Hyperspectral Image Analysis

Rock cores, Moglicë, Albania

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This report includes the details of the conducted hyperspectral image analysis on the scanned rock core samples from Moglicë, Albania.

1. Scans

Three groups of scans are included in this report:

Scan group number	Sample type	Camera	Lens	White reference panel used
1	Rock core cut/joint surface	SWIR	30 cm	20% reflectance
2	Rock core cut/joint surface	SWIR	Microscropic	20% reflectance
3	Rock cores	SWIR	1 m	20% reflectance

The scans were performed by Jessica Chiu and Lisa Henriksen at the HySpex Laboratory in Oslo between 20th and 23rd September 2021. The scanning was instructed and assisted by Dr. Friederik Koerting from Hyspex, NEO.

2. Data pre-processing

The following lists the steps for preparing and processing the relative reflectance data from the scans for mineral classification:

1. Radiometric calibration and reflectance retrieval of the raw data using the 'HySpex rad' software. Empirical Line Calibration processing is performed using ENVI software to retrieve the reflectance data for the core box images, as the panel was not scanned in the same scene.
2. Extract each image's region of interests (ROI) using the ROI tool in the ENVI software. It involves clipping the scanned surface of the sample and removing the background. The edges along the cylindrical rock cores are shadowed, and the data are generally noisy. Therefore, the edges are removed.
3. Use the saturation mask to export spectral data within the ROIs without oversaturated pixels.
4. Data smoothing of the reflectance data using the Savitzky-Golay smoothing filter.
5. Apply hull correction to detrend the data to facilitate minimum wavelength mapping (see next section).

3. Method for mineral classification

The following lists the steps for mineral classification:

1. Understand the possible minerals present in the samples based on observations, core logging data, results from scanning electron microscopy (SEM), X-ray refraction diffraction analysis (XRD), and visual inspection of the spectral data.

2. Understand the SWIR spectral characteristics via literature and spectral libraries, such as the USGS spectral library [2] (Figure 1)
3. Outline a simple binary decision tree [3], [4] (Figure 5) for pixel-wise mineral classification of the scans. A decision tree provides a transparent logic behind the classification scheme and reproducible classification results.
4. Use minimum wavelength mapping (MWL) to map the positions and depths of absorption features within various wavelength ranges. The open-source Python toolbox hylite [4] is used for the minimum wavelength mapping.
5. Execute the classification. Python toolbox hylite [4] is used for running the classification using a decision tree.

Minimum Wavelength Mapping (MWL)

For each MWL, three to four features are set as targets for the mapping. Results from MWL are included in Appendix A to C. The results are given by plots showing the quality of the curve fitting, and spectral and spatial distribution of the positions of the mapped features. The plots in Appendix A to C are generated using the demo for hylite. The repository of the demo can be found here: https://github.com/samthiele/hylite_demo2

Decision tree

The decision for each node in the decision tree are summarised in Table 1 and illustrated in Figure 2. A minimum depth threshold is set for each node to determine whether a mapped feature is considered. I.e. if the depth is lower than the threshold, even though it has been mapped as a feature in MWL, the feature is considered absent (i.e. 'no') for the node. The thresholds are set manually.

Table 1 Description of the nodes in the proposed decision tree for mineral classification.

Node	Decision	MWL results used[1]	Remarks
1	Feature(s) between 1380 and 1440 nm	MWL 1	
2	Feature(s) between 1890 and 2000 nm	MWL 2	
3	Feature(s) between 2140 and 2220 nm	MWL 2	
4	Double features between 2140 and 2220 nm	MWL 3	Diagnostic for kaolinite [3]
5	Feature(s) between 2285 and 2350 nm	MWL 2	
6	Feature(s) between 2233 and 2253 nm	MWL 3	
7	Feature(s) between 2317 and 2350 nm	MWL 3	
8	Depth ratio of the feature present in node 3 over that in node 2	MWL 1	Degree of crystallinity to differentiate montmorillonite and montmorillonite-illite-mixture [3]
9	Feature(s) between 2333 and 2353 nm	MWL 3	

[1] Refer to Figure 4 for the corresponding wavelength ranges used for MWL.

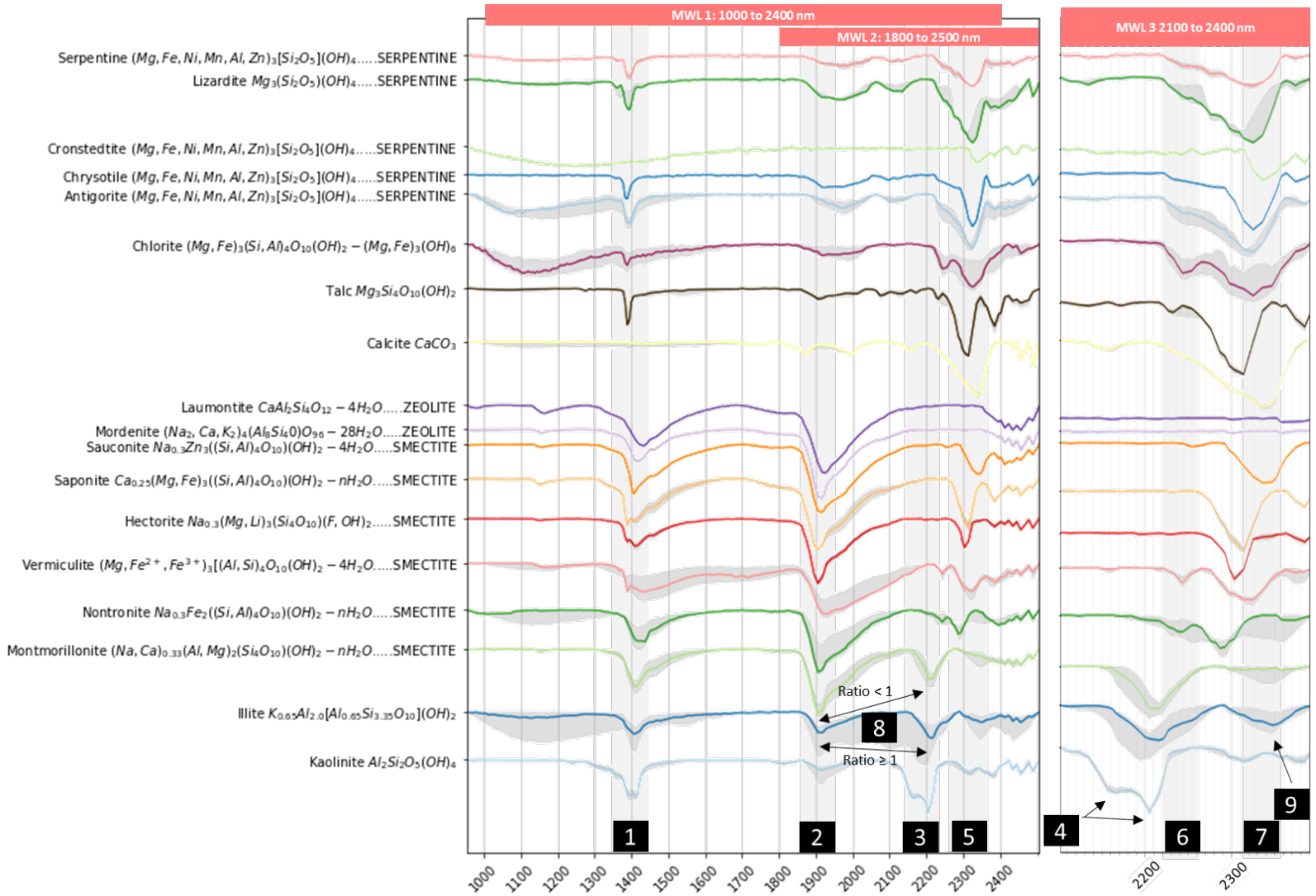


Figure 1 Hull corrected SWIR spectra of the potential minerals in the scanned samples. The SWIR spectra are collected from the USGS 7 Spectral Library [2]*. Numbers 1 to 9 (black rectangles on the bottom) represent the wavelength regions where features can be identified for classification using the classification tree. Feature locations are identified using minimum wavelength mapping within three wavelength regions (peach rectangles on the top): 1000 - 2400 nm, 1800 - 2500 nm, and 2100 - 2300 nm.*

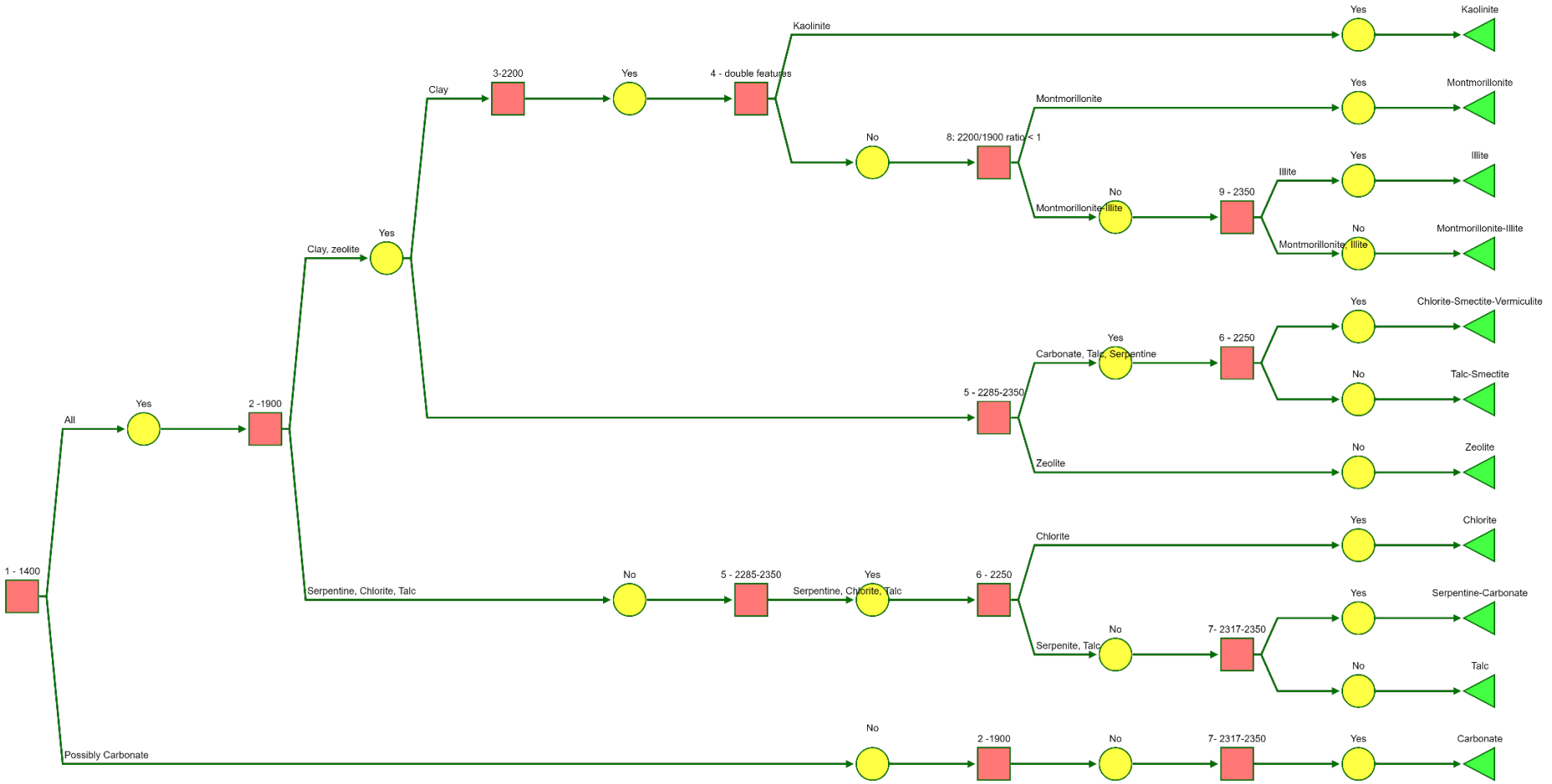


Figure 2 Decision tree used for classification. 'Yes' refers to feature(s) determined via minimum wavelength mapping that is/are present around the specific wavelength or within a particular range. For example, node 5 in the decision tree looks for whether any feature is present between 2285 nm and 2350 nm. Figure constructed using open-source software SilverDecisions [5].

4. Classification results

High-resolution images are provided separately. The overview of the results is provided in Table 1.

The spectra of up to five randomly selected pixels for each class are provided in Appendix A to C. The plots are annotated by:

- Wavelength ranges of the three MWLs
- Mapped features from MWL, with symbol |, -, x for MWL 1, MWL 2, and MWL 3, respectively
- Shaded regions represent the wavelength ranges for various nodes in the decision tree (see Table 1)
- If a node in the decision tree is 'yes', the node number is shown in white rectangles; if the node is 'no', the node number is shown in black rectangles; if the node decision does not matter for the classification, the node number is hidden.

3.1.1. TS 1 to TS 5 - 30 cm lens

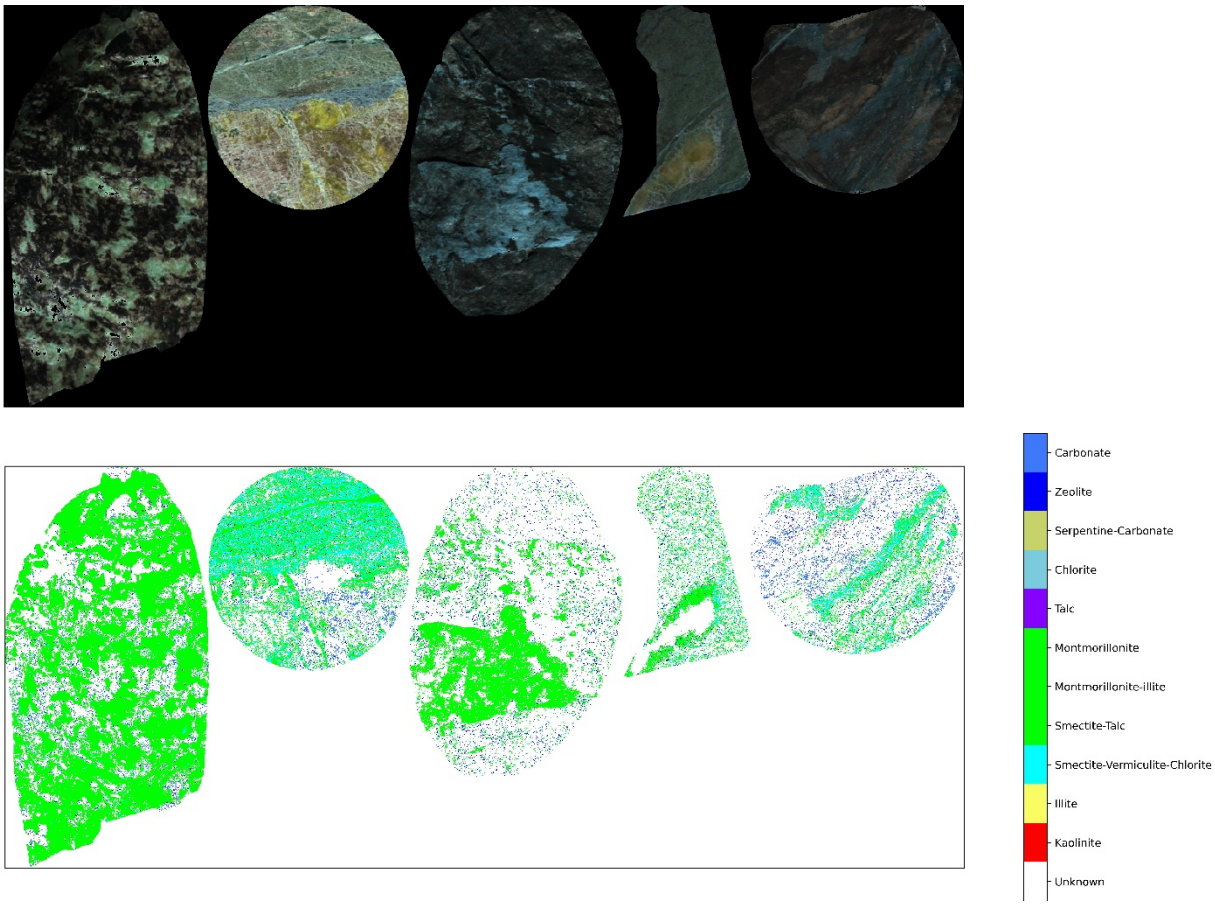


Figure 3 TS 1 to TS 5 - 30 cm lens: RGB representation (top) from the SWIR band (50, 130, 220) and classification results (bottom).

