remote sensing

MDPI

Supplementary Material

Discrimination of Fe-Ni-laterites from bauxites using a novel SVM-based methodology on Sentinel-2 data

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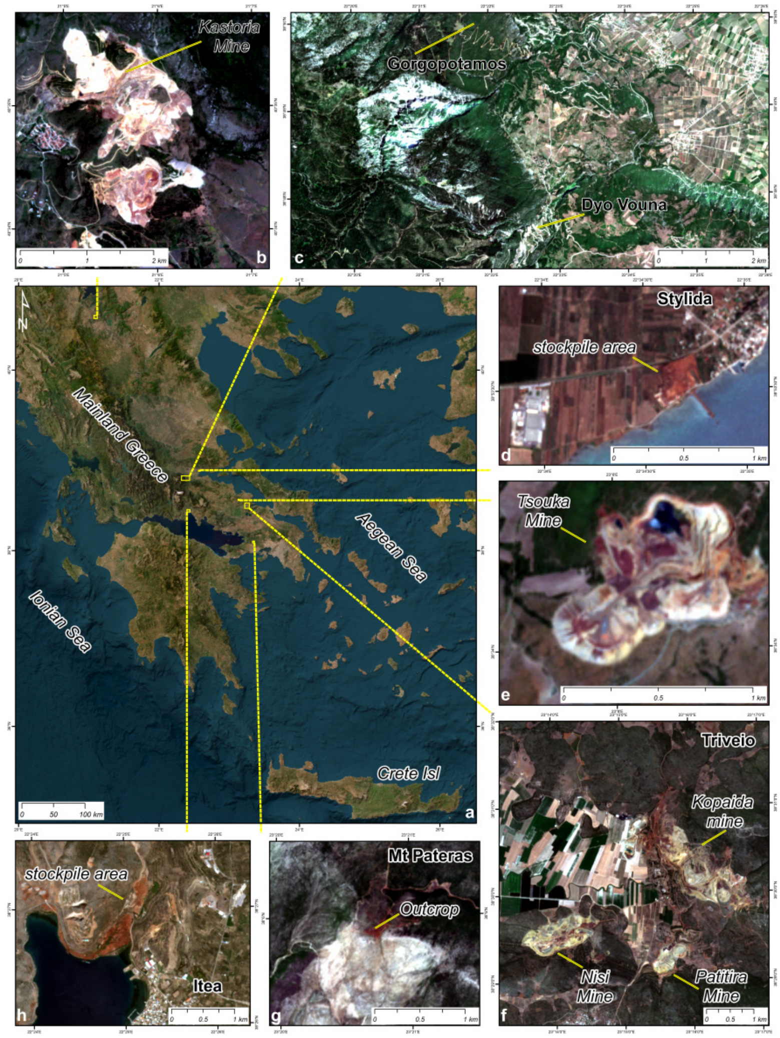


Figure S1. Locations of the studied ore occurrences in Greece: (**a**) site locations in Greece; (**b**) Kastoria Fe-Ni-laterite open-pit mine, (**c**) Gorgopotamos and Dyo-Vouna bauxite open-pit mines, (**d**) Stylida Fe-Ni-laterite stockpile area; (**e**) Tsouka Fe-Ni-laterite open-pit mine; (**f**) Nisi and Kopaida Fe-Ni-laterite open-pit mines, Patitira bauxite open-pit mine and Triveio Fe-Ni-laterite grinding plant; (**g**) Mt Pateras bauxite outcrop; (**h**) Itea stockpile area. The background images from (**a**) to (**h**) are true color composites of the Sentinel-2 satellite images used in this study.

