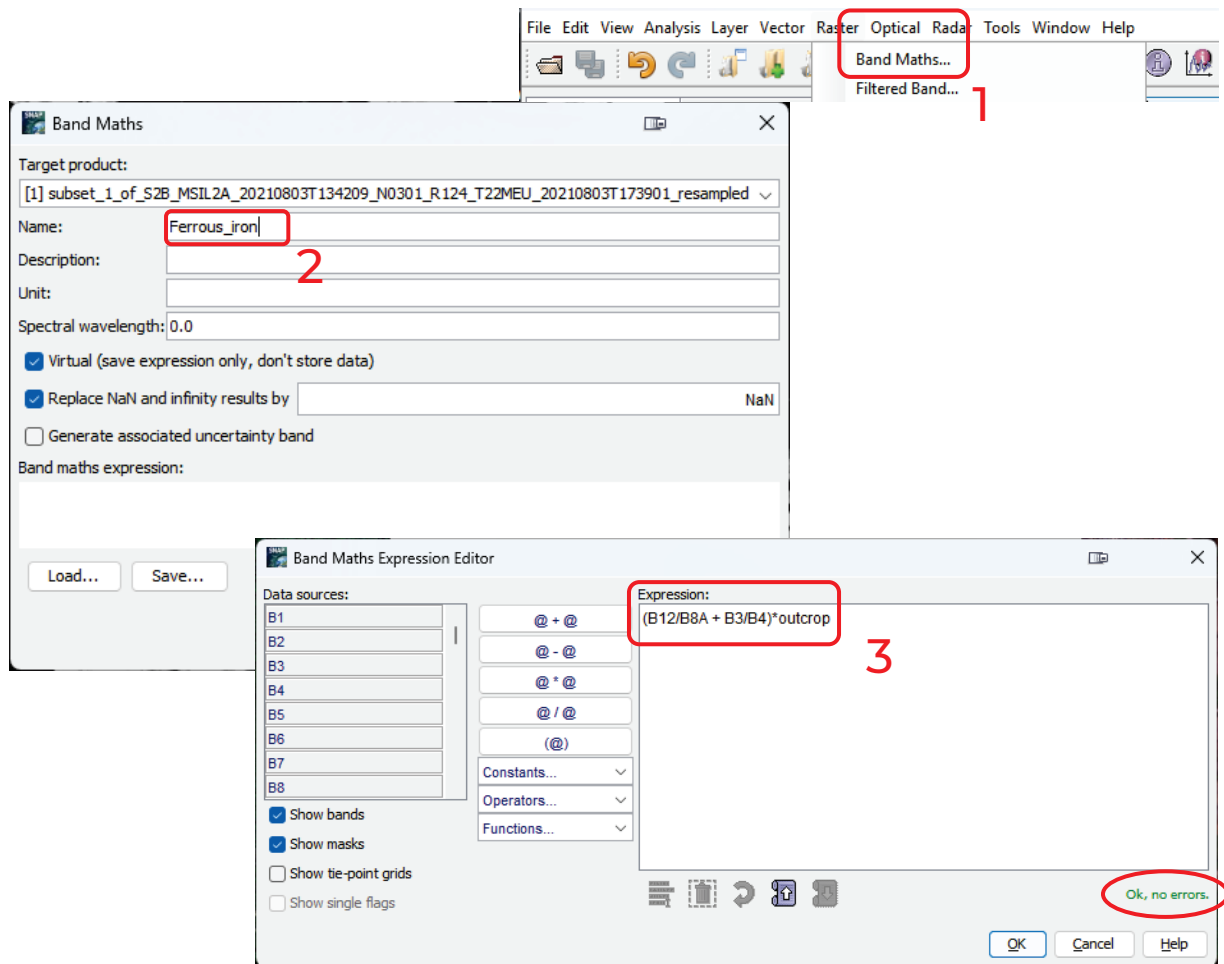
The second band ratio will be following:

$$\text{Ferrous iron (Fe}^{2+}\text{)} = \frac{B12}{B8A} + \frac{B3}{B4}$$

To apply it only for our extracted outcrop area, we will use the following band math:

$$(B12/B8A+B3/B4)*outcrop$$

For the reference to this band ratio for iron bearing minerals see:  
 Ge, W., Cheng, Q., Jing, L., Wang, F., Zhao, M., & Ding, H. (2020). Assessment of the Capability of Sentinel-2 Imagery for Iron-Bearing Minerals Mapping: A Case Study in the Cuprite Area, Nevada. *Remote Sensing*, 12(18), 3028. DOI: 10.3390/rs12183028



The third ratio that we will use was developed by *Ibrahim et al., 2018*.

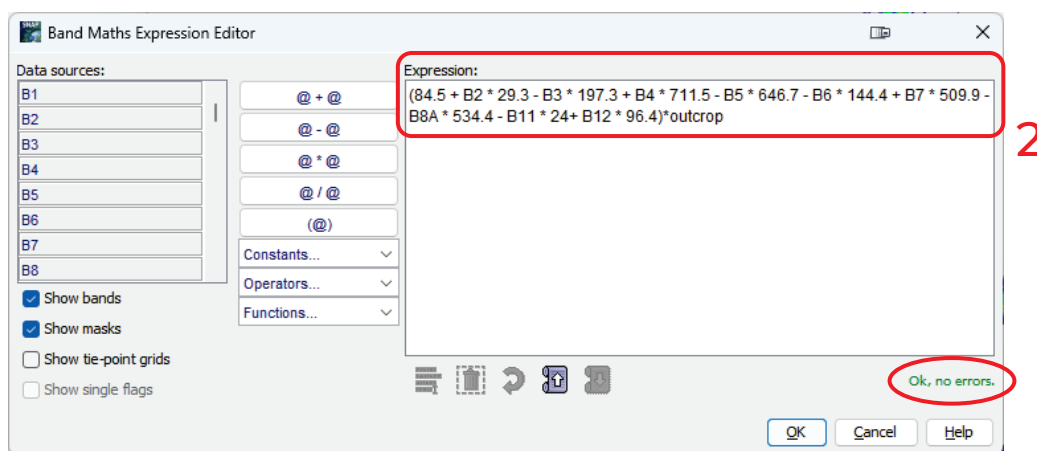
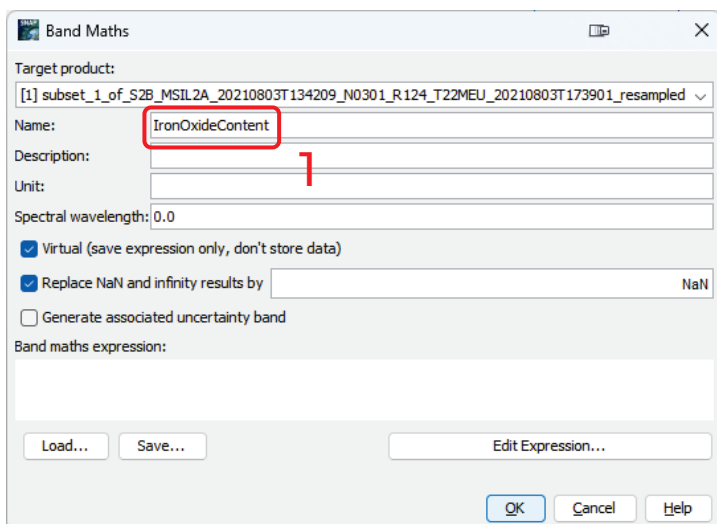
$$\text{IronOxideContent} = 84.5 + B2 * 29.3 - B3 * 197.3 + B4 * 711.5 - B5 * 646.7 - B6 * 144.4 + B7 * 509.9 - B8A * 534.4 - B11 * 24 + B12 * 96.4$$