3.1.2. TS 4 – microscopic lens

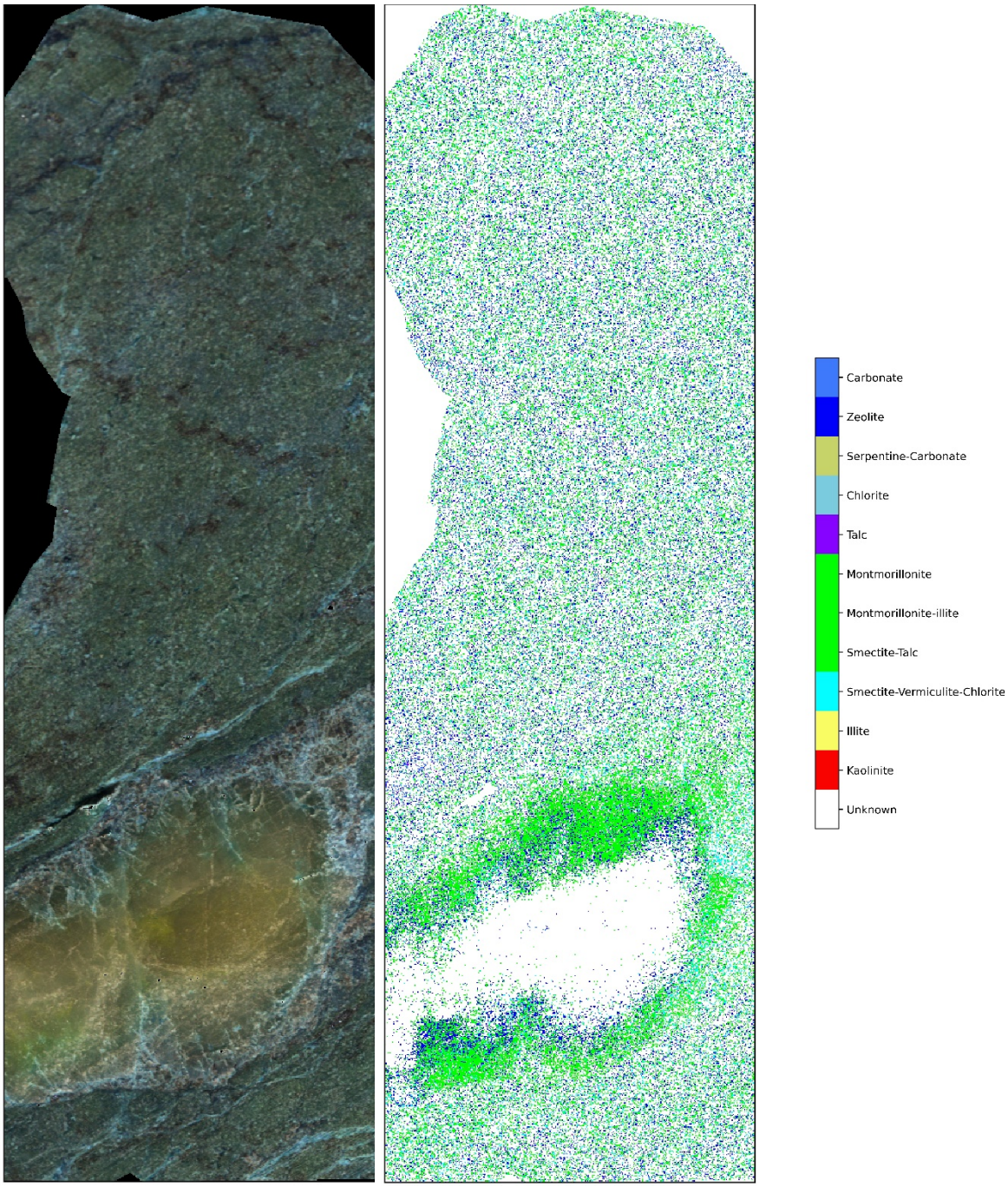


Figure 4 TS 4 - microscopic lens: RGB representation (left) from the SWIR band (50, 130, 220) and classification results (right).

3.1.3. Rock Cores 68-80 m – 1 m lens

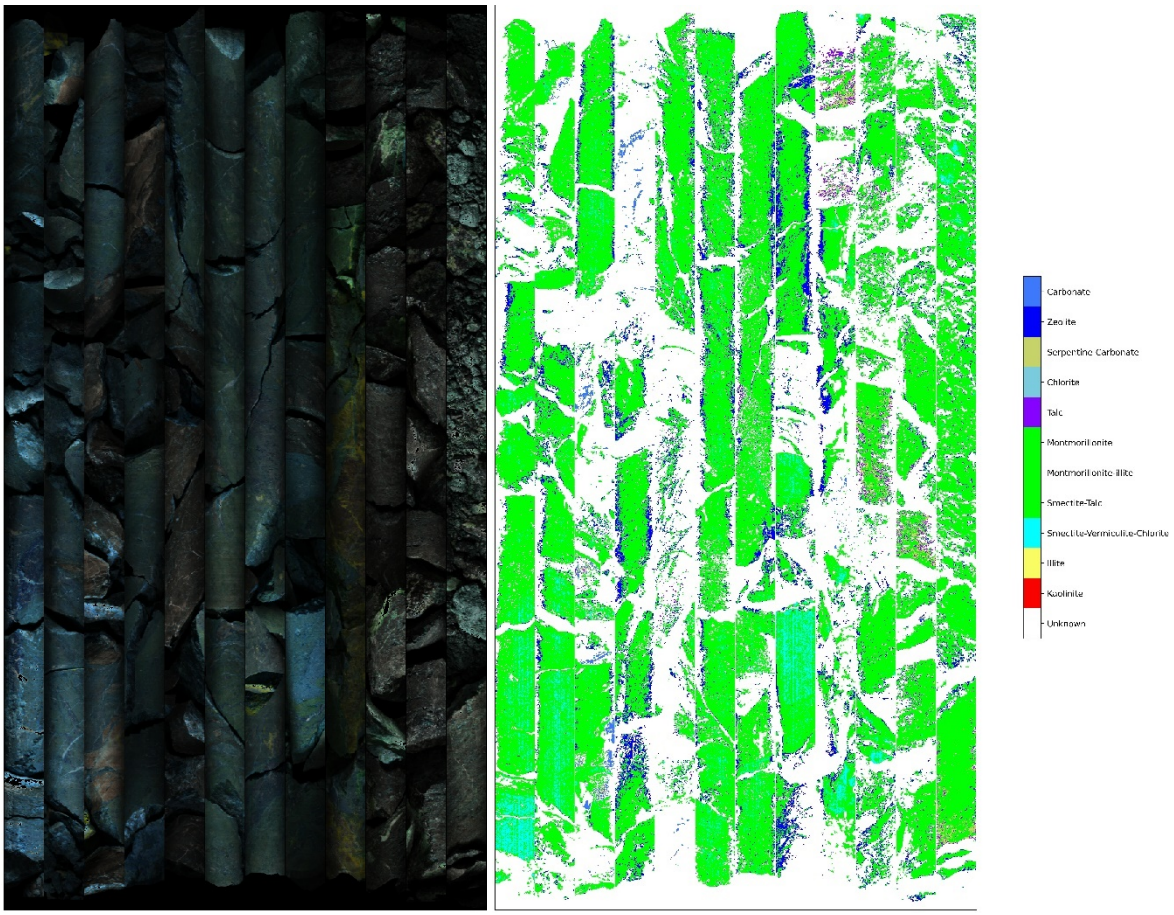


Figure 5 Rock cores 68 to 80 m – 1 m lens: RGB representation (left) from the SWIR band (50, 130, 220) and classification results (right).

Figure 6 Approximate extent for extracting the classified pixels for nine sampling locations (S1 to S9) from the rock cores.

4. Remarks

Note that the proposed classification scheme is rather simplified. Therefore, the classification results should be used with caution.

As the hyperspectral images are pixelated, the mineral grains cannot be examined in the given spatial resolution to provide the classification of individual minerals. Class 7, 8, 10 and 11 represent their dominant minerals within the pixel.

Calcite can be present in any pixels with absorption features around 2350 nm (likely due to Fe-OH and Mg-OH absorption).

H_2O-bearing minerals, including zeolite and smectite, exhibit dominating absorption features at 1400 nm and 1900 nm (likely due to H-OH absorption), as well as around 2350 nm. If these minerals are present within a pixel, their SWIR absorption features will likely overprint other minerals. For instance, as illustrated in Figure 1, if both serpentine and smectite mineral are present in the same pixel, the absorption feature between 2317 nm and 2350 nm (i.e. node 7) will be influenced by both minerals. Smectite is likely present due to the absorption features at 1400 nm and 1900 nm. At the same time, one cannot exclude the presence of serpentine. Therefore, serpentine may be present in those pixels under Class 3 Smectite-Vermiculite-Chlorite and Class 4 Smectite-Talc.

Zeolite will not be 'visible' if any other clay minerals (smectite, illite, montmorillonite) are present in the same pixel. Therefore, zeolite may as well be present in those pixels under Class 1 to Class 6.

As shown in the spectral plots in Appendix A to C, for Class 5 Montmorillonite-illite and Class 6 Montmorillonite, absorption features have generally been mapped at around 2300 nm. All other minerals including serpentine, chlorite, talc, calcite and smectite that share the same feature cannot be excluded in these pixels.

A more complex decision tree and more advanced spectral data unmixing techniques are needed to further determine the possible compositional ratio among minerals within the assemblages of the abovementioned minerals in each pixel.

Table 2 Classification results using the proposed decision tree. A spread sheet of the results is provided separately.

Scans		TS 1 to TS 5 - 30 cm lens		TS 1 - 30 cm lens		TS 2 - 30 cm lens		TS 3 - 30 cm lens		TS 4 - 30 cm lens		TS 5 - 30 cm lens		TS 4 - microscopic lens		Rock cores 68 to 80m - 1 m lens	
		% of analysed	Pixel count	% of analysed	Pixel count	% of analysed	Pixel count	% of analysed	Pixel count	% of analysed	Pixel count	% of analysed	Pixel count	% of analysed	Pixel count	% of analysed	Pixel count
Image area			692406		147412		144722		154406		91998		153868		469632		1006500
Pixels outside Region of Interests			345994		36354		86920		62026		63358		97336		22971		79980
Number of analysed pixels			346412		111058		57802		92380		28640		56532		446661		926520
Class numbe	**Possible mineral(s)**																
CLASS: 0	**Unknown**	52.53	181979	31.30	34758	40.04	23143	68.93	63676	69.98	20043	71.39	40359	66.81	298398	43.94	407102
CLASS: 1	**Kaolinite**	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
CLASS: 2	**Illite**	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
CLASS: 3	**Smectite-Vermiculite-Chlorite**	6.06	20980	0.79	879	23.88	13804	0.77	712	5.32	1523	7.19	4062	4.73	21106	2.21	20505
CLASS: 4	**Smectite-Talc**	36.11	125103	63.82	70877	29.98	17330	26.13	24137	20.91	5988	11.98	6771	15.85	70815	46.48	430616
CLASS: 5	**Montmorillonite-illite**	0.15	524	0.05	53	0.65	373	0.07	69	0.10	28	0.00	1	0.03	119	0.00	17
CLASS: 6	**Montmorillonite**	0.41	1435	0.19	209	0.98	566	0.44	406	0.68	195	0.10	59	1.08	4820	0.04	339
CLASS: 7	**Talc**	0.26	886	0.46	514	0.02	9	0.02	17	0.03	8	0.60	338	0.22	988	0.71	6609
CLASS: 8	**Chlorite**	0.03	94	0.04	39	0.01	7	0.01	7	0.00	1	0.07	40	0.29	1280	0.00	1
CLASS: 9	**Serpentine-Carbonate**	0.23	797	0.40	448	0.12	70	0.03	24	0.03	8	0.44	247	0.52	2334	0.61	5660
CLASS: 10	**Zeolite**	1.94	6707	0.85	946	1.72	994	2.79	2574	2.74	784	2.49	1409	8.00	35750	5.66	52400
CLASS: 11	**Carbonate**	2.28	7907	2.10	2335	2.61	1506	0.82	758	0.22	62	5.74	3246	2.47	11051	0.35	3271

Sampling locations		S1		S2		S3		S4		S5		S6		S7		S8		S9	
		% of analysed pixels	Pixel count	% of analysed pixels	Pixel count	% of analysed pixels	Pixel count	% of analysed pixels	Pixel count	% of analysed pixels	Pixel count	% of analysed pixels	Pixel count	% of analysed pixels	Pixel count	% of analysed pixels	Pixel count	% of analysed pixels	Pixel count
Image area			2280		2627		3510		2808		2479		4815		3910		3476		4524
Pixels outside Region of Interests			7		6		0		0		0		0		14		0		97
Number of analysed pixels			2273		2621		3510		2808		2479		4815		3896		3476		4427
Class numbe	**Possible mineral(s)**																		
CLASS: 0	**Unknown**	45.58	1036	43.80	1148	77.09	2706	93.45	2624	3.63	90	85.05	4095	69.22	2697	5.96	207	80.33	3556
CLASS: 1	**Kaolinite**	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
CLASS: 2	**Illite**	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
CLASS: 3	**Smectite-Vermiculite-Chlorite**	7.00	159	0.04	1	0.91	32	0.00	0	20.65	512	0.00	0	0.54	21	3.14	109	1.47	65
CLASS: 4	**Smectite-Talc**	40.96	931	43.91	1151	21.17	743	2.67	75	75.43	1870	12.34	594	28.34	1104	88.90	3090	15.90	704
CLASS: 5	**Montmorillonite-illite**	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
CLASS: 6	**Montmorillonite**	0.00	0	0.00	0	0.06	2	0.04	1	0.00	0	0.00	0	0.13	5	0.00	0	0.00	0
CLASS: 7	**Talc**	0.00	0	7.36	193	0.00	0	0.00	0	0.00	0	0.00	0	0.05	2	0.00	0	0.16	7
CLASS: 8	**Chlorite**	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
CLASS: 9	**Serpentine-Carbonate**	0.00	0	3.05	80	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.09	4
CLASS: 10	**Zeolite**	6.47	147	1.56	41	0.68	24	3.67	103	0.28	7	2.62	126	1.23	48	2.01	70	1.02	45
CLASS: 11	**Carbonate**	0.00	0	0.27	7	0.09	3	0.18	5	0.00	0	0.00	0	0.49	19	0.00	0	1.04	46

5. References

[1] Y. H. Li *et al.*, “Research and Application of Several Key Techniques in Hyperspectral Image Preprocessing,” *Front. Plant Sci.*, vol. 12, p. 173, Feb. 2021, doi: 10.3389/fpls.2021.627865.