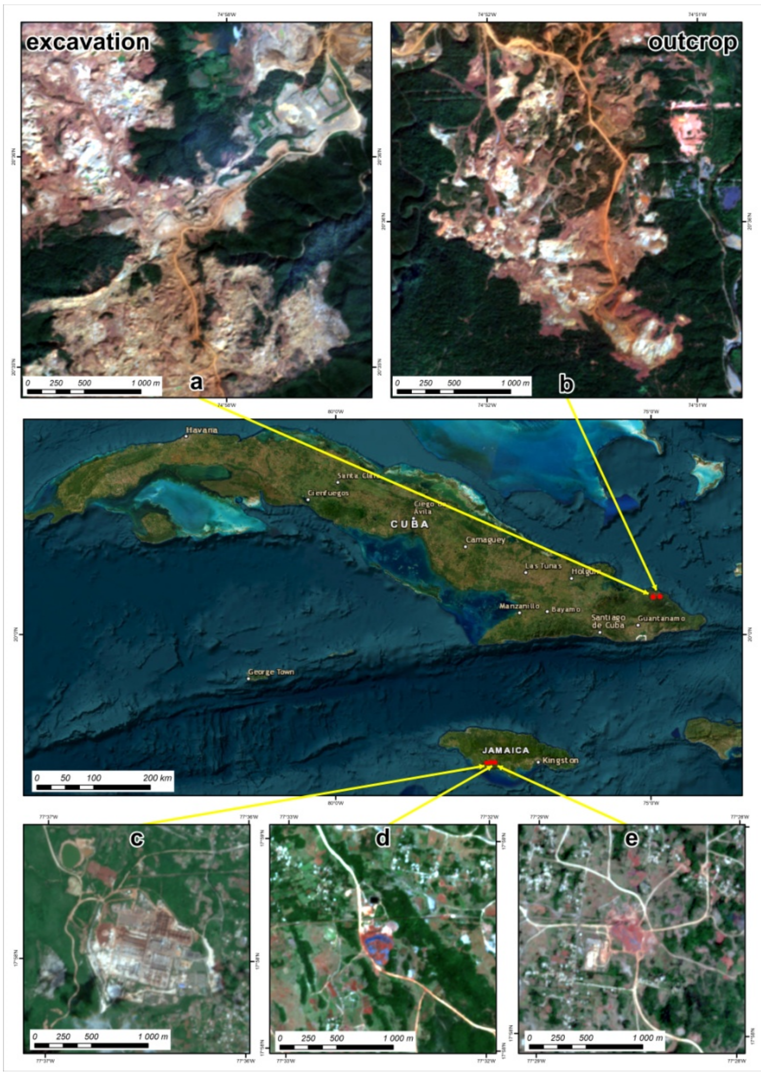
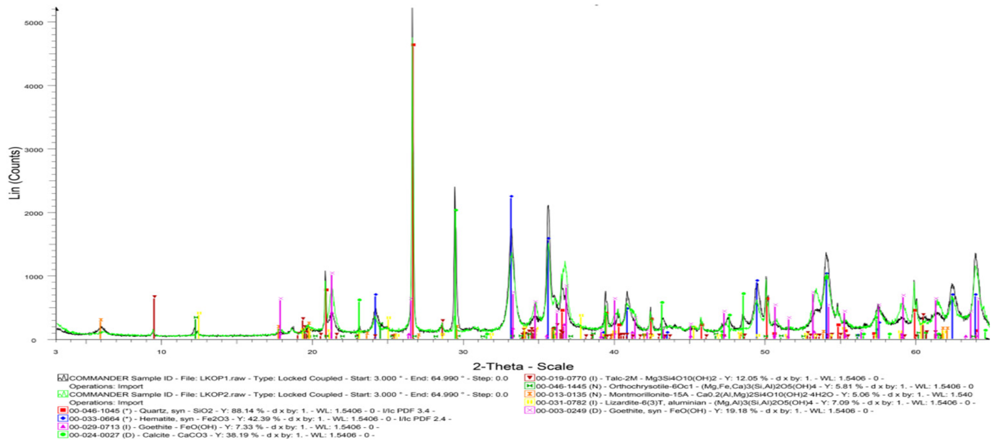