To apply it only for our extracted outcrop area, we will use the following band math:

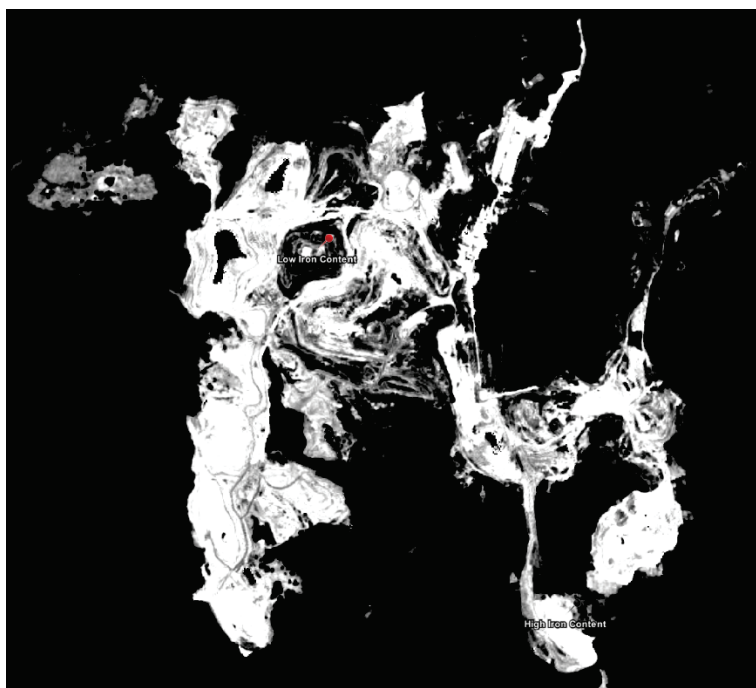
$$(84.5 + B2 * 29.3 - B3 * 197.3 + B4 * 711.5 - B5 * 646.7 - B6 * 144.4 + B7 * 509.9 - B8A * 534.4 - B11 * 24 + B12 * 96.4) * \text{outcrop}$$

For the reference see:

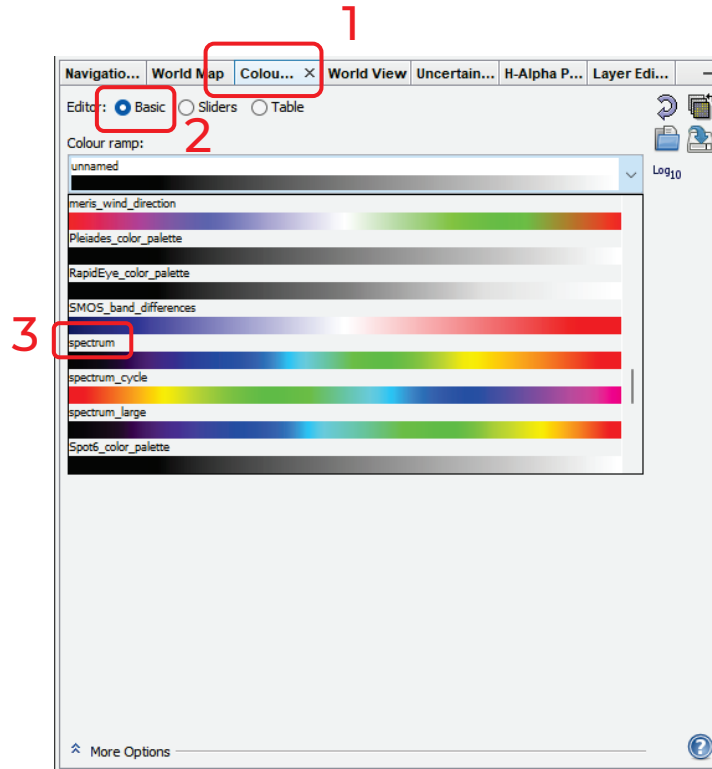
*Ibrahim, E., Barnabé, P., Ramanaidou, E., & Pirard, E. (2018). Mapping mineral chemistry of a lateritic outcrop in new Caledonia through generalized regression using Sentinel-2 and field reflectance spectra. International Journal of Applied Earth Observation and Geoinformation, 73, 653–665. DOI: 10.1016/j.jag.2018.08.004*



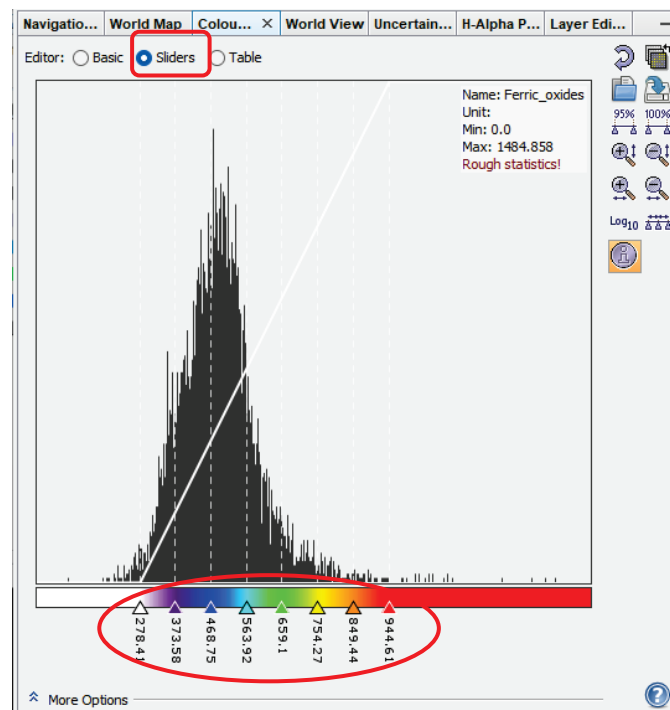
The resulting bands are displayed in grayscale.



By using *Colour Manipulation tool* (1) and *Basic editor* (2), we can assign various Colour ramps to the new band. For instance, we can use the „spectrum“ style (3).

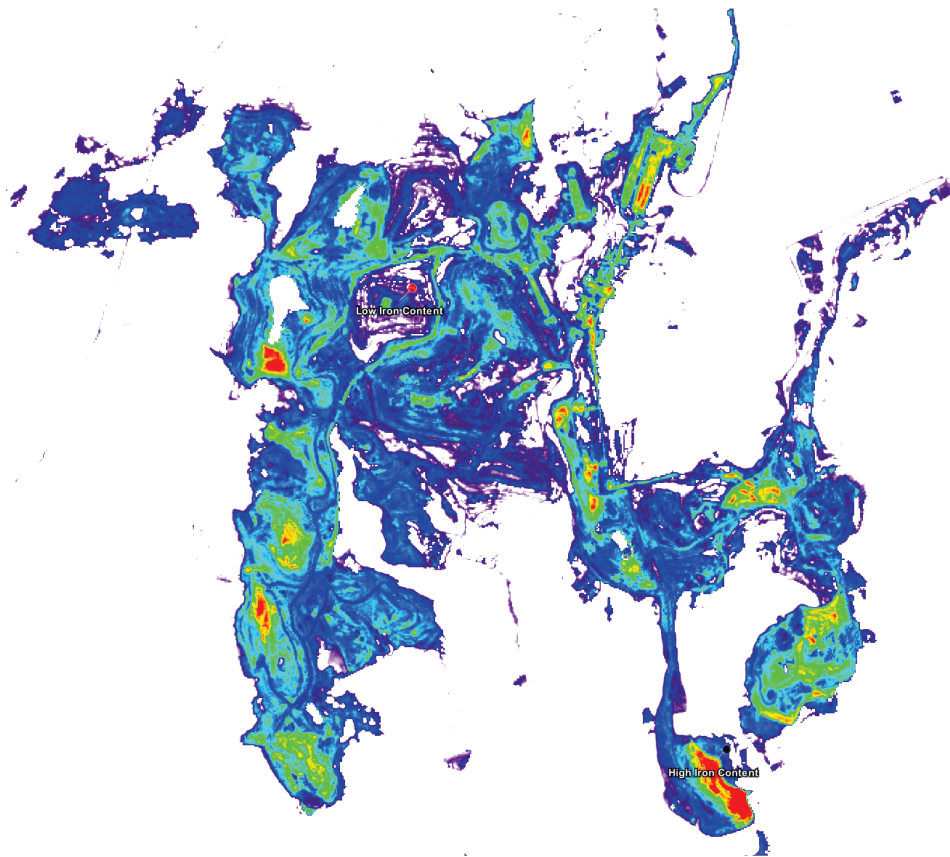


We can edit the final colour appearance by adjusting the position/colour of individual sliders.