[2] R. N. Clark, G. A. Swayze, A. J. Gallagher, T. V. V. King, and W. M. Calvin, “The U. S. Geological Survey, Digital Spectral Library: Version 1 (0.2 to 3.0um),” *Open-File Rep.*, 1993, doi: 10.3133/OFR93592.

[3] F. M. Moud, F. Deon, M. van der Meijde, F. van Ruitenbeek, and R. Hewson, “Mineral Interpretation Discrepancies Identified between Infrared Reflectance Spectra and X-ray Diffractograms,” *Sensors 2021, Vol. 21, Page 6924*, vol. 21, no. 20, p. 6924, Oct. 2021, doi: 10.3390/S21206924.

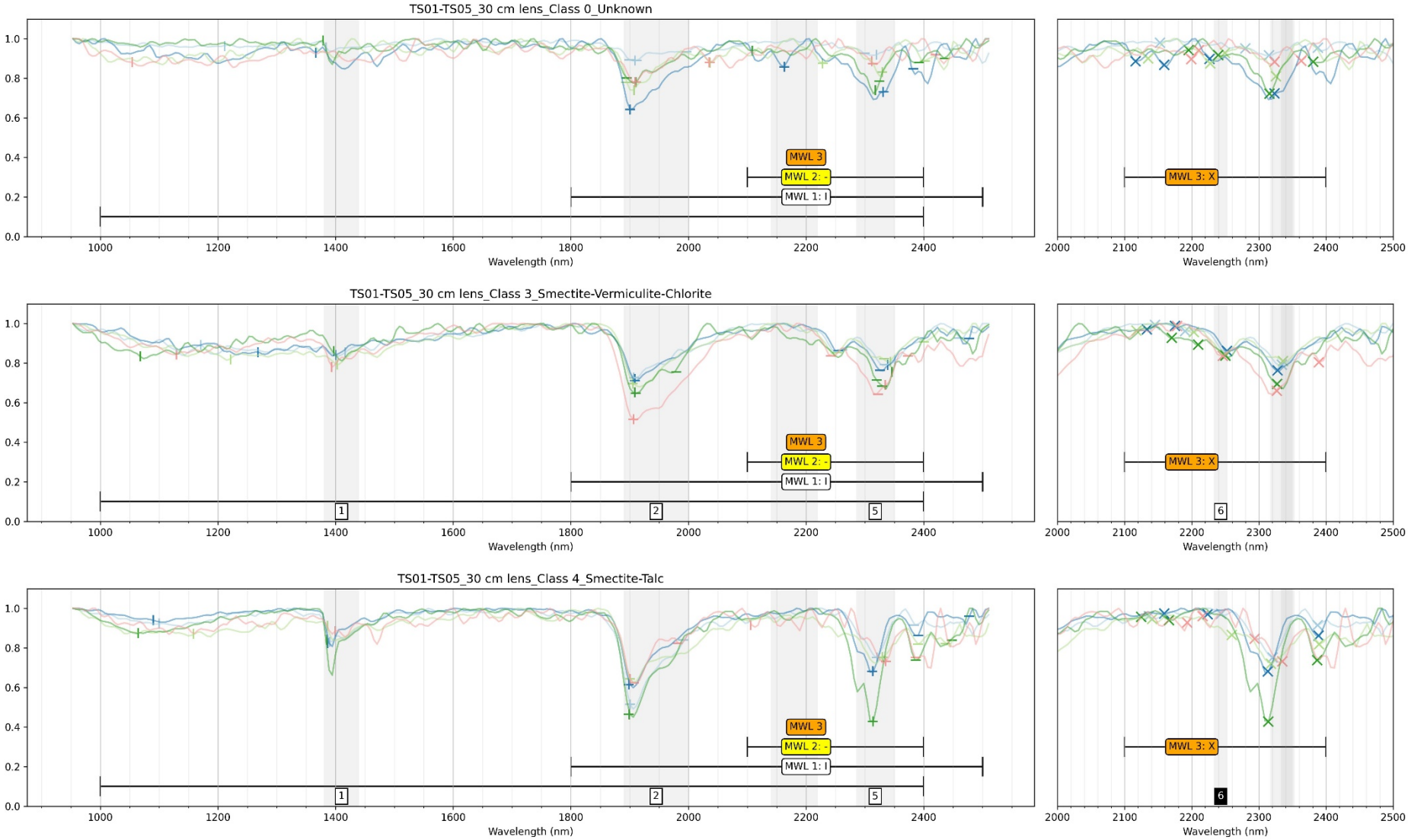
[4] S. T. Thiele *et al.*, “Multi-scale, multi-sensor data integration for automated 3-D geological mapping,” *Ore Geol. Rev.*, vol. 136, p. 104252, Sep. 2021, doi: 10.1016/J.OREGEOREV.2021.104252.

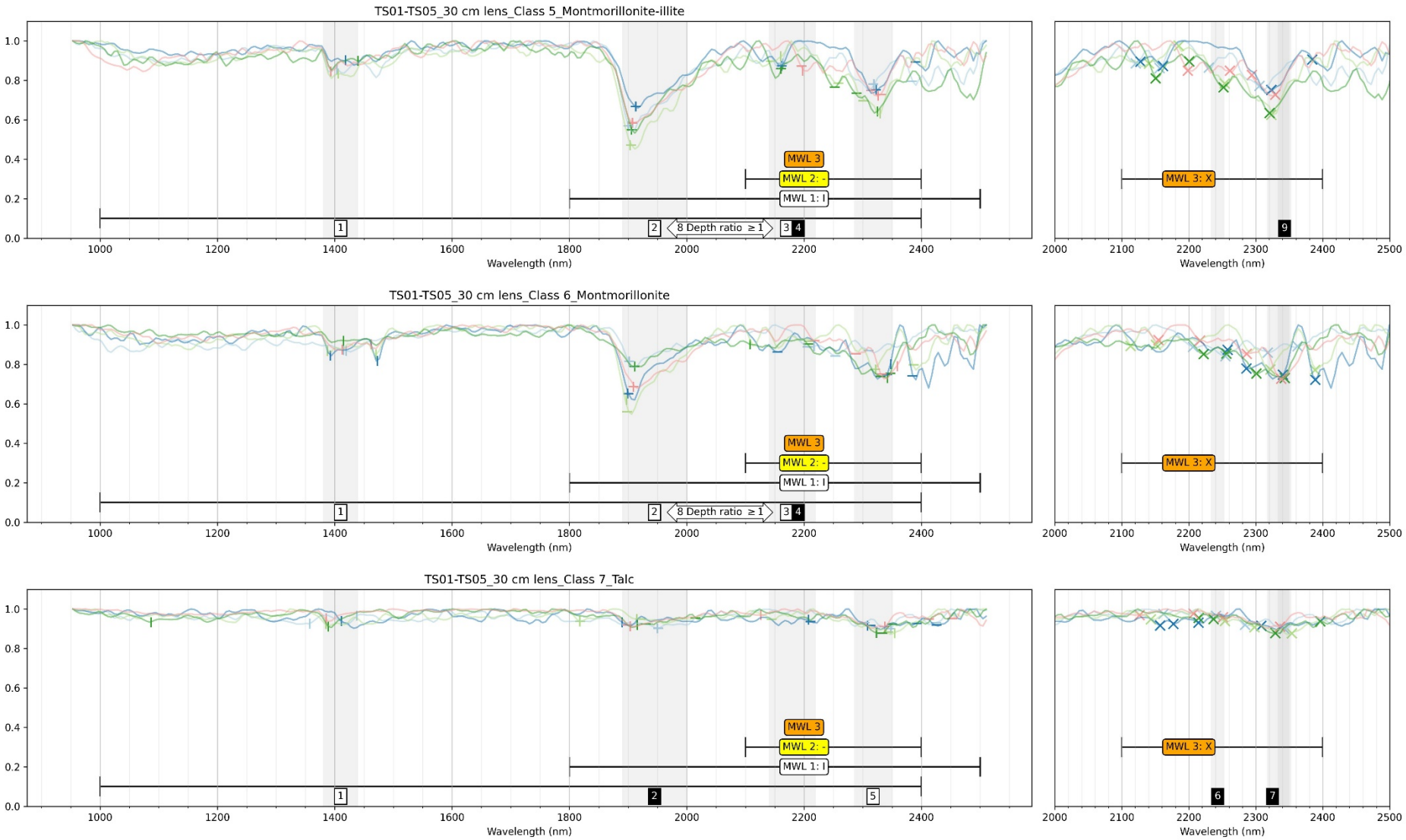
[5] B. Kamiński, M. Jakubczyk, and P. Szufel, “A framework for sensitivity analysis of decision trees,” *Cent. Eur. J. Oper. Res.*, vol. 26, no. 1, pp. 135–159, Mar. 2018, doi: 10.1007/S10100-017-0479-6/FIGURES/9.

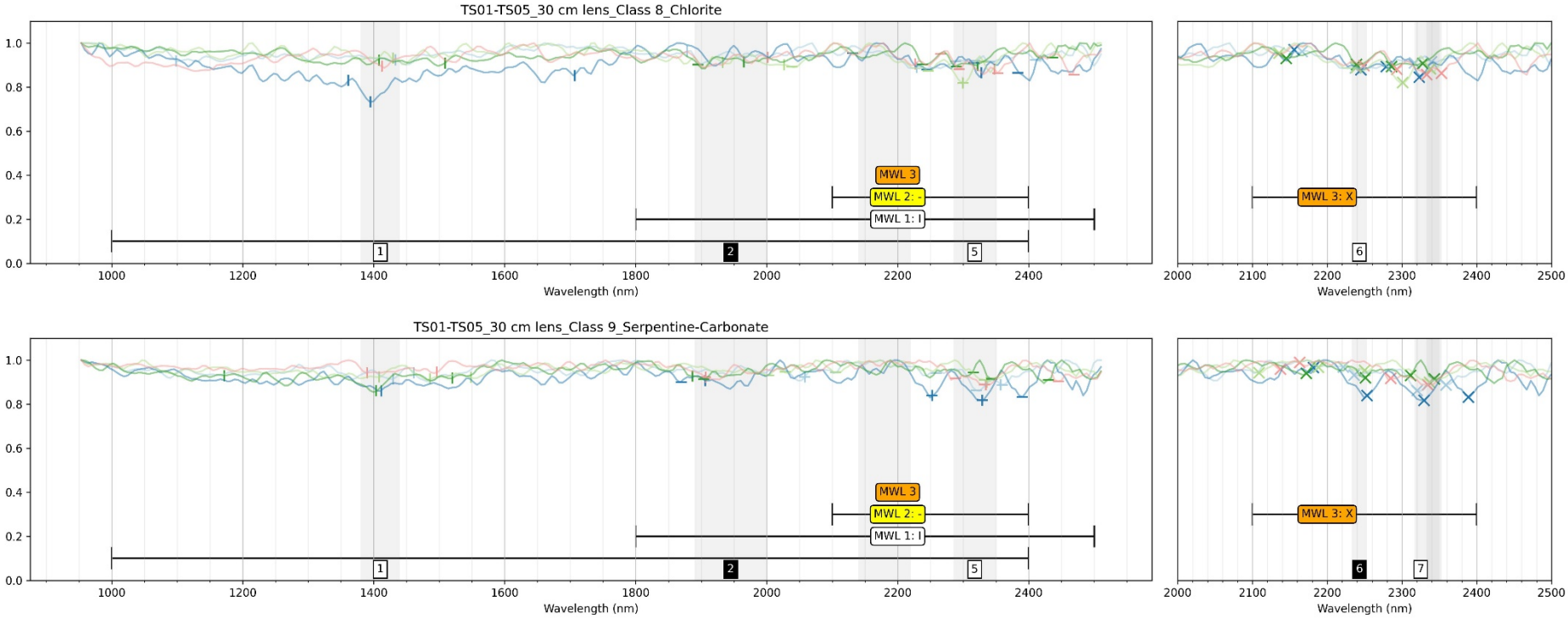
APPENDIX A

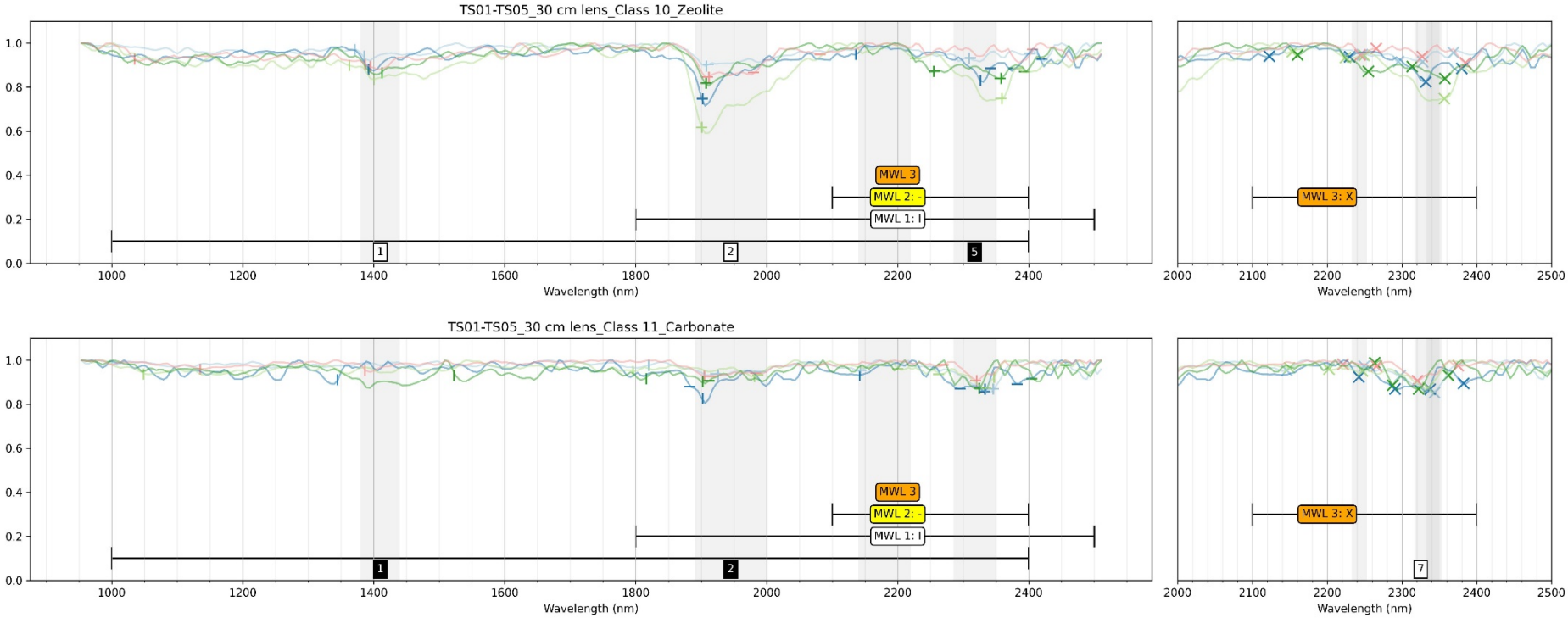
Rock samples - 30 cm lens - SWIR spectra of classes