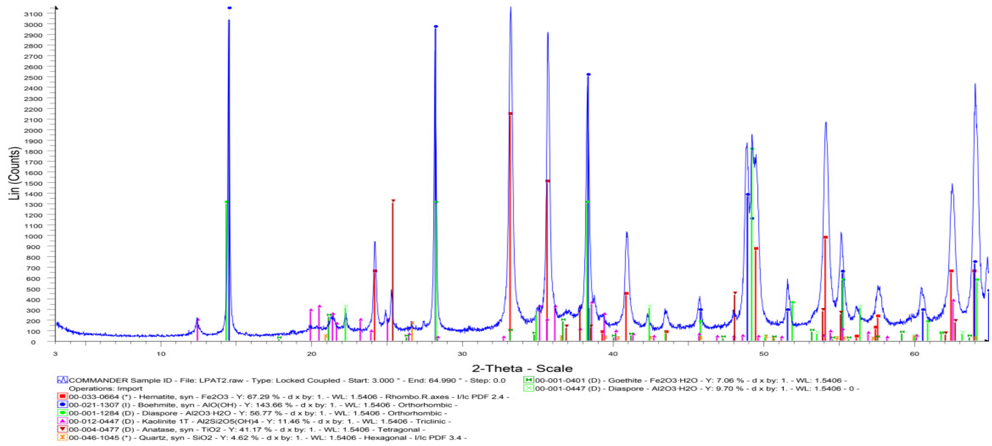
Figure S2. Locations of the studied ore occurrences in Cuba and Jamaica: (**a**) open-pit mines in Moa Bay (Cuba); (**b**) outcrops in Moa Bay (Cuba); (**c**), (**d**) and (**e**) locations of bauxite stockpiles in Jamaica (Jam1, Jam2 and Jam3 correspondingly). The (**a**)-(**e**) background images correspond to the true color composites of the Sentinel-2 images used in this study.

Table S1. Sentinel-2 data acquisition dates and corresponding study areas that are covered by each dataset.

Date	Site
08/06/2018	Kastoria (Fe-Ni-laterite open-pit mine)
02/07/2020	Stylida (Fe-Ni-laterite stock area)
31/08/2020	Itea (bauxite stockpiles)
	Mt. Pateras (bauxite outcrop)
	Gorgopotamos, Dyo-Vouna (bauxite open-pit mines)
27/07/2021	Tsouka, Nisi, Kopaida (Fe-Ni-laterite open-pit mines)
	Triveio (Fe-Ni-laterite stockpiles),
	Patitira (bauxite open-pit mine)
27/12/2022	Cuba Fe-Ni-laterite outcrop
01/04/2021	Cuba Fe-Ni-laterite open-pit mine
26/09/2021	Jamaica-1, Jamaica-2, Jamaica-3 (bauxite stockpiles)



(**a**)



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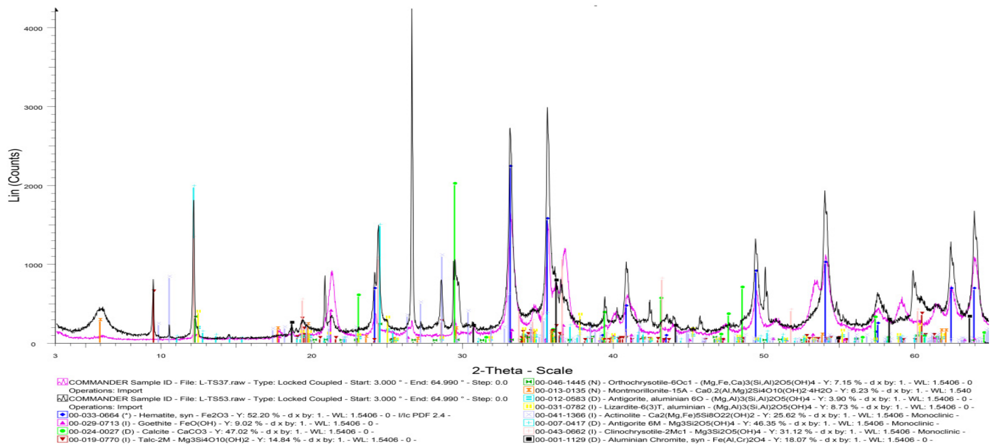


(**c**)

Figure S3. X-ray powder diffraction (XRD) pattern of Fe-Ni-laterite ore samples in Kopaida, Patitira and Tsouka open-pit mines. (**a**) Kopaida open pit mine. The minerals that are present are: goethite, quartz, calcite, montmorillonite, antigorite or lizardite; (**b**) a Ni-rich bauxite ore sample from the contact between the lowermost part of the bauxite laterite ore and the carbonate basement from Patitira open pit mine. The minerals identified are boehmite, diaspore, hematite, anatase, kaolinite, goethite, quartz, allophane, calcite; (**c**) Tsouka open pit excavation. samples are mostly composed of quartz, hematite, antigorite, calcite, clinochrysotile, actinolite, talc, goethite, montmorillonite, lizardite, orthochrysotile..