The final image of the Ferric oxides content:



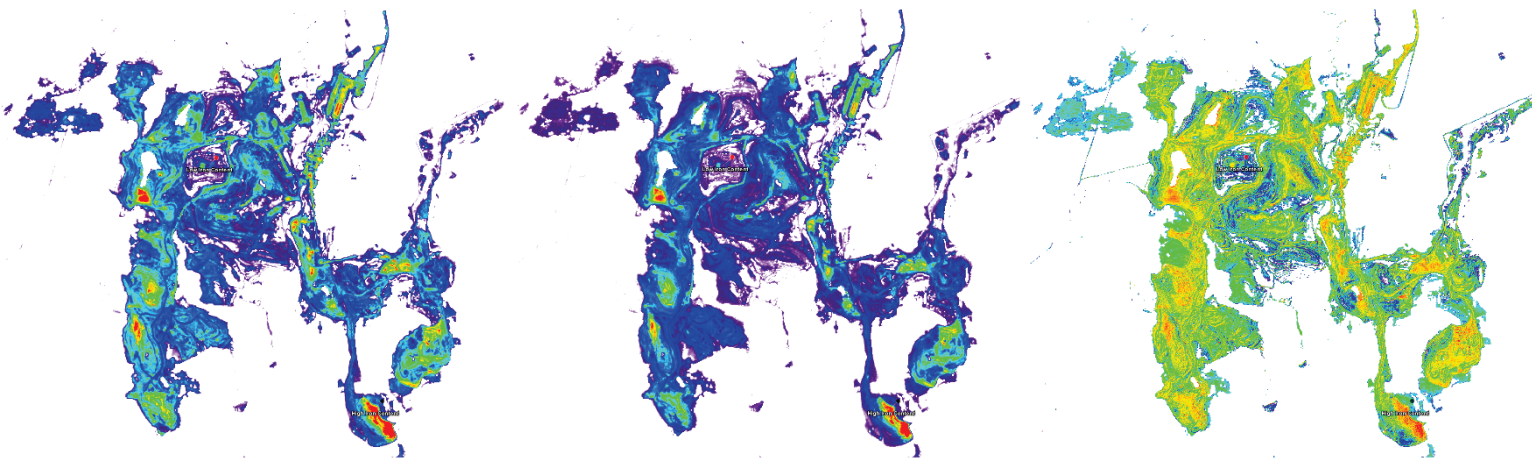
## 2.6. Visualisation

Then, we can compare the visual representation of individual bands showing the iron content.

Ferric oxides content

Ferrous iron content

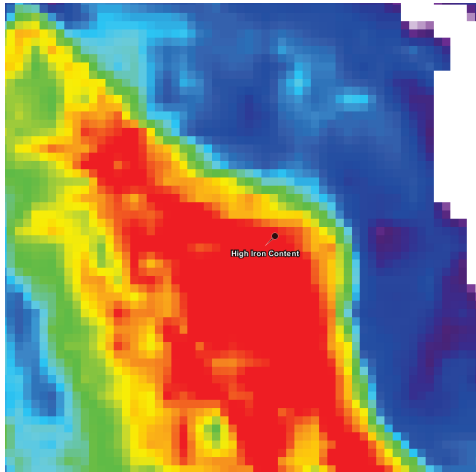
Iron oxide content



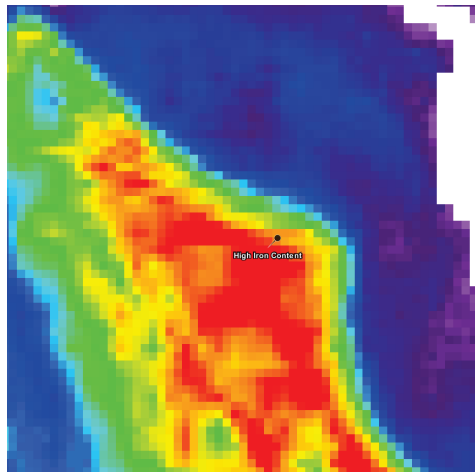
### 2.6.1. High Iron Content pin comparison

Finally, we can assess our work by comparing the results with the provided pins.