Minimum wavelength mapping results

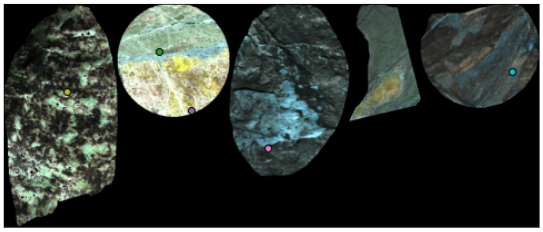

TS01-TS05_30 cm lens_Class 0_Unknown
MWL 3
MWL 2: -
MWL 1: I
MWL 3: X
Wavelength (nm)
TS01-TS05_30 cm lens_Class 3_Smectite-Vermiculite-Chlorite
MWL 3
MWL 2: -
MWL 1: I
MWL 3: X
1
2
5
6
Wavelength (nm)
TS01-TS05_30 cm lens_Class 4_Smectite-Talc
MWL 3
MWL 2: -
MWL 1: I
MWL 3: X
1
2
5
6
Wavelength (nm)

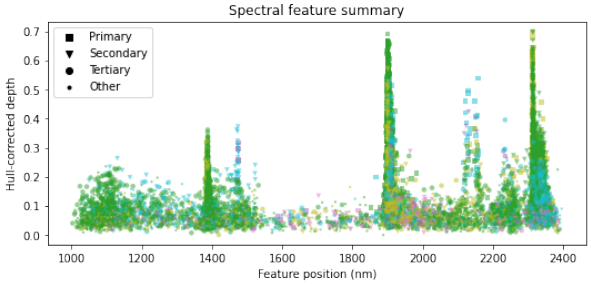

TS01-TS05_30 cm lens_Class 5_Montmorillonite-illite
MWL 3
MWL 2: -
MWL 1: I
1
2
8 Depth ratio ≥ 1
3
4
MWL 3: X
9
Wavelength (nm)
TS01-TS05_30 cm lens_Class 6_Montmorillonite
MWL 3
MWL 2: -
MWL 1: I
1
2
8 Depth ratio ≥ 1
3
4
MWL 3: X
Wavelength (nm)
TS01-TS05_30 cm lens_Class 7_Talc
MWL 3
MWL 2: -
MWL 1: I
1
2
5
MWL 3: X
6
7
Wavelength (nm)

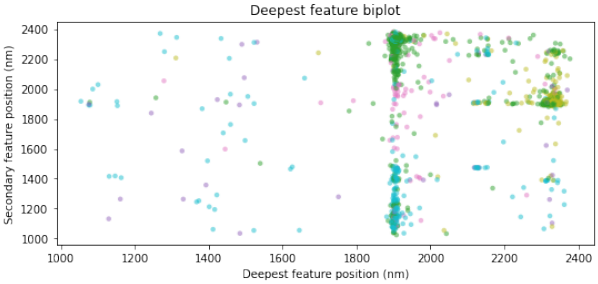

TS01-TS05_30 cm lens_Class 8_Chlorite
MWL 3
MWL 2: -
MWL 1: I
MWL 3: X
1
2
5
6
Wavelength (nm)
TS01-TS05_30 cm lens_Class 9_Serpentine-Carbonate
MWL 3
MWL 2: -
MWL 1: I
MWL 3: X
1
2
5
6
7
Wavelength (nm)

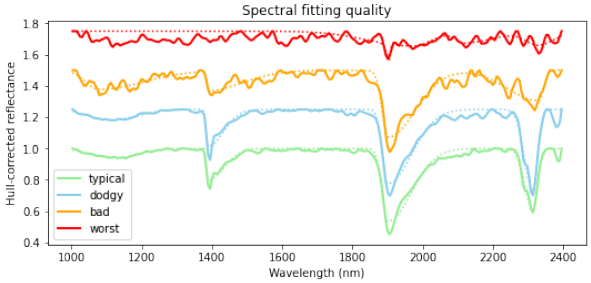

TS01-TS05_30 cm lens_Class 10_Zeolite
MWL 3
MWL 2: -
MWL 1: I
MWL 3: X
Wavelength (nm)
TS01-TS05_30 cm lens_Class 11_Carbonate
MWL 3
MWL 2: -
MWL 1: I
MWL 3: X
Wavelength (nm)

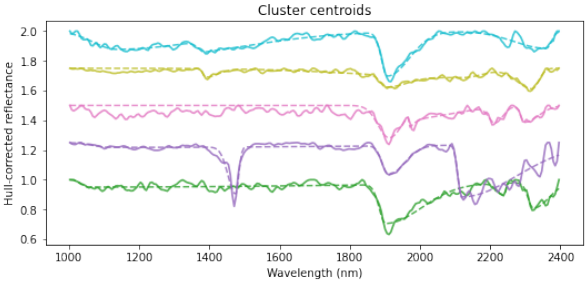
MWL 1: 1000 - 2400 nm (Gaussian fitting)

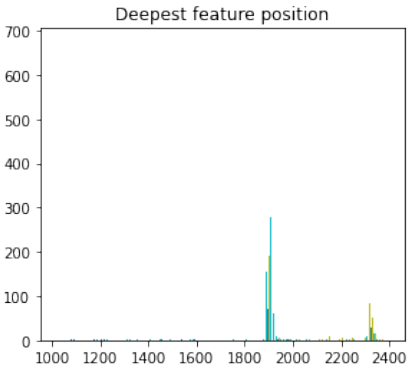


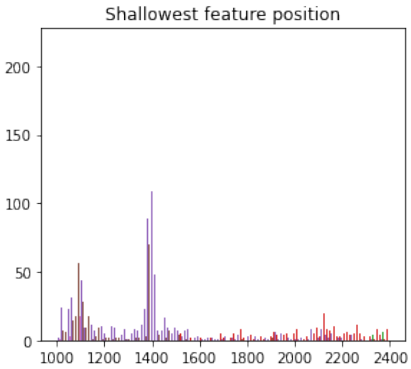


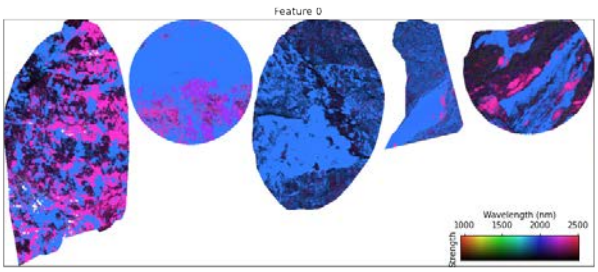


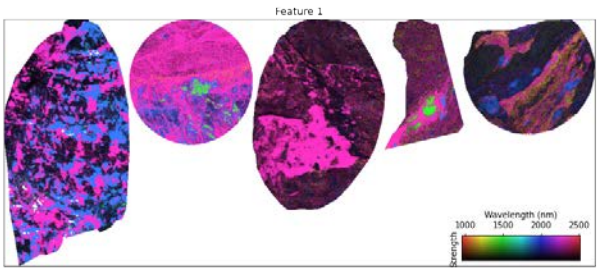


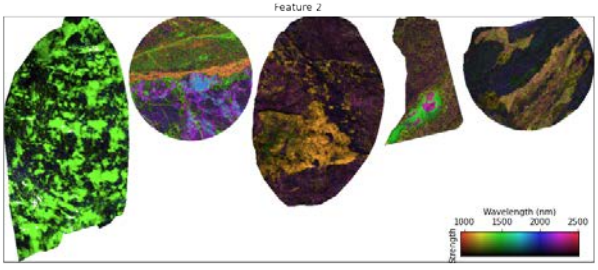


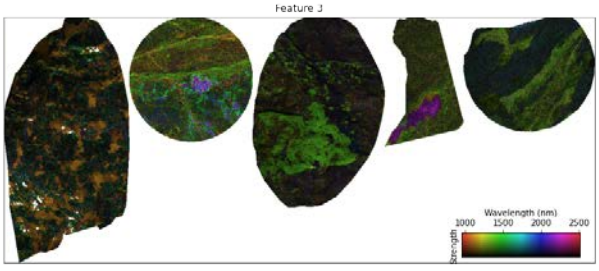




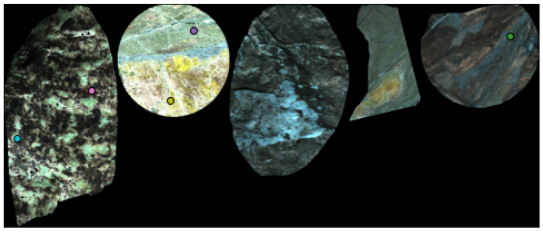


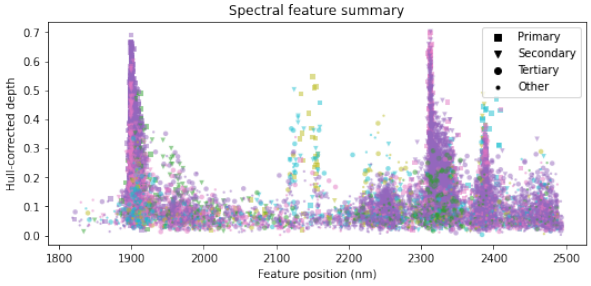


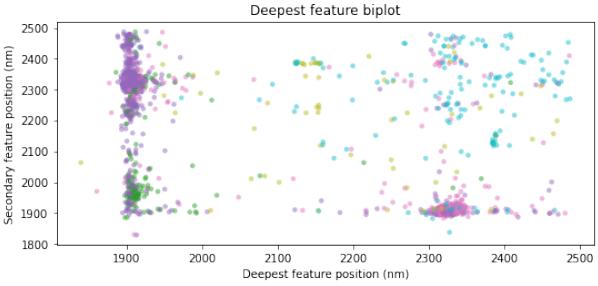


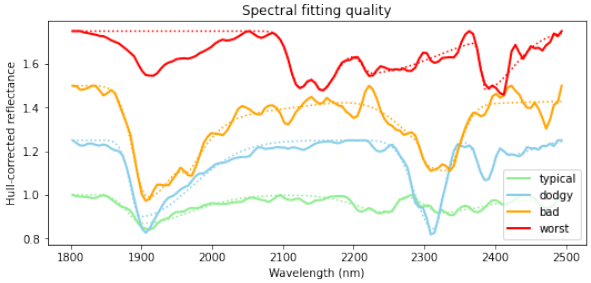


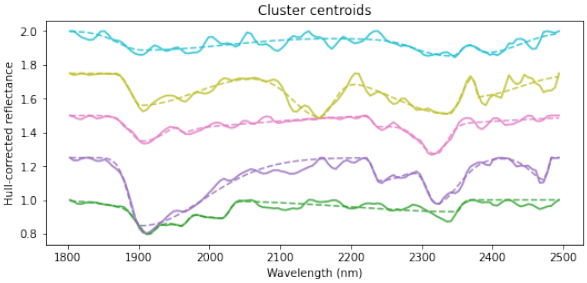
MWL 2: 1800 - 2500 nm (Gaussian fitting)