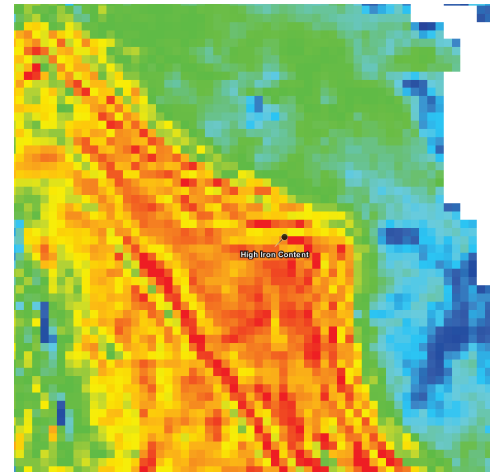
Ferric oxides content



Ferrous iron content

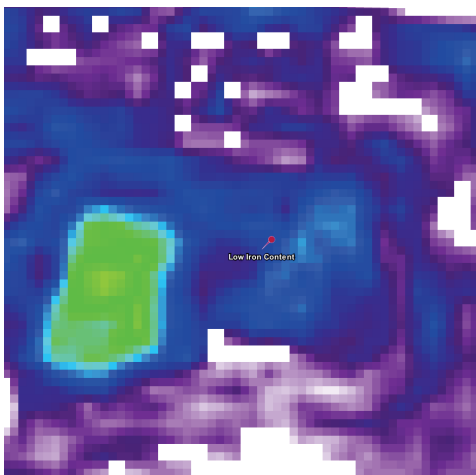


Iron oxide content

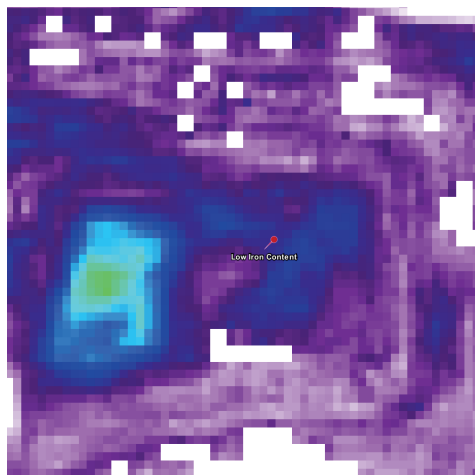


### 2.6.2. Low Iron Content pin comparison

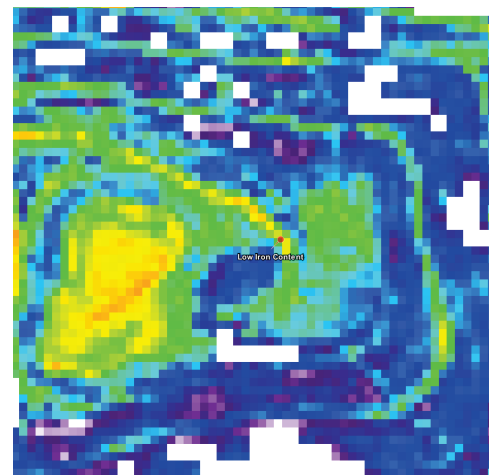
Ferric oxides content



Ferrous iron content



Iron oxide content



# 3 Spectral Angle Mapper (SAM)

## 3.1. Introduction to SAM

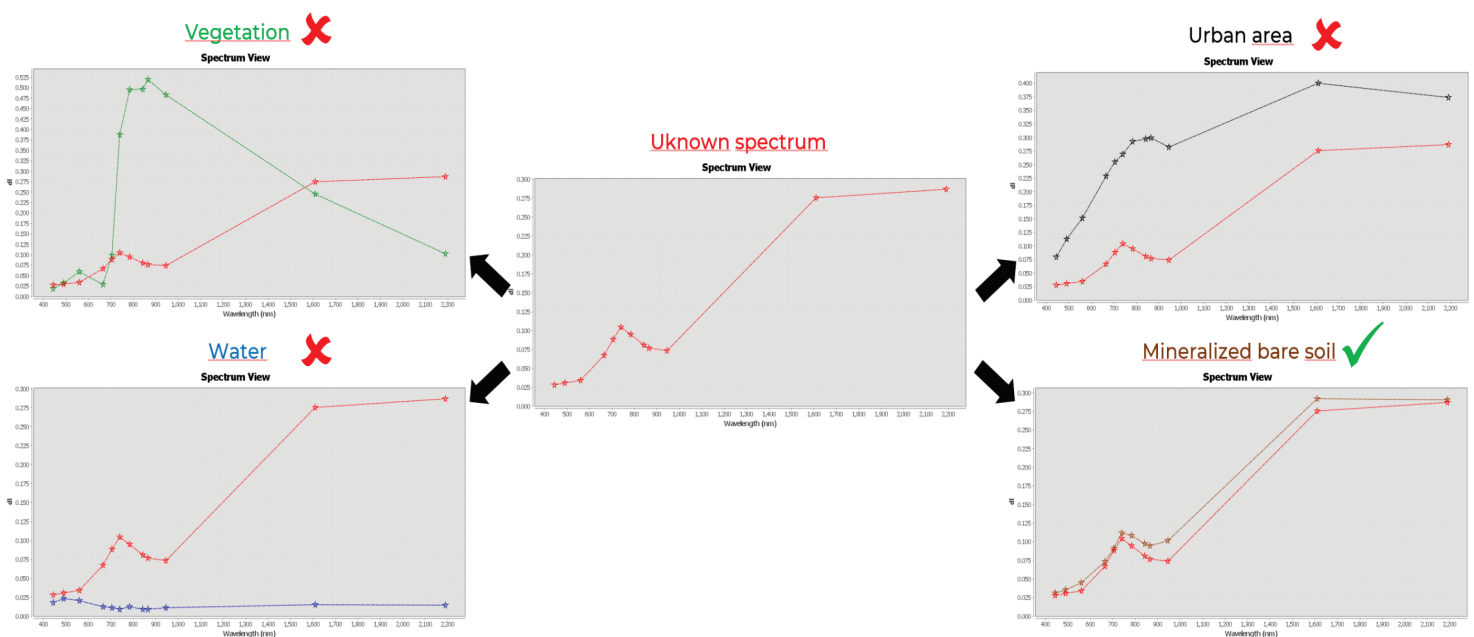
Spectral Angle Mapper allows to identify target materials from multispectral satellite images, based on the fact that similar materials have a similar spectral signature.

Therefore, we can classify spectra based on the degree of similarity.

We can:

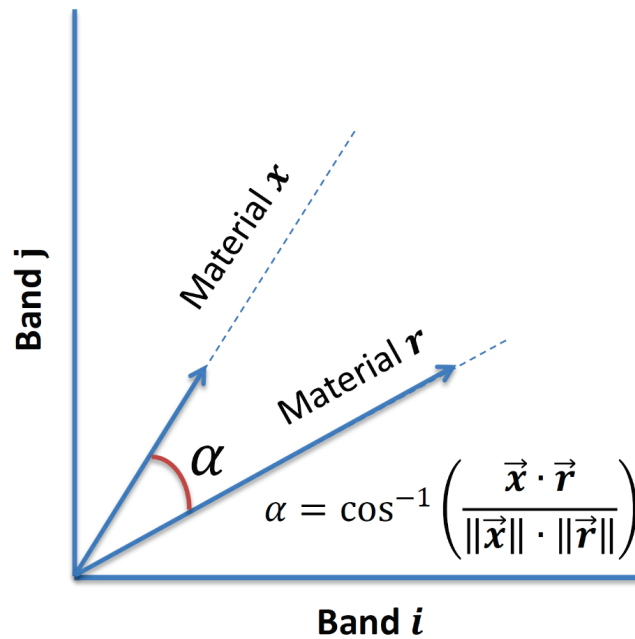
- compare an unknown spectrum to a set of reference spectra and define how is this one spectrum related to the reference spectra;
- define how similar a set of unknown spectra are to a single reference spectrum.

We can do this for all pixels in a multispectral image like Sentinel-2.



A degree of similarity between two spectra is defined by the spectral angle  $\alpha$ , which is defined in an  $N$ -dimensional space, where  $N$  represents the number of bands used in a multispectral image.

$$\alpha = \cos^{-1} \left( \frac{\sum_{i=1}^N x_i r_i}{(\sum_{i=1}^N x_i^2)^{1/2} (\sum_{i=1}^N r_i^2)^{1/2}} \right)$$



The smaller the spectral angle is, the more likely these two spectra are similar.

Dot product of vectors  $x$  and  $r$

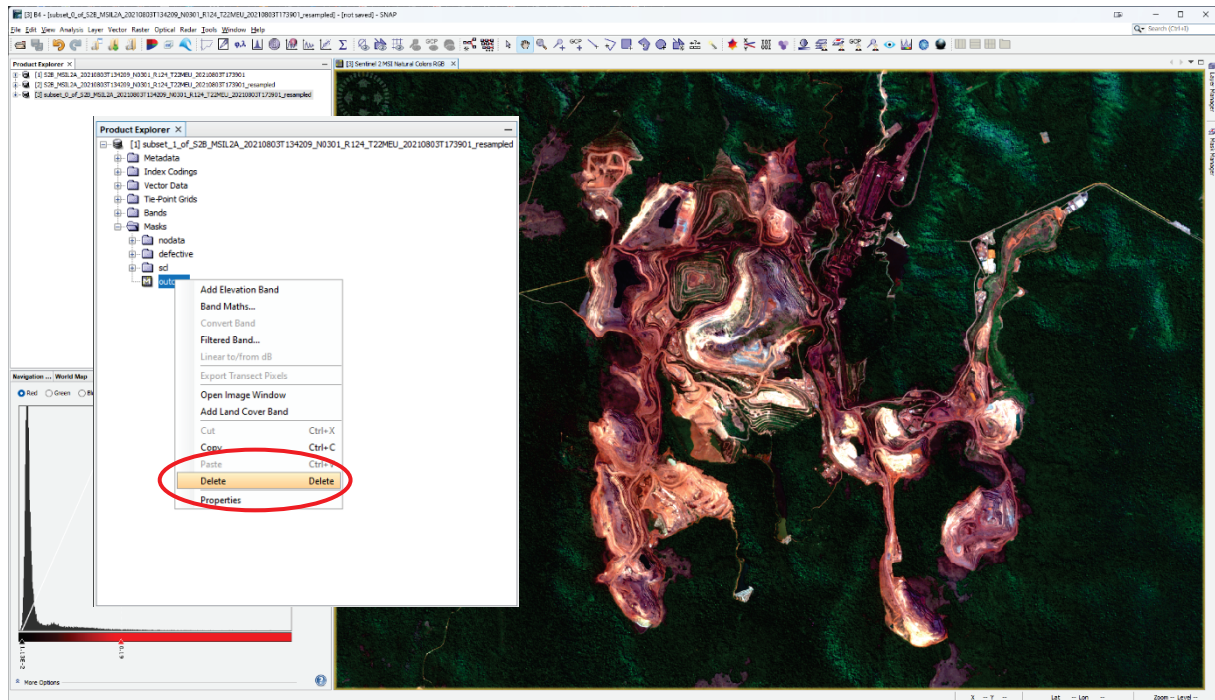
Spectral angle  $\rightarrow$  
$$\alpha = \cos^{-1} \left( \frac{\sum_{i=1}^N x_i r_i}{(\sum_{i=1}^N x_i^2)^{1/2} (\sum_{i=1}^N r_i^2)^{1/2}} \right)$$

Norm of vector  $x$       Norm of vector  $r$

### 3.2. Study area and image subset

For this part of the exercise, we will use the same subset for the same outcrop as in the previous part.

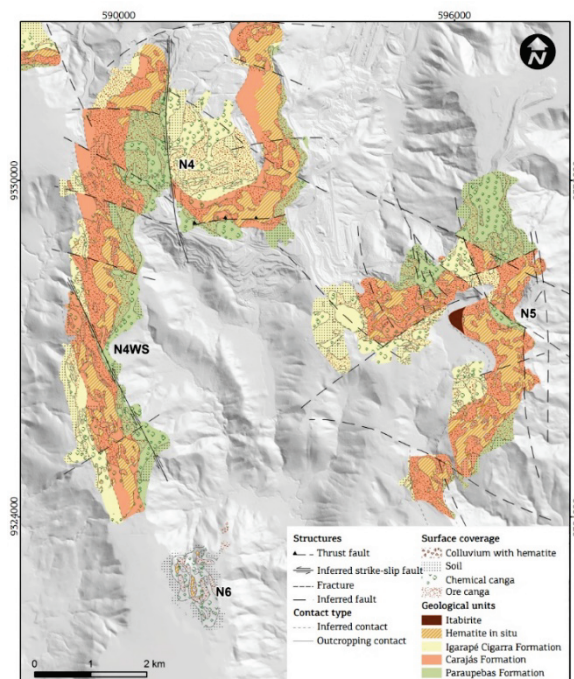
You can delete the mask for outcrop and use the whole subset area.



### 3.3. Identified mineral – Hematite

As can be observed from the geological setting, the outcrop area contains Hematite in situ.

For the reference spectra of Hematite, we can use freely available data from *USGS Spectral Library*.



We can find there Spectra of materials in ASCII format resampled to Sentinel-2 MSI characteristics.

| Spectra of materials in ASCII format  |         |                 |
|---|---------|-----------------|
| <a href="#">ASCIIData_splib07b_cvCRISMJMTR3.zip</a><br>"spectra convolved to CRISM joined MTR3 characteristics" | 6.01 MB | application/zip |
| <a href="#">ASCIIData_splib07b_cvM3-target.zip</a><br>"spectra convolved to M3 target mode characteristics"     | 4.32 MB | application/zip |
| <a href="#">ASCIIData_splib07b_cvVIMS.zip</a><br>"spectra convolved to VIMS characteristics"                    | 4.35 MB | application/zip |
| <a href="#">ASCIIData_splib07b_rsASTER.zip</a><br>"spectra resampled to ASTER characteristics"                  | 1.32 MB | application/zip |
| <a href="#">ASCIIData_splib07b_rsLandsat8.zip</a><br>"spectra resampled to Landsat8 OLI characteristics"        | 1.3 MB  | application/zip |
| <a href="#">ASCIIData_splib07b_rsSentinel2.zip</a><br>"spectra resampled to Sentinel-2 MSI characteristics"     | 1.39 MB | application/zip |
| <a href="#">ASCIIData_splib07b_rsWorldView3.zip</a><br>"spectra resampled to WorldView3 characteristics"        | 1.45 MB | application/zip |

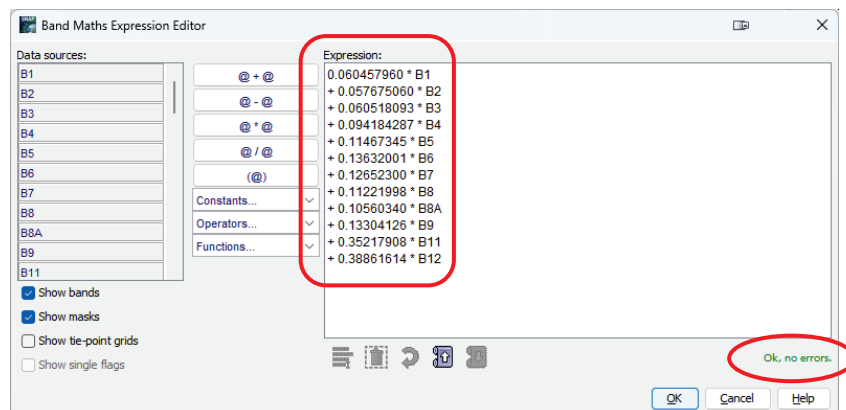
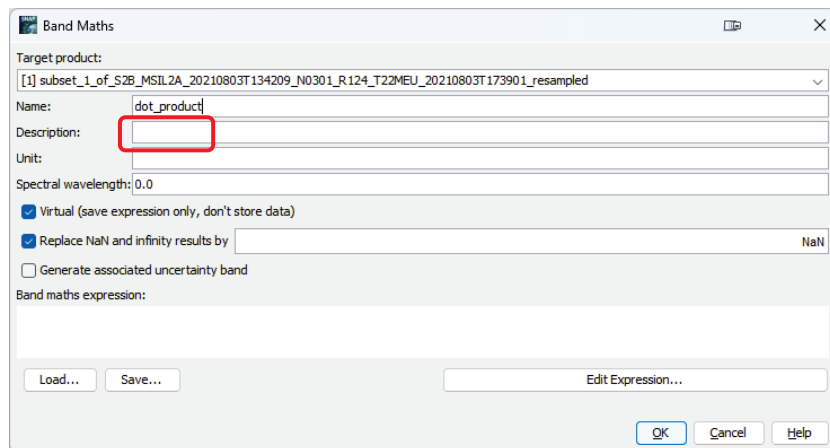
From this dataset, we can retrieve values of spectral reflectance for hematite in individual Sentinel-2 bands.