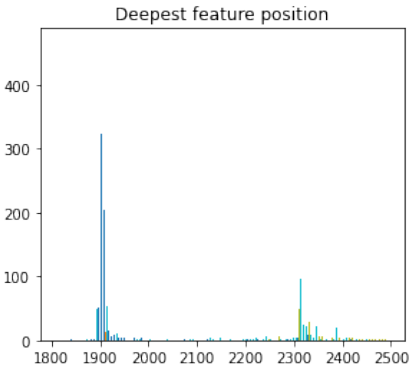


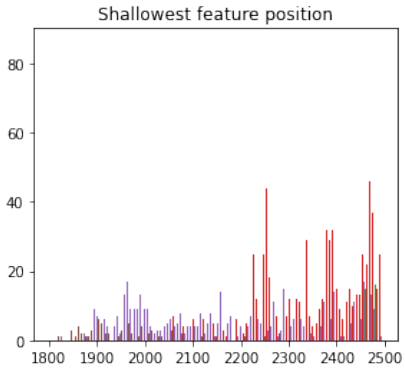


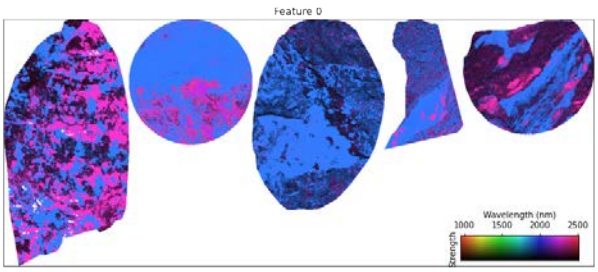


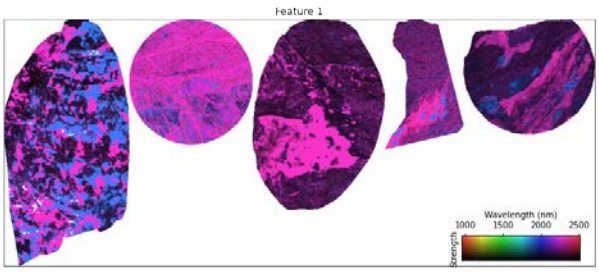


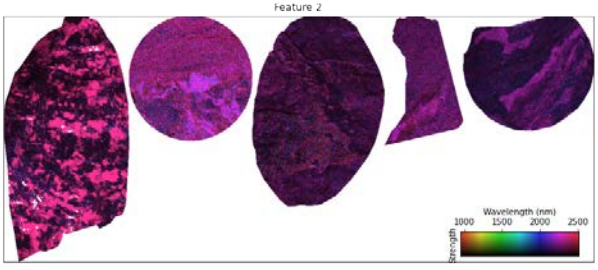


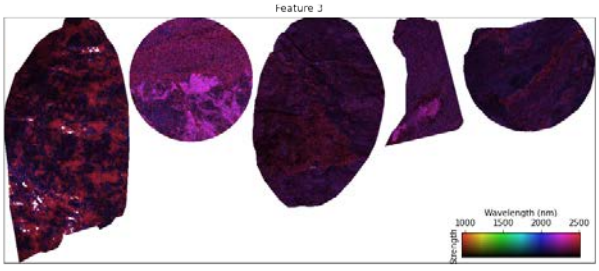




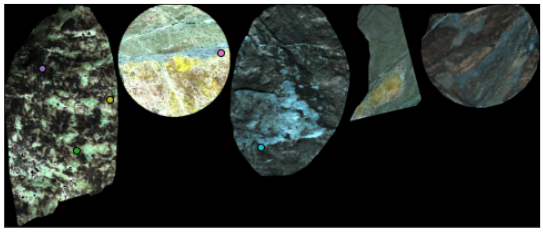


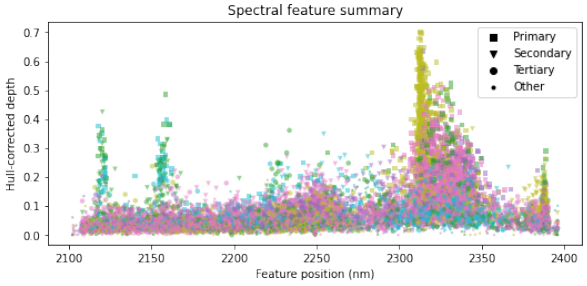


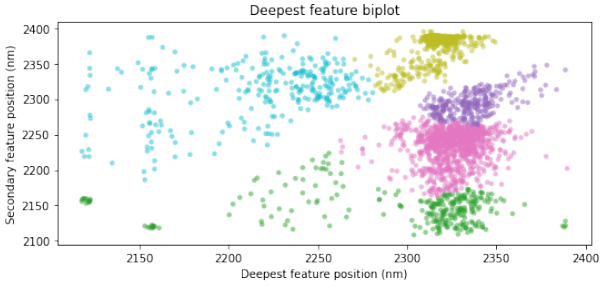


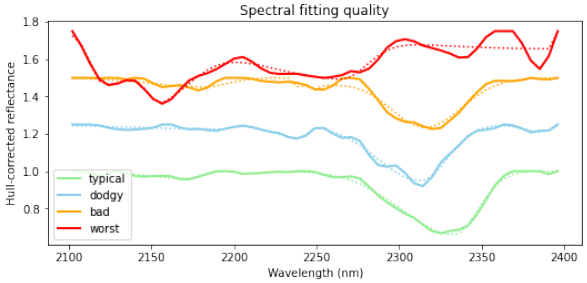


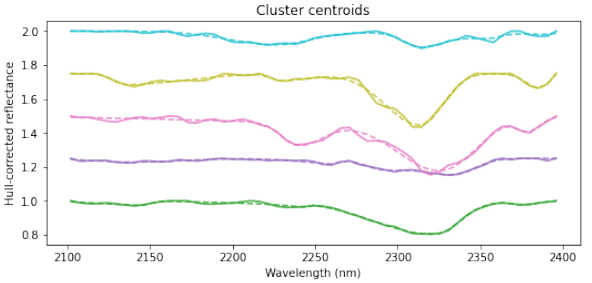
MWL 3: 2100 - 2300 nm (Gaussian fitting)

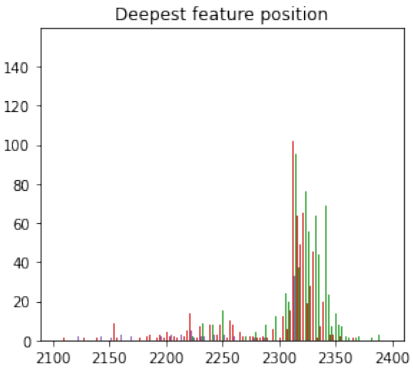


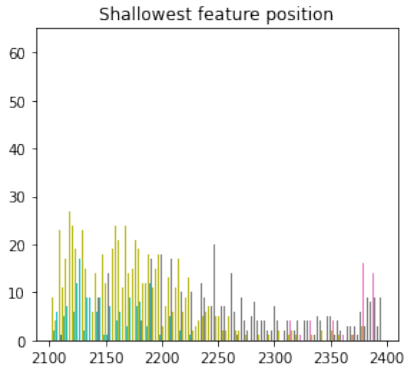


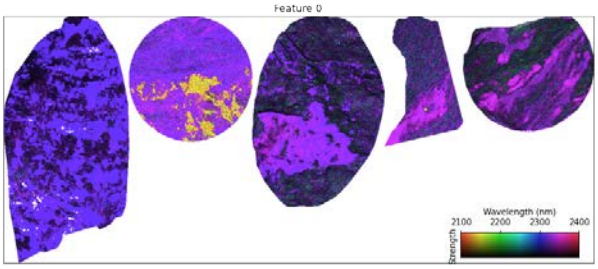


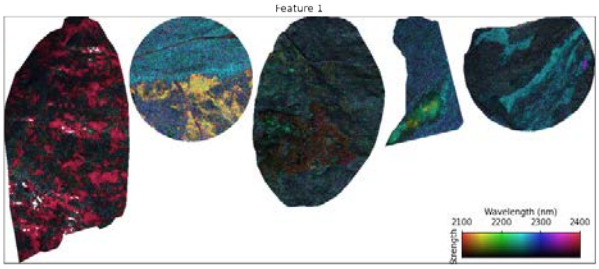


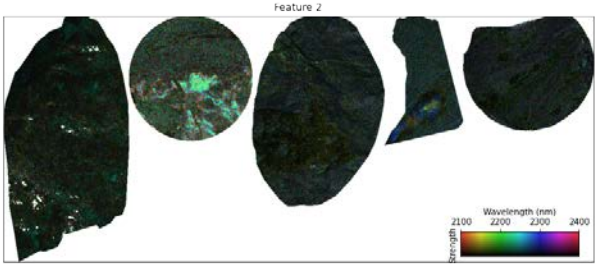


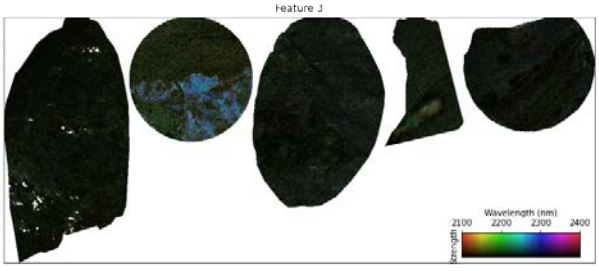








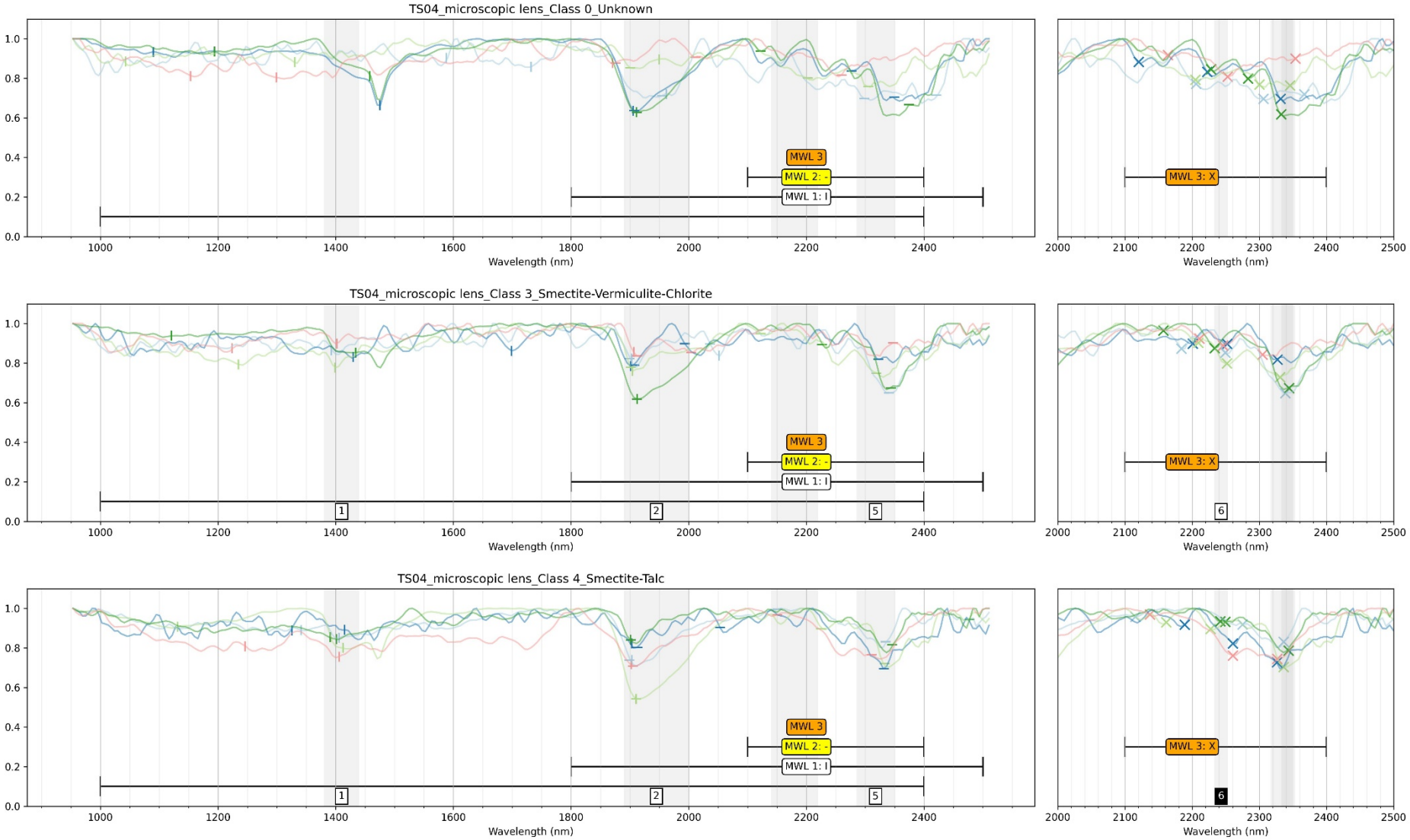


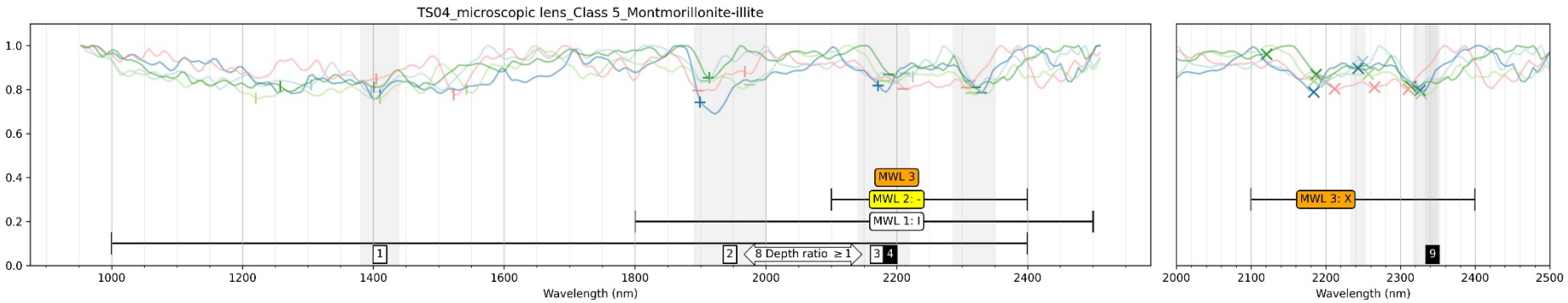


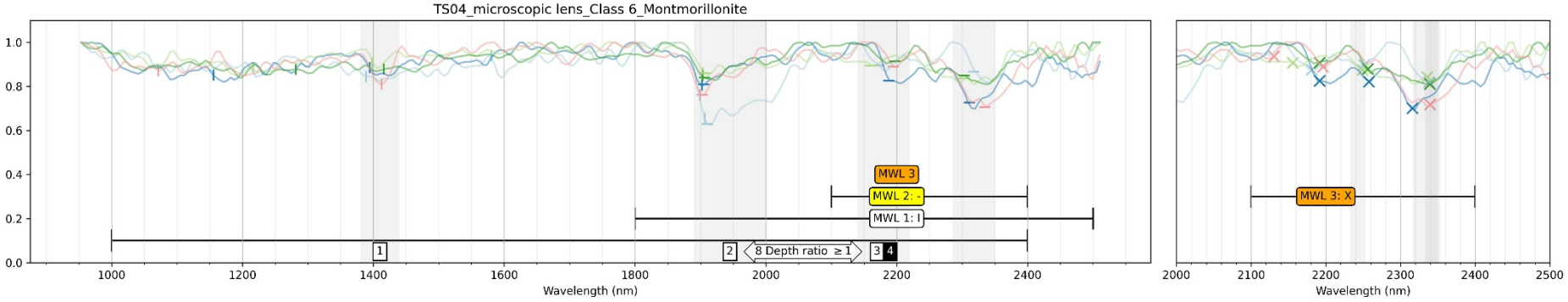
APPENDIX B

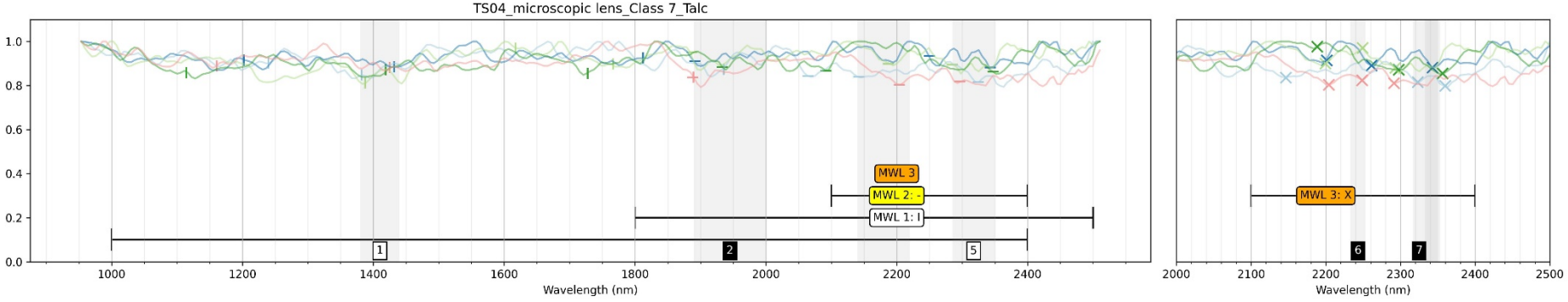
Rock sample for TS04 - microscopic lens - SWIR spectra of classes