### 3.4. Dot product of vectors x and r

Firstly, we will compute the dot product between the reference spectra and S2 scene.

dot\_product

$$\begin{aligned}
 &0.060457960 * B1 \\
 &+ 0.057675060 * B2 \\
 &+ 0.060518093 * B3 \\
 &+ 0.094184287 * B4 \\
 &+ 0.11467345 * B5 \\
 &+ 0.13632001 * B6 \\
 &+ 0.12652300 * B7 \\
 &+ 0.11221998 * B8 \\
 &+ 0.10560340 * B8A \\
 &+ 0.13304126 * B9 \\
 &+ 0.35217908 * B11 \\
 &+ 0.38861614 * B12
 \end{aligned}$$

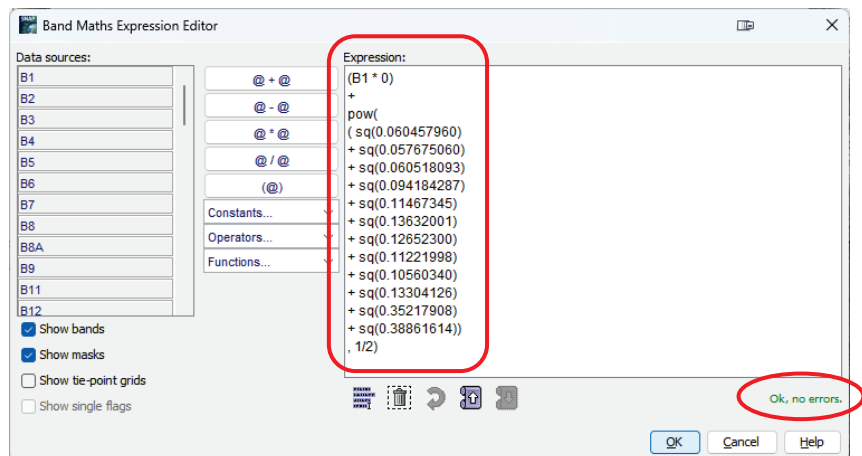
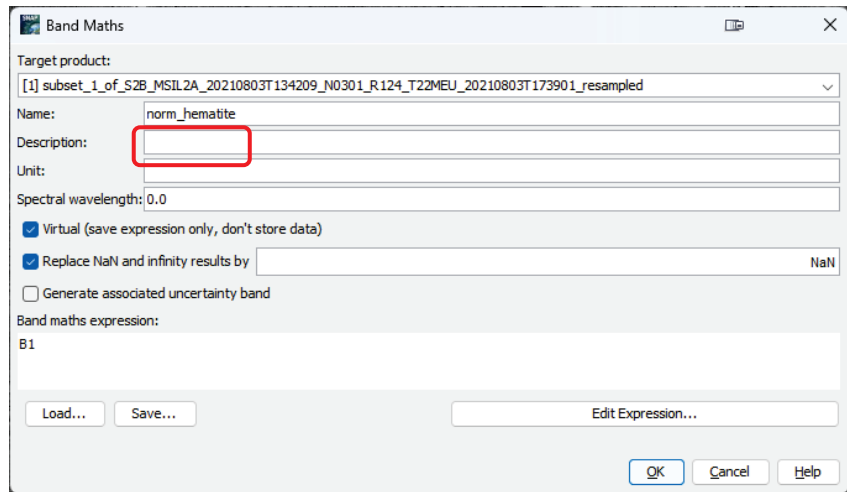


### 3.5. Norm product of vector x

Secondly, we will compute the Frobenius norm of reference spectra for Hematite.

norm\_hematite

$(B1 * 0) + \text{pow}(\sqrt{0.060457960} + \sqrt{0.057675060} + \sqrt{0.060518093} + \sqrt{0.094184287} + \sqrt{0.11467345} + \sqrt{0.13632001} + \sqrt{0.12652300} + \sqrt{0.11221998} + \sqrt{0.10560340} + \sqrt{0.13304126} + \sqrt{0.35217908} + \sqrt{0.38861614})$   
 $, 1/2)$

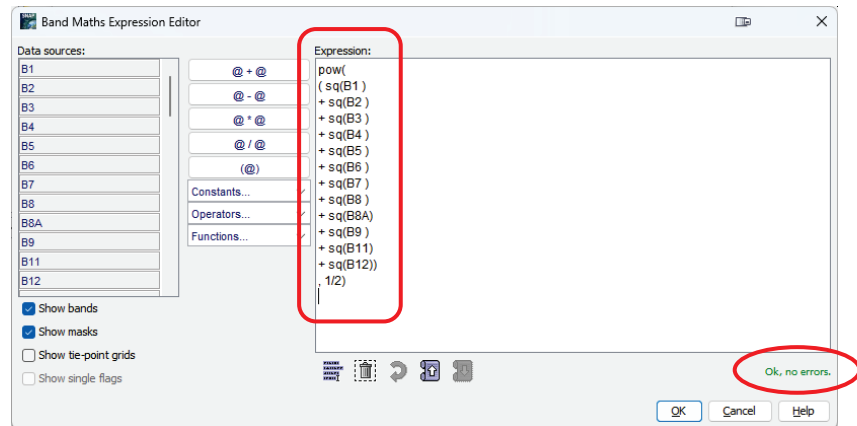
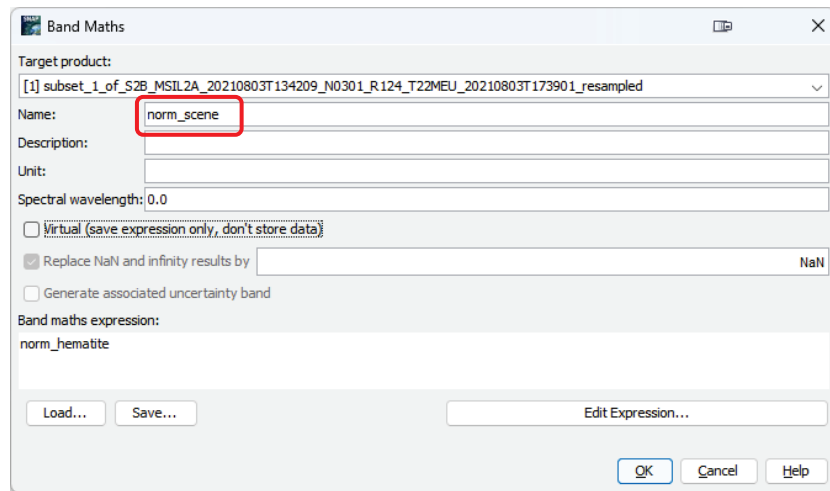


### 3.6. Norm product of vector r

Thirdly, we will compute the Frobenius norm of S2 scene.

norm\_scene

pow(  
( sq(B1 )  
+ sq(B2 )  
+ sq(B3 )  
+ sq(B4 )  
+ sq(B5 )  
+ sq(B6 )  
+ sq(B7 )  
+ sq(B8 )  
+ sq(B8A )  
+ sq(B9 )  
+ sq(B11 )  
+ sq(B12 )  
, 1/2)

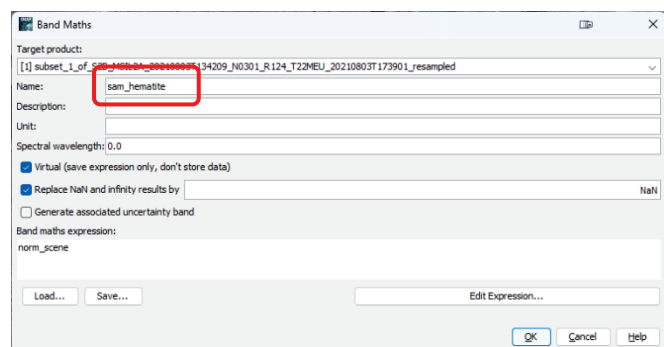


### 3.7. Spectral angle values for Hematite

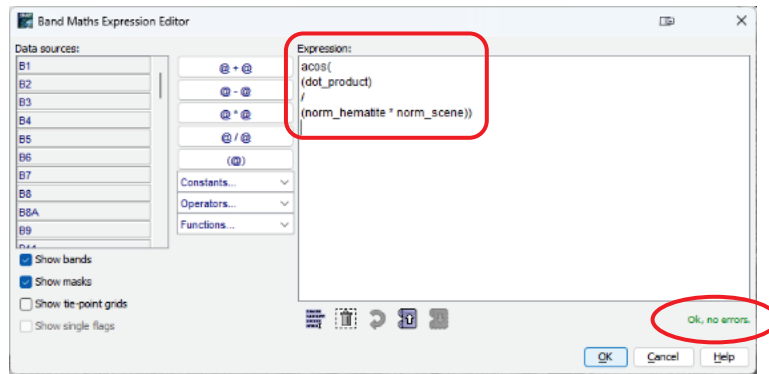
Finally, we will compute spectral angle values for Hematite.