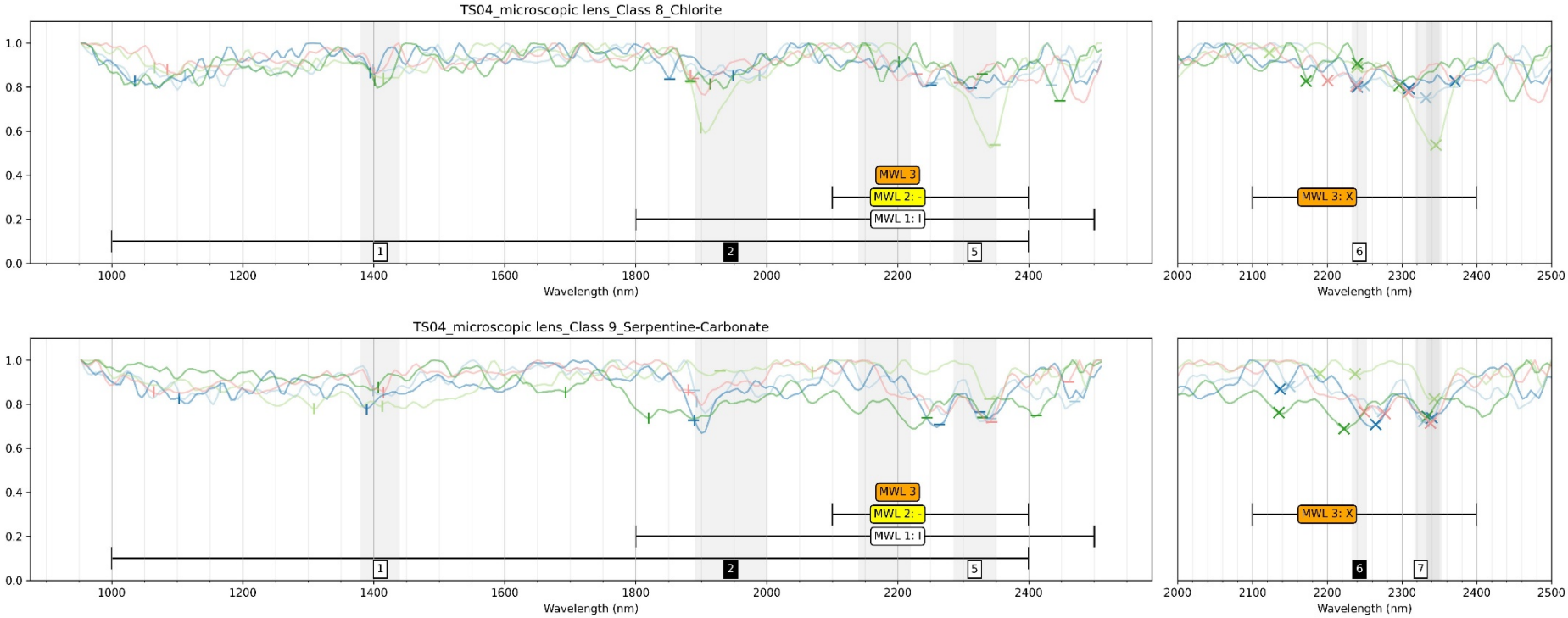
Minimum wavelength mapping results

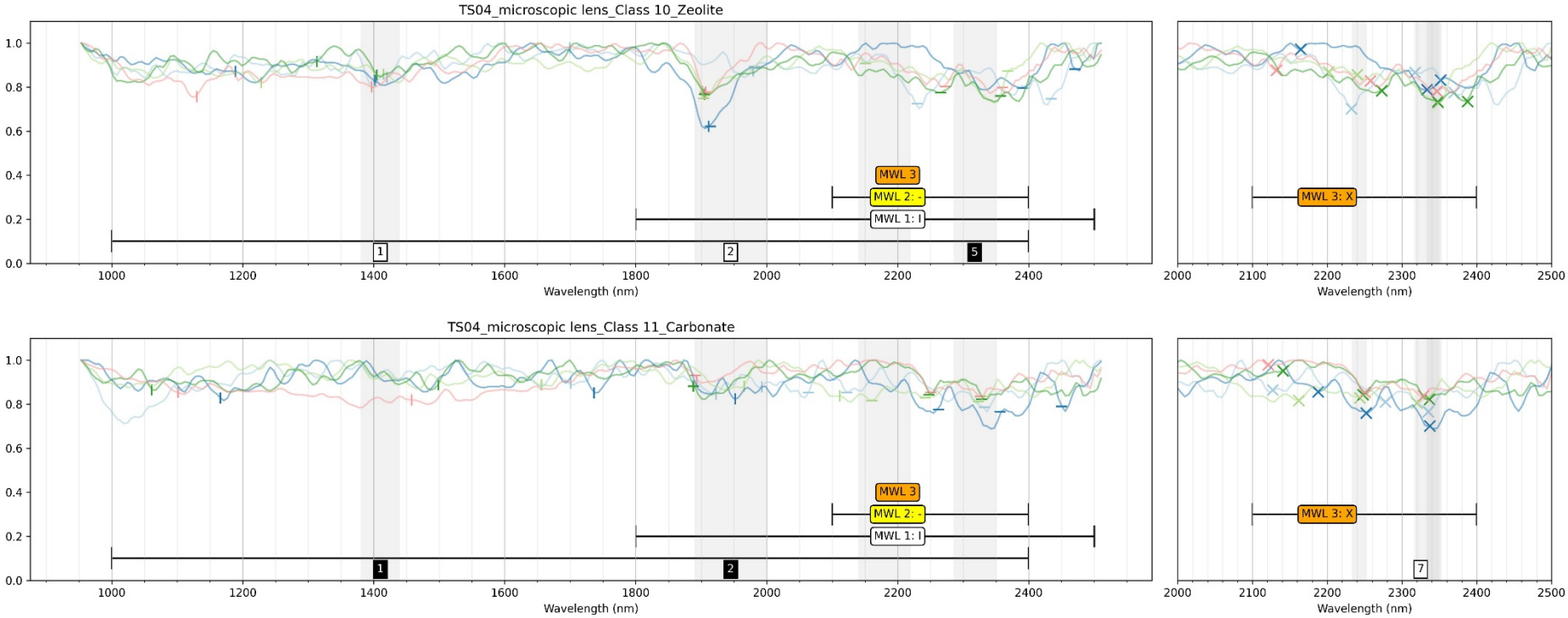

TS04_microscopic lens_Class 0_Unknown
MWL 3
MWL 2: -
MWL 1: I
MWL 3: X
Wavelength (nm)
TS04_microscopic lens_Class 3_Smectite-Vermiculite-Chlorite
MWL 3
MWL 2: -
MWL 1: I
1
2
5
6
MWL 3: X
Wavelength (nm)
TS04_microscopic lens_Class 4_Smectite-Talc
MWL 3
MWL 2: -
MWL 1: I
1
2
5
6
MWL 3: X
Wavelength (nm)


TS04_microscopic lens_Class 5_Montmorillonite-illite
MWL 3
MWL 2: -
MWL 1: I
MWL 3: X
8 Depth ratio ≥ 1
Wavelength (nm)

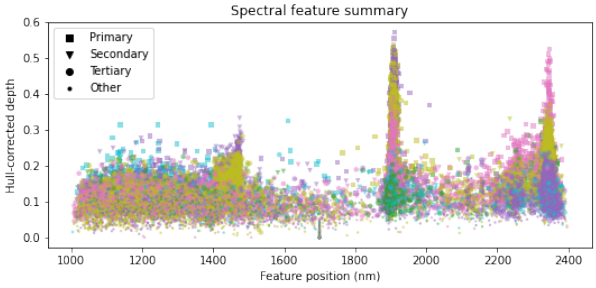

TS04_microscopic lens_Class 6_Montmorillonite
MWL 3
MWL 2: -
MWL 1: I
MWL 3: X
8 Depth ratio ≥ 1
Wavelength (nm)

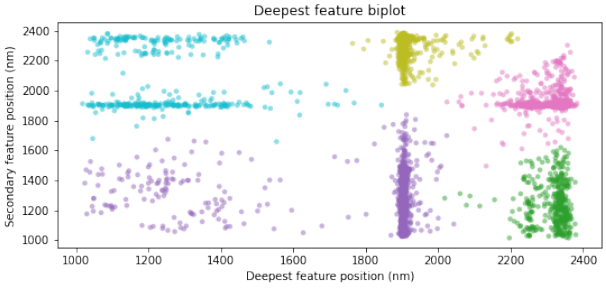

TS04_microscopic lens_Class 7_Talc
MWL 3
MWL 2: -
MWL 1: I
MWL 3: X
Wavelength (nm)

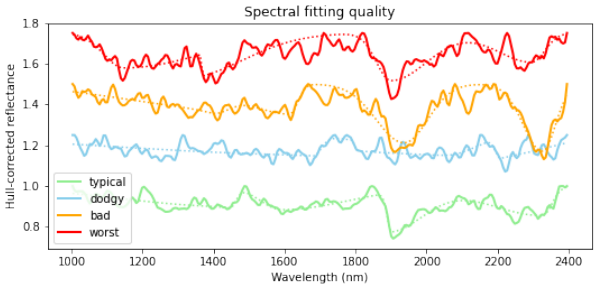

TS04_microscopic lens_Class 8_Chlorite
MWL 3
MWL 2: -
MWL 1: I
1
2
5
MWL 3: X
6
Wavelength (nm)
TS04_microscopic lens_Class 9_Serpentine-Carbonate
MWL 3
MWL 2: -
MWL 1: I
1
2
5
MWL 3: X
6
7
Wavelength (nm)

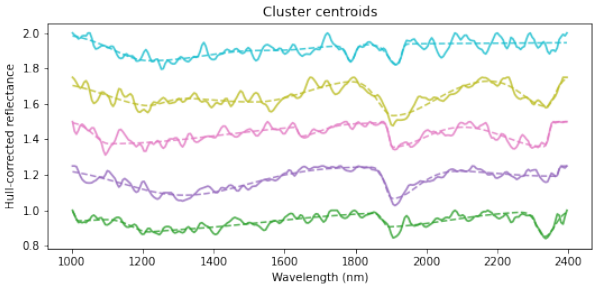

TS04_microscopic lens_Class 10_Zeolite
MWL 3
MWL 2: -
MWL 1: I
1
2
5
MWL 3: X
Wavelength (nm)
TS04_microscopic lens_Class 11_Carbonate
MWL 3
MWL 2: -
MWL 1: I
1
2
MWL 3: X
7
Wavelength (nm)

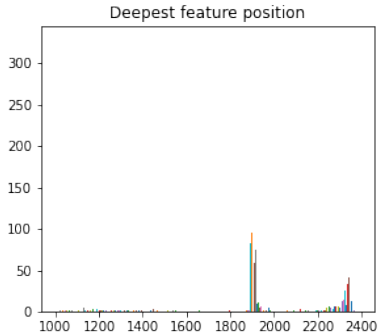
MWL 1: 1000 - 2400 nm (Gaussian fitting)

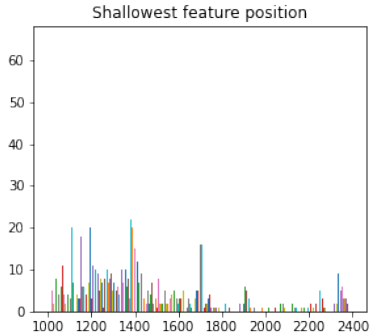


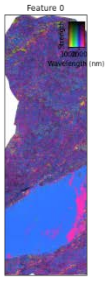


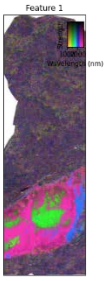




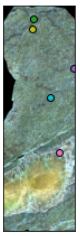


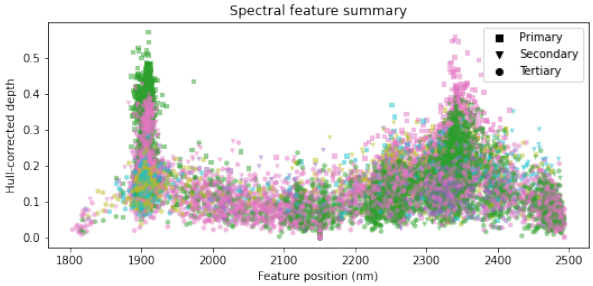


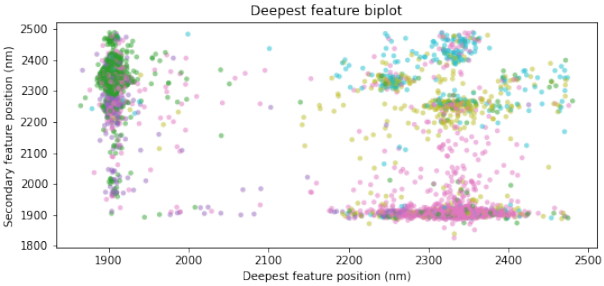


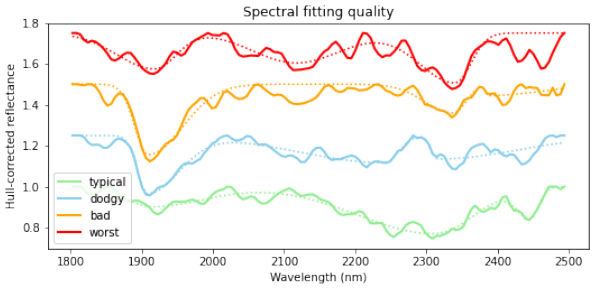


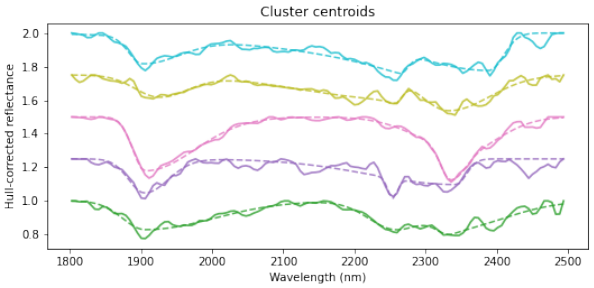
MWL 2: 1800 - 2500 nm (Gaussian fitting) -- only three features were mapped

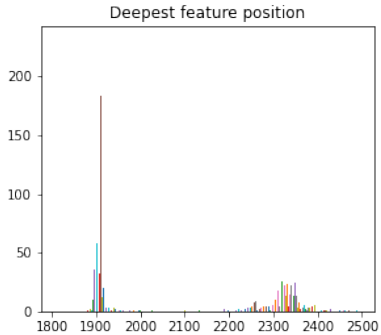


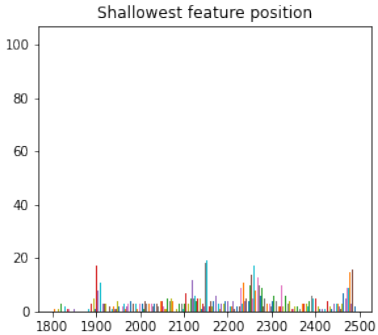


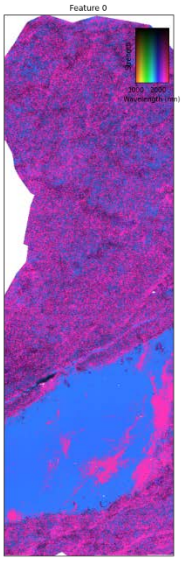


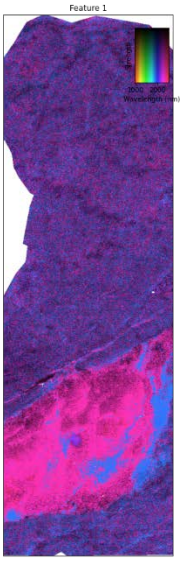


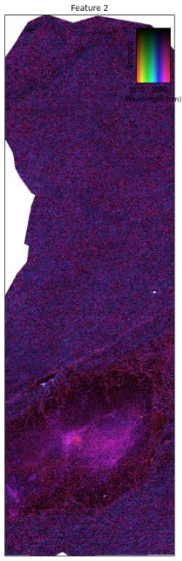




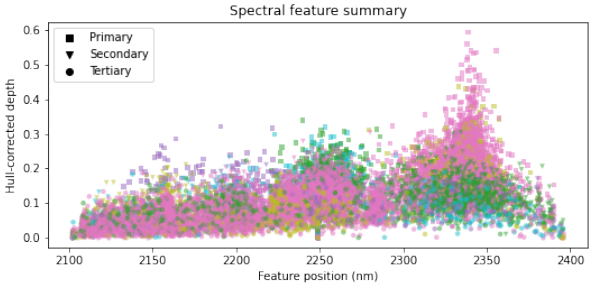


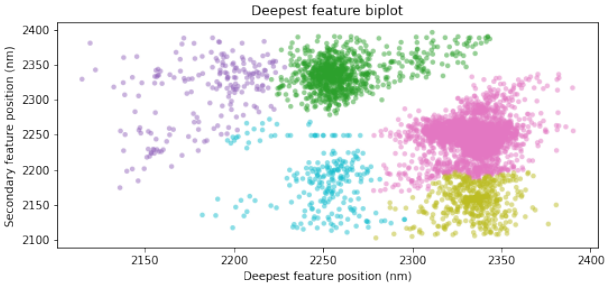


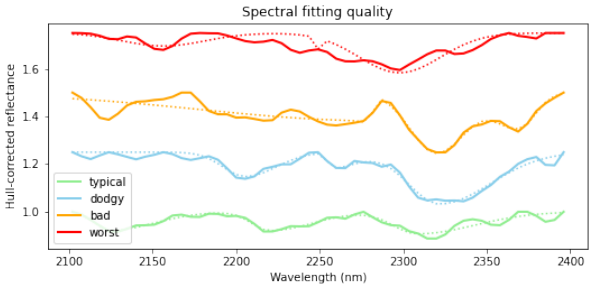


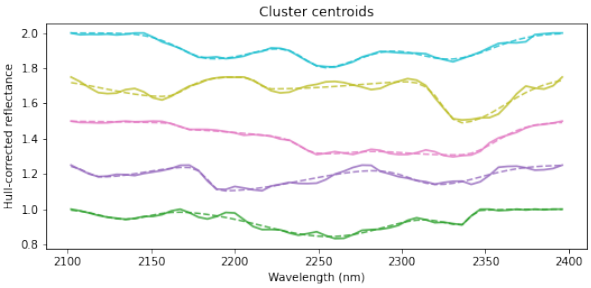


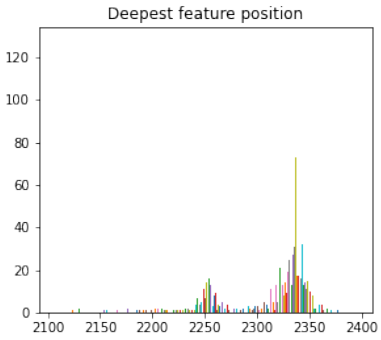
MWL 3: 2100 - 2300 nm (Gaussian fitting)