sam\_hematite

acos(  
(dot\_product)  
/  
(norm\_hematite\*norm\_scene))

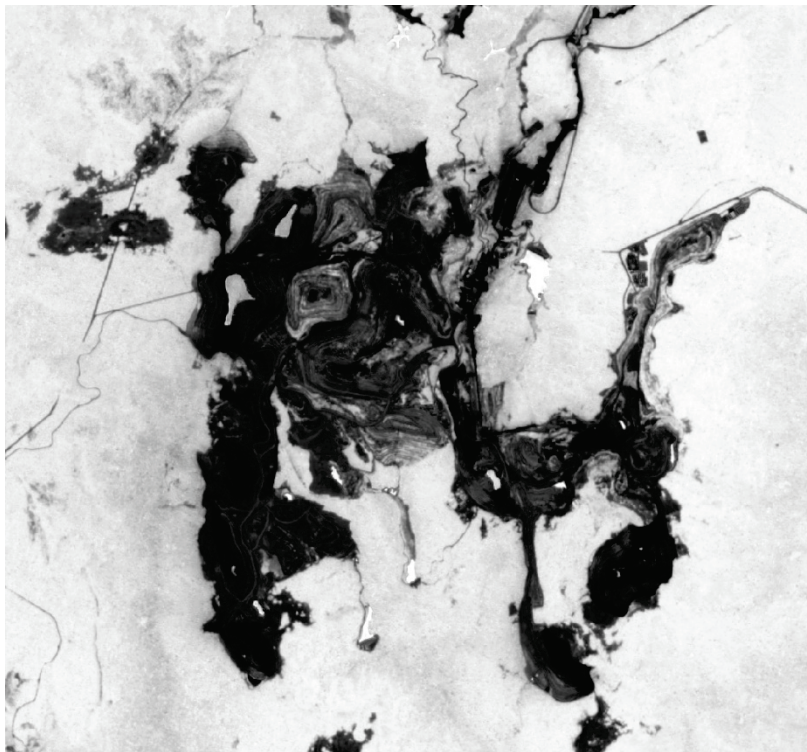






### 3.8. Final image visualisation and interpretation

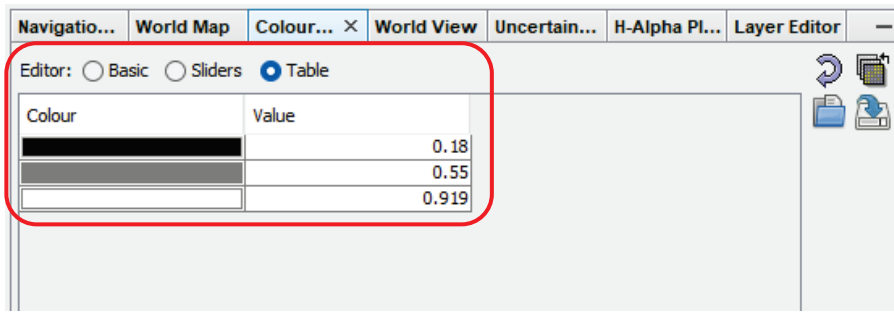
The resulting band is displayed in grayscale.



Computed angles corresponding to the grayscale values can be seen in Colour Manipulation tool, for instance Table editor.

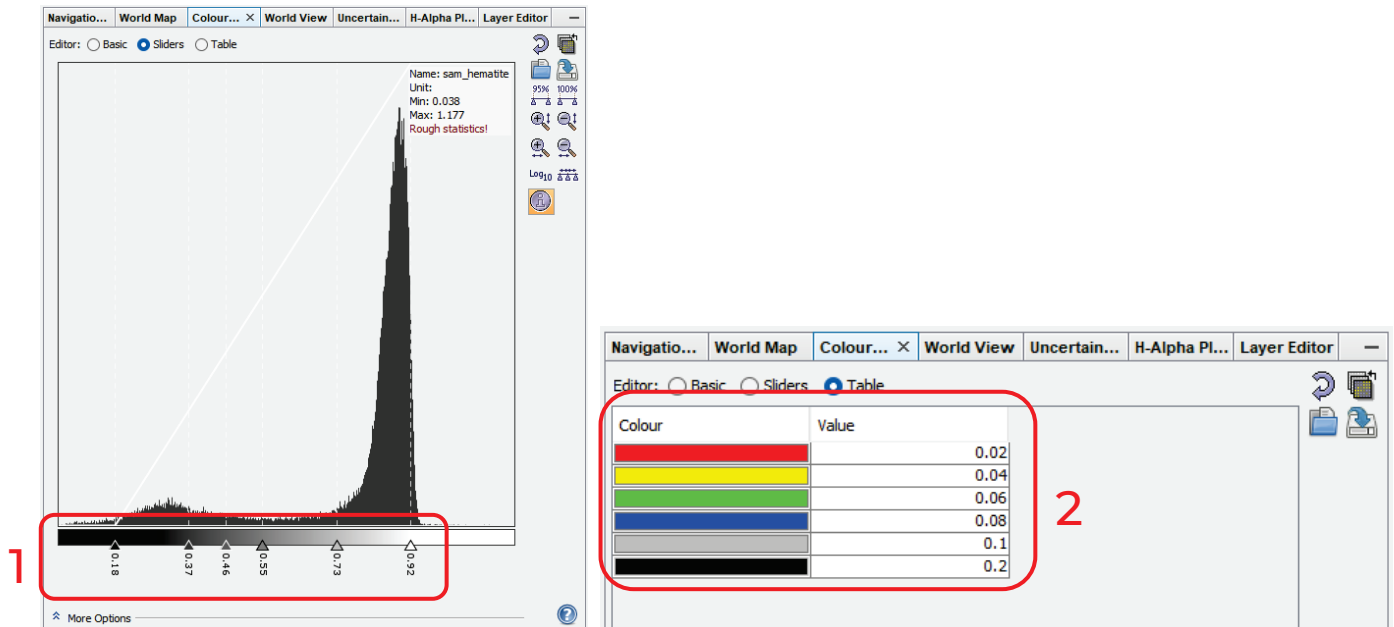
Values of the angle are in radians.

Pixels with smaller angles (darker colour) are mostly similar to the reference spectrum of Hematite.