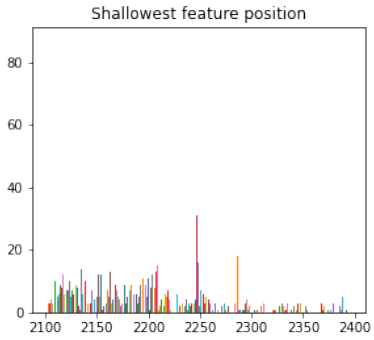


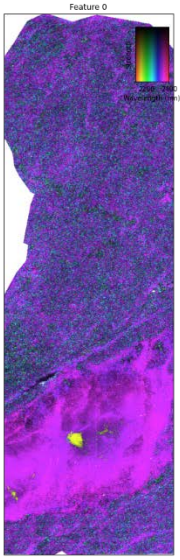


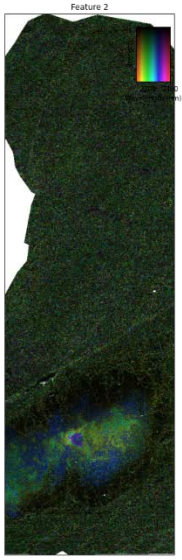








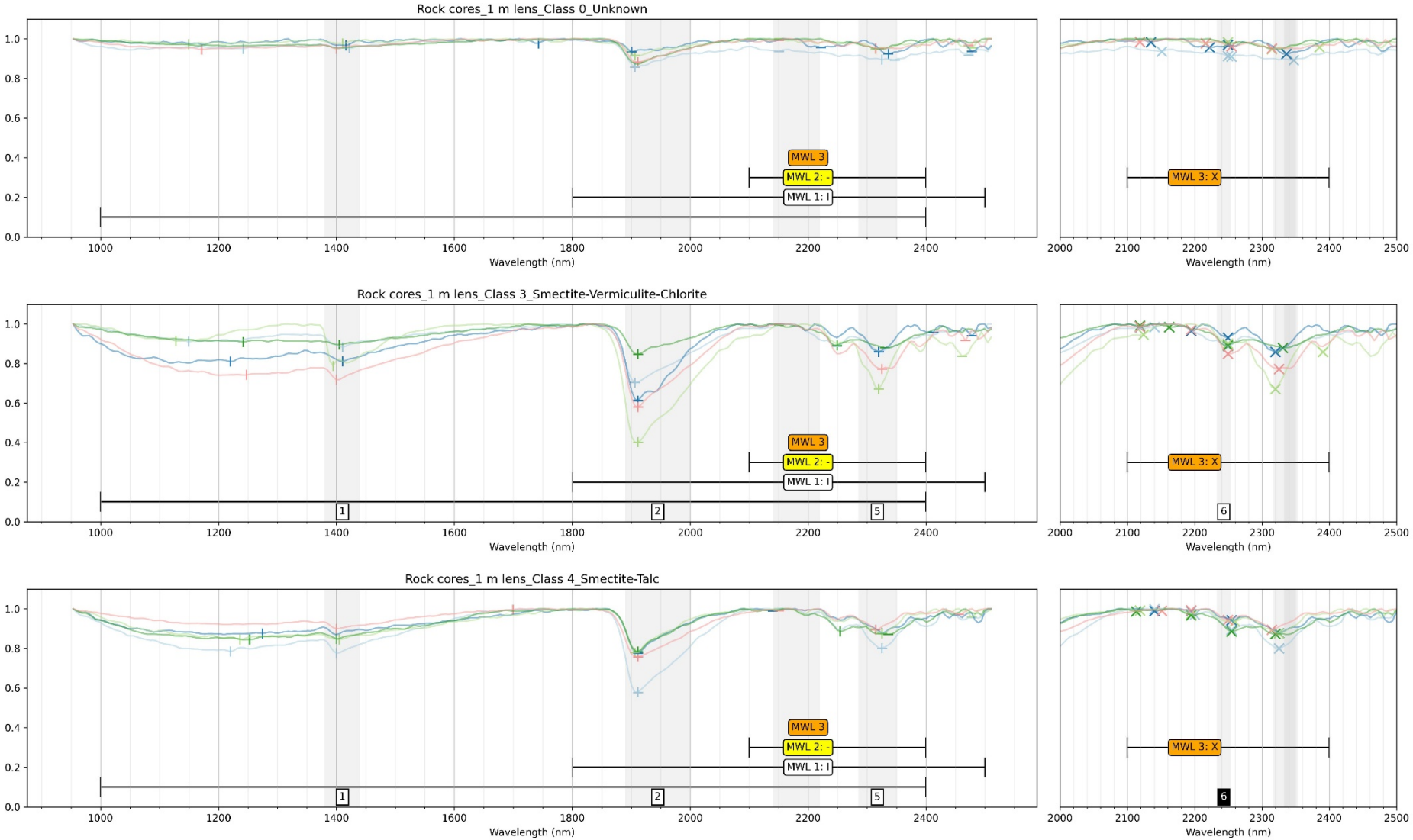


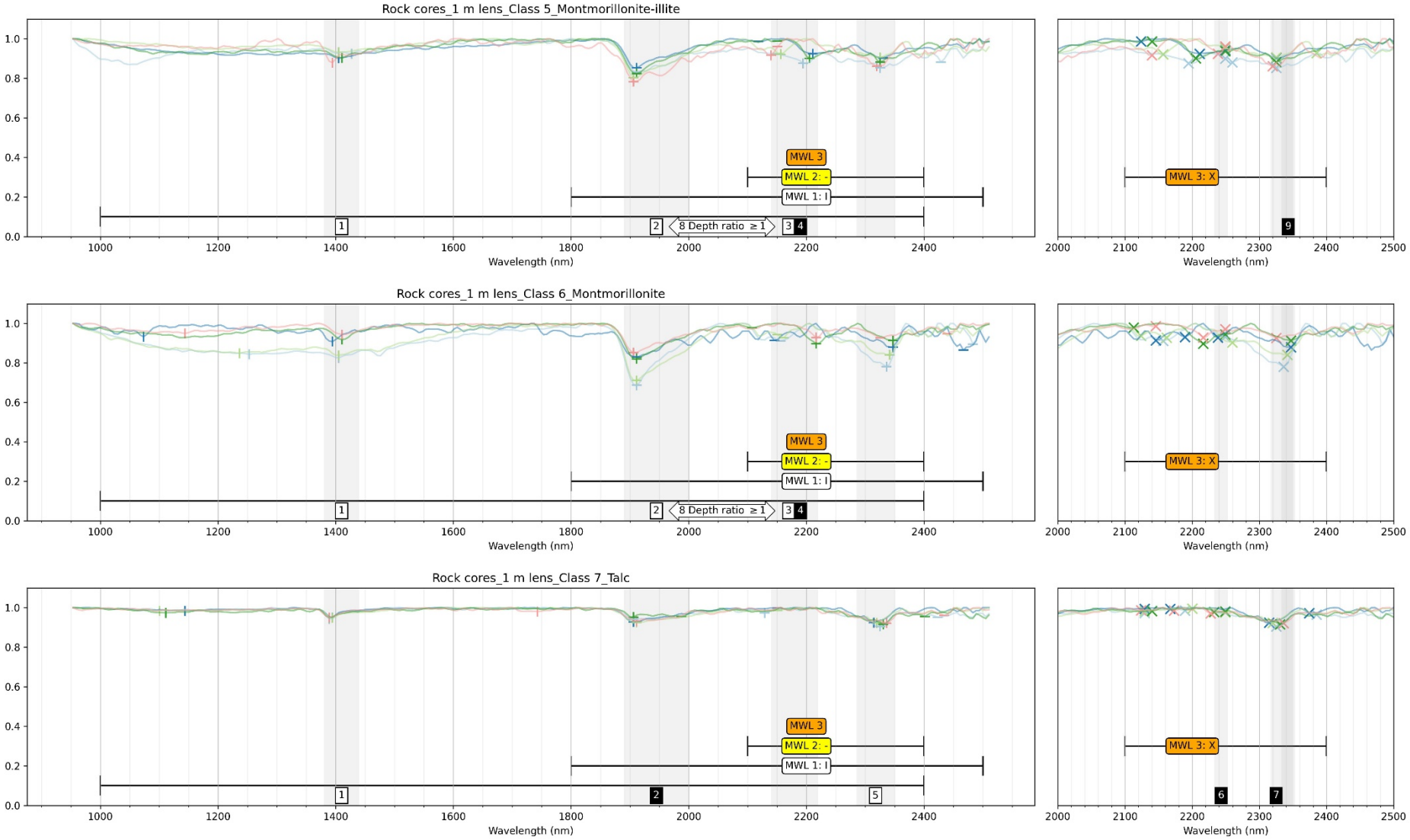


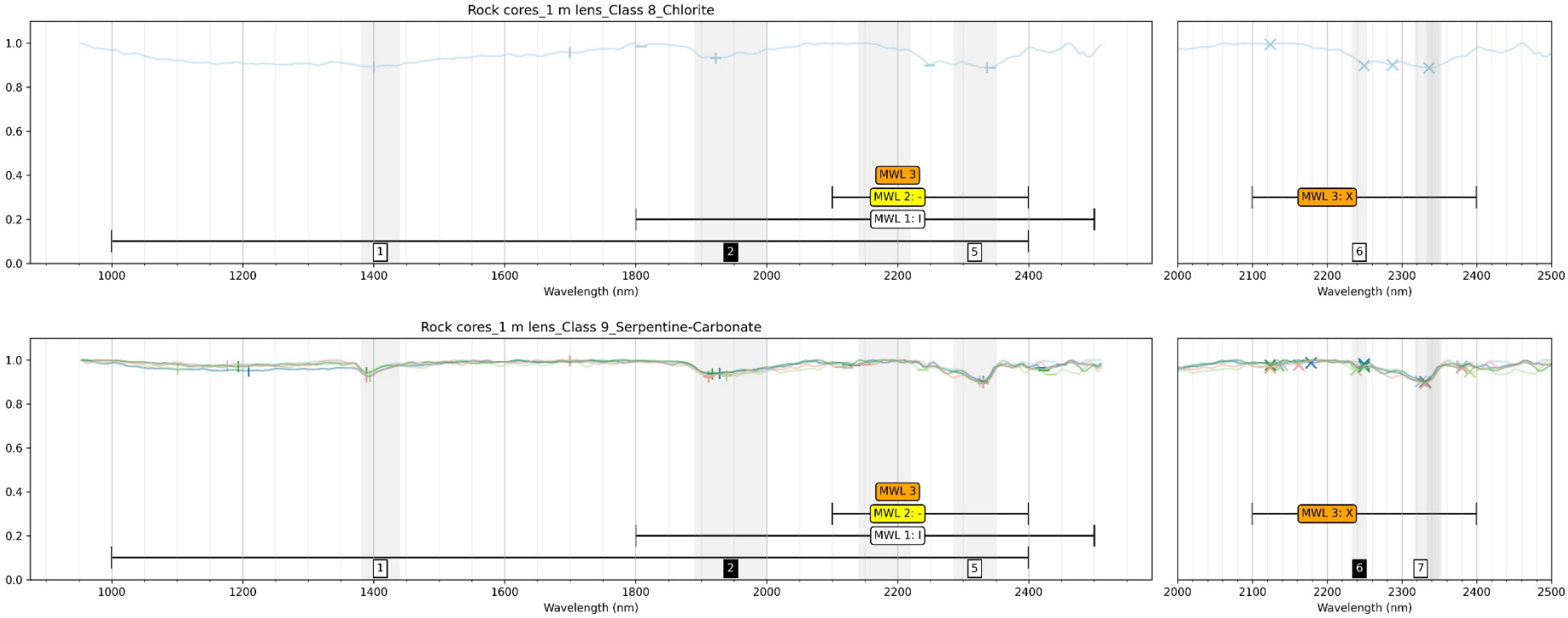
APPENDIX C

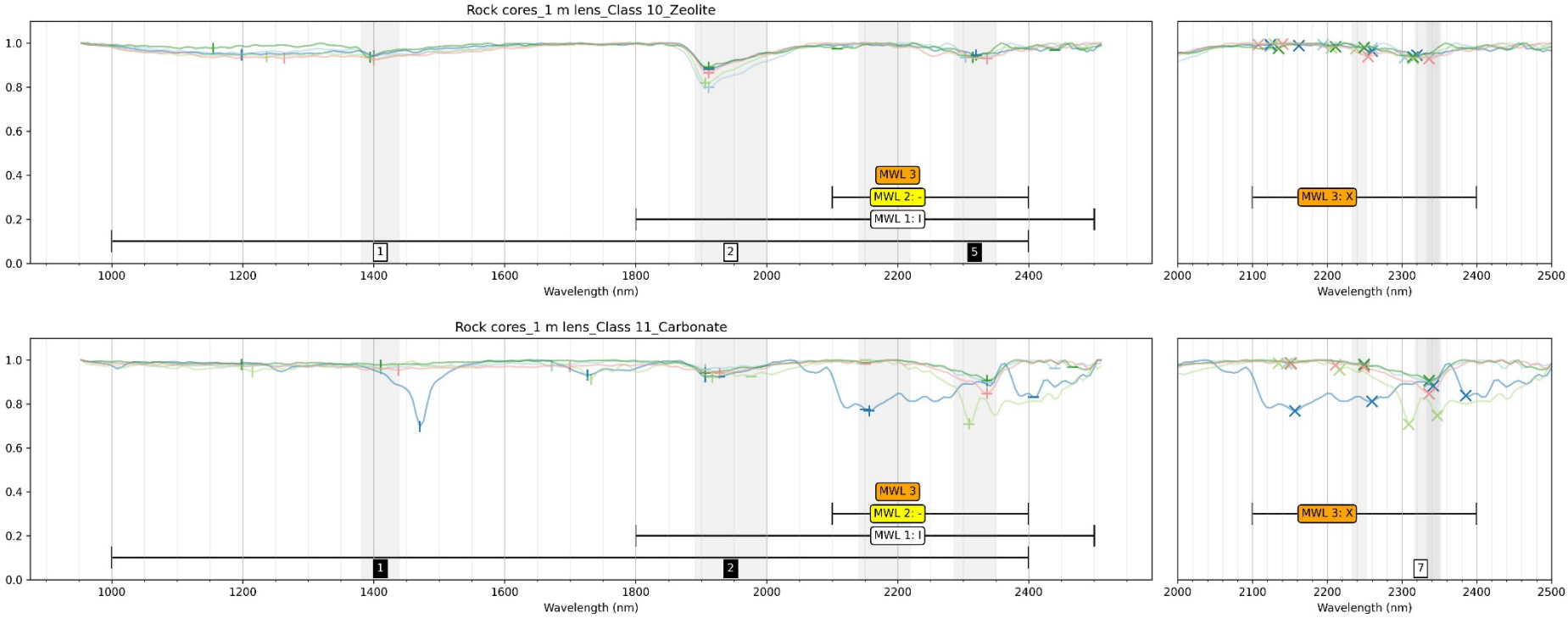
Rock cores – 1m lens - SWIR spectra of classes

Minimum wavelength mapping results

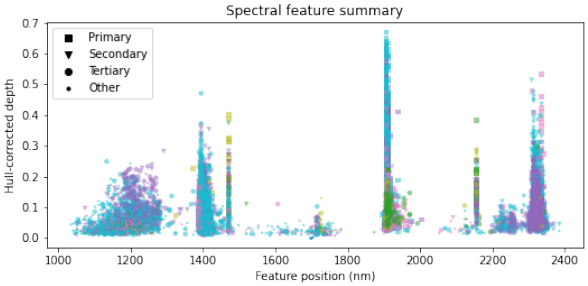

Rock cores_1 m lens_Class 0_Unknown
MWL 3
MWL 2: -
MWL 1: I
MWL 3: X
Wavelength (nm)
Rock cores_1 m lens_Class 3_Smectite-Vermiculite-Chlorite
MWL 3
MWL 2: -
MWL 1: I
MWL 3: X
1
2
5
6
Wavelength (nm)
Rock cores_1 m lens_Class 4_Smectite-Talc
MWL 3
MWL 2: -
MWL 1: I
MWL 3: X
1
2
5
6
Wavelength (nm)

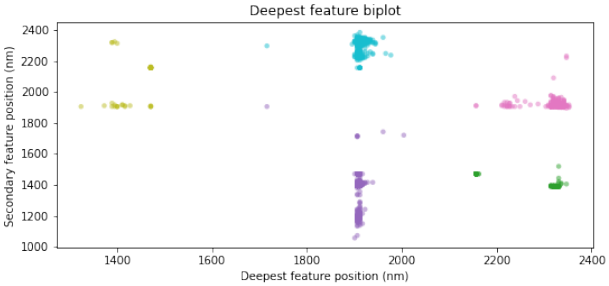

Rock cores_1 m lens_Class 5_Montmorillonite-illite
MWL 3
MWL 2: -
MWL 1: I
MWL 3: X
8 Depth ratio ≥ 1
Wavelength (nm)
Rock cores_1 m lens_Class 6_Montmorillonite
MWL 3
MWL 2: -
MWL 1: I
MWL 3: X
8 Depth ratio ≥ 1
Wavelength (nm)
Rock cores_1 m lens_Class 7_Talc
MWL 3
MWL 2: -
MWL 1: I
MWL 3: X
Wavelength (nm)

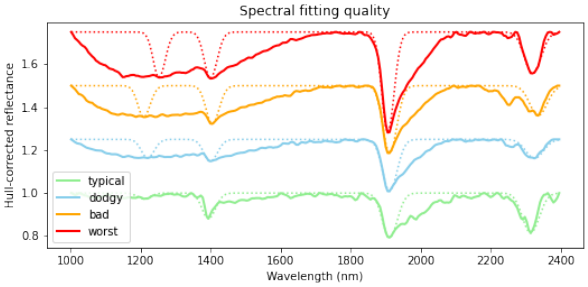

Rock cores_1 m lens_Class 8_Chlorite
MWL 3
MWL 2: -
MWL 1: I
MWL 3: X
Wavelength (nm)
Rock cores_1 m lens_Class 9_Serpentine-Carbonate
MWL 3
MWL 2: -
MWL 1: I
MWL 3: X
Wavelength (nm)

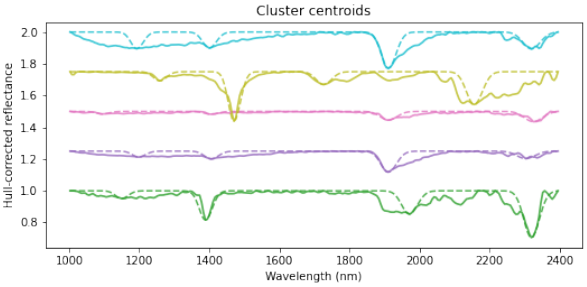

Rock cores_1 m lens_Class 10_Zeolite
MWL 3
MWL 2: -
MWL 1: I
1
2
5
MWL 3: X
Wavelength (nm)
Rock cores_1 m lens_Class 11_Carbonate
MWL 3
MWL 2: -
MWL 1: I
1
2
MWL 3: X
7
Wavelength (nm)

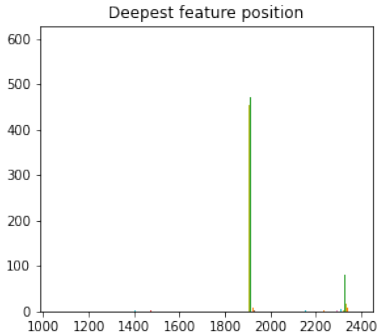
MWL 1: 1000 - 2400 nm (Min-max fitting)

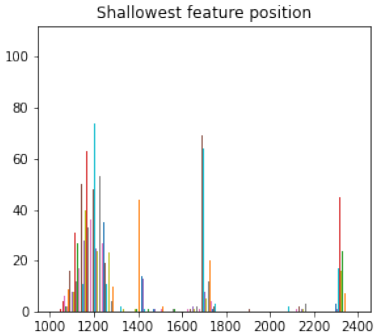


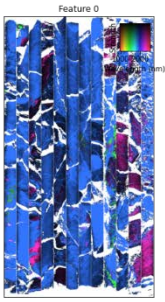


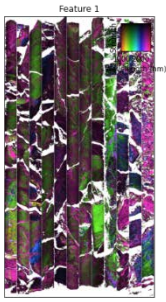


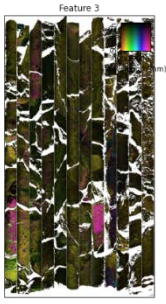




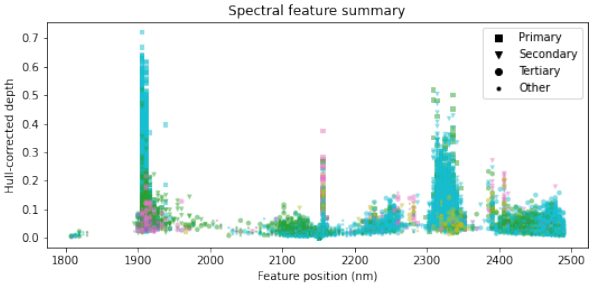


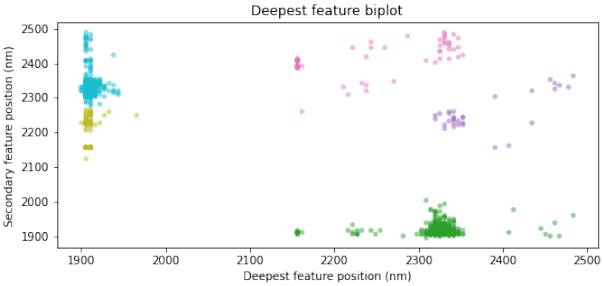


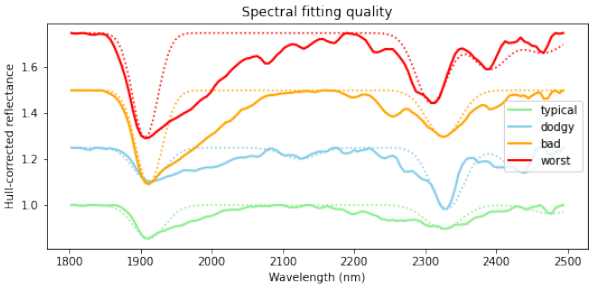


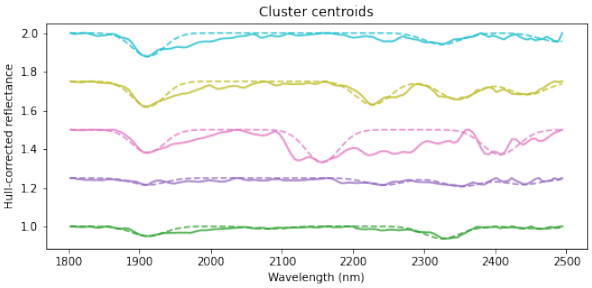


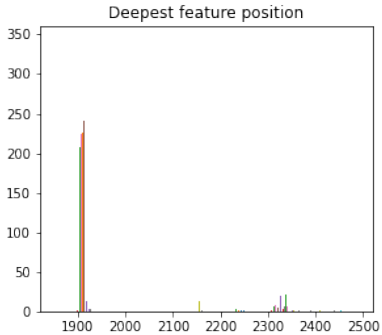
MWL 2: 1800 - 2500 nm (Min-max fitting)

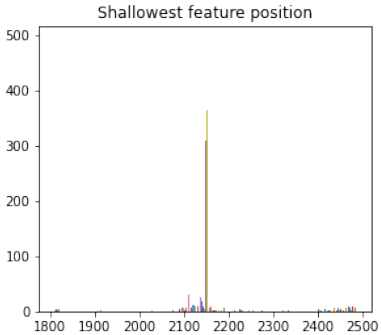


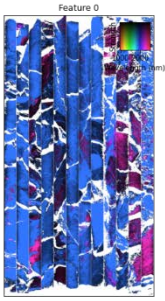


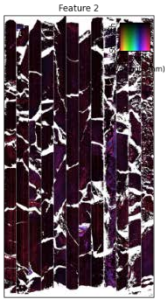


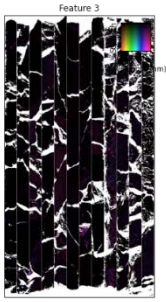












MWL 3: 2100 - 2300 nm (Min-max fitting)