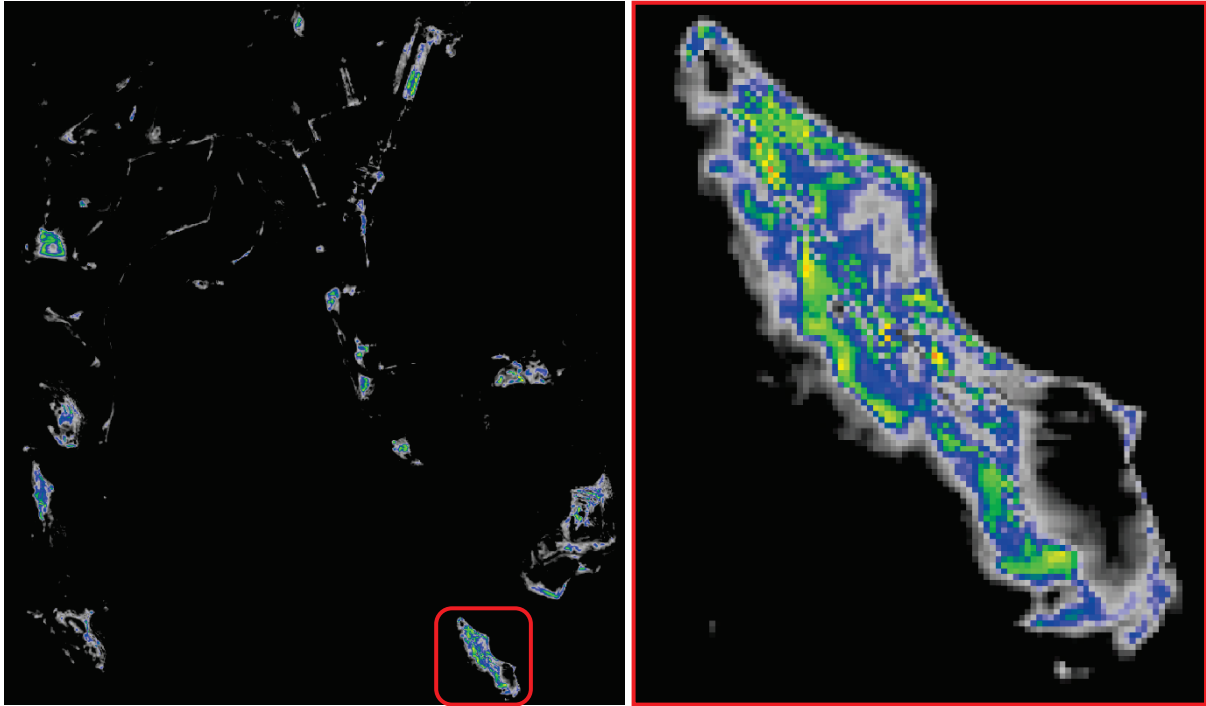


We can adjust the colour representation of the final image to be more relevant and representative:

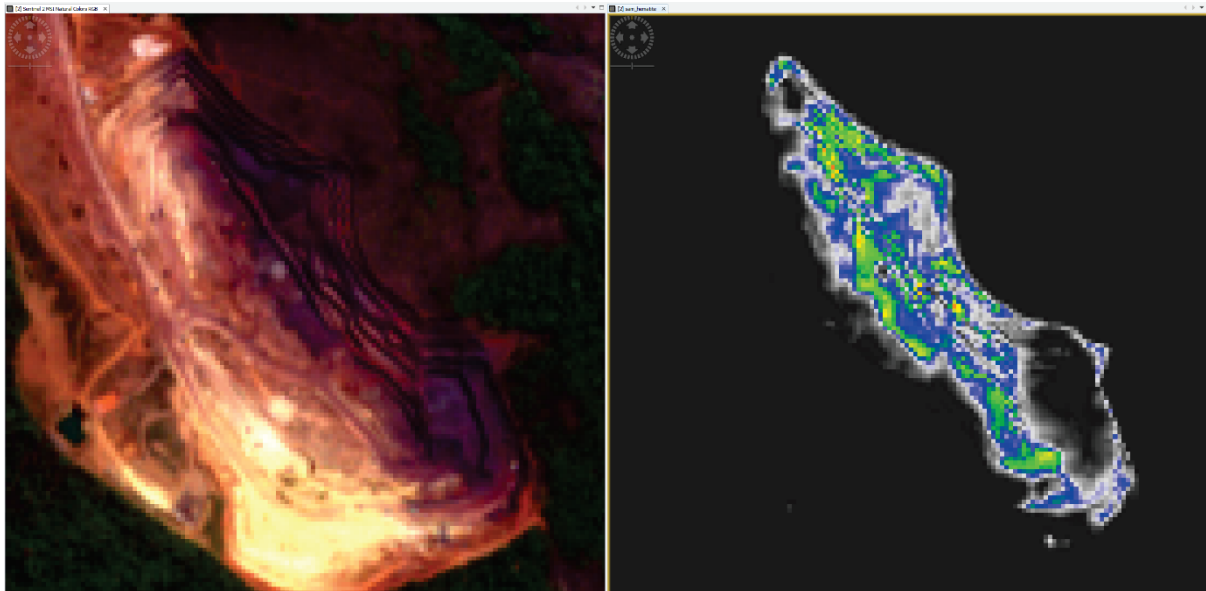
1. add 3 new sliders to the colour bar;
2. in Table editor – edit the values and colours.



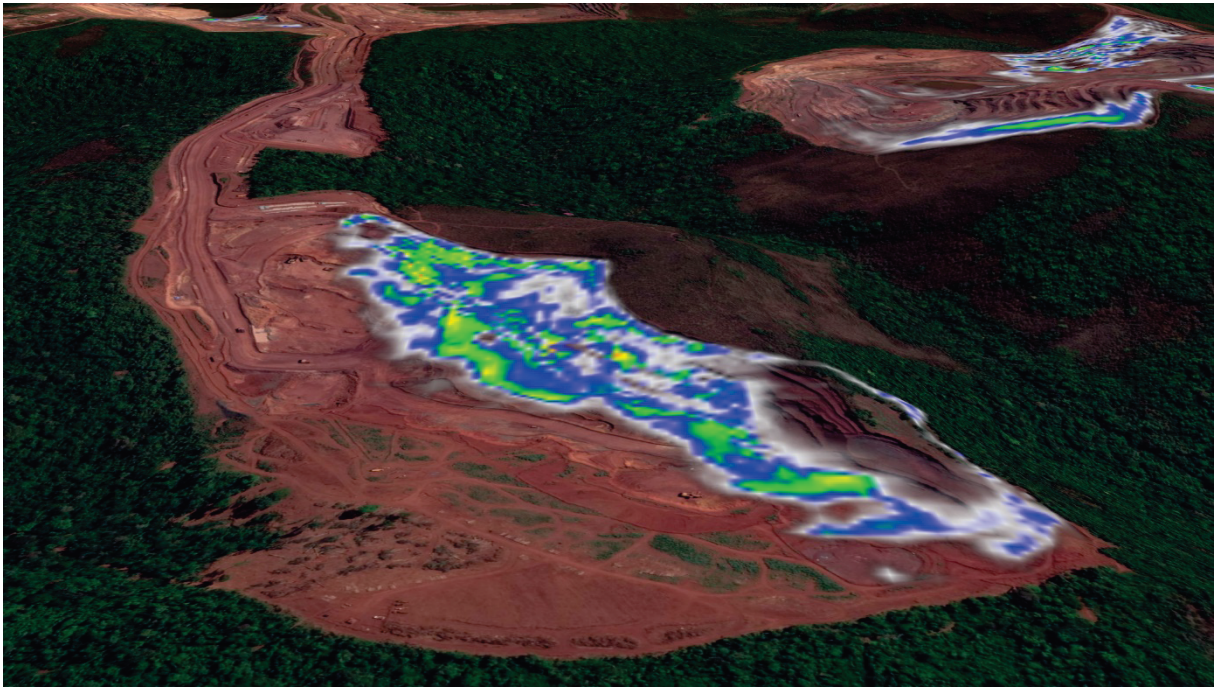
According to this colour representation of the final image, we can easily recognize pixels with a spectral signature similar to the reference spectrum of Hematite.



We can also compare the SAM result with the RGB composition and the colour of pixels containing hematite.



Finally, we can export the image to .KMZ format and display it in Google Earth.



THANK YOU FOR FOLLOWING THE EXERCISE!