Table S2. Chemical analyses results (Energy Dispersive XRF) of the samples from the open-pit mines (wt%). Samples from Tsouka mine site (L-TS), samples from Kopaida mine site (L-Kop) and samples from Patitira mine site (L-Pat).

	Ni	**Fe**	**As**	**Mn**	**Cr**	**Bal**	**Co**	**Zn**	**Ti**	**Nb**	**Pb**	**V**	**Bi**
L-TS37	1.16	47.20		0.51	2.61	50.56	0.24	0.03	0.06				
L-TS32	0.33	49.70	0.00	0.41	2.79	49.11	0.14	0.01	0.13				
L-TS53	0.76	28.50	0.00	0.37	1.90	70.26	0.15	0.00					
L-KOP1	0.80	31.70	0.00	0.35	2.30	66.61	0.13	0.02	0.07				
L-KOP2	0.78	33.68	0.00	0.23	1.93	65.03	0.19	0.02	0.19				
L-KOP3	0.51	24.65	0.01	0.26	1.58	71.69	0.08	0.01	0.07				
L-PAT1	0.85	23.50	0.02	0.16	0.79	75.15	0.10	0.01	1.01	0.01	0.00	0.11	0.01
L-PAT2	0.28	29.86	0.03	0.13	0.97	69.36	0.10	0.01	1.18	0.00	0.00	0.14	0.00

Table S3. Chemical analyses results (Energy Dispersive XRF) for Al_2O_3 and $Fe_2O_{3\ (total)}$ content (wt%) of six samples from Mt Pateras bauxite outcrop.

SAMPLE	**Al2O3**	**Fe2O3total**	**Ore**
1	45.70	24.43	
2	40.49	17.93	
3	35.20	24.66	Bauxite at Mt Pateras
4	43.36	22.96	
5	42.73	22.85	
6	44.74	25.05	

Table S4. Al_2O_3 and Fe_2O_{3total} contents (wt%) of bauxite ores, retrieved from literature.

SAMPLE	Al_2O_3	Fe_2O_{3total}	Ore	Reference
Nb	28.46	21.35	Ni-rich Bauxite Laterite (Nisi)	Samples of bauxite laterite (nd, nc & p1.2) refer to rich Ni-rich bauxite, nh, refer to bauxite laterite, p2.1,p2.2, p3.1, p3.2 p1.1 and p1.2 refer to [41]
Nc	19.13	35.62		
Nd	20.30	35.60		
p1.1	32.80	38.74	Ni-rich Bauxite Laterite (Patitira)	
p1.2	20.61	44.61		
Nz	31.40	48.20	Bauxitic Laterite (Nisi)	
Nh	44	41.60		
p2.1	29.80	46.90	Bauxitic Laterite (Patitira)	
p2.2	20.58	54.33		
p3.1	29.82	36.90		
p3.2	22.67	49.62		
PSI1	53.54	23	Bauxite from Parnassos mine site Agia Anna	[58]
PSI2	53.42	25.57		
PSI3	52.69	29.04		
PSI4	54.47	25.94		
PSI5	48.84	53.16		
PSI6	57.25	22.79		
hem bauxites	49.30	19.10	Bauxite (Jamaica)	[68]
goeth bauxites	48.20	17		
36	52.90	10.60	Bauxite (Jamaica)	[62]
60	44.30	9.40		
96	49.90	19.10		
122	47.90	17.10		
162	46.40	19.50		
St. Ann	47.52	20.33	Jamaican bauxite (according to Hill, 1972)	[70]
Manchester	46.04	20.51		
St. Elizabeth	42.08	26.66		

Table S5. Al_2O_3 and Fe_2O_{3total} contents (wt%) of Fe-Ni-laterite ores, retrieved from literature.

SAMPLE	Al_2O_3	Fe_2O_{3total}	Ore	Reference
N11	8.60	42.50	Fe-Ni-laterite in Nisi	[43]
N14	6.85	54.45		
N18	10.80	42.18		
G739	4.70	42.18	Fe-Ni-laterite from drillholes in Kopaida	[50,71]
G742	2.98	52.50		
G743	3.20	47.00		
G747	5.93	43.54		
G748	4.02	43.66		
G749	5.24	44.83		
G756	6.57	49.09		
G760	4.01	41.45		
G761	3.52	44.90		
G765	8.31	26.70		
G773	5.05	47.75		
G774	3.29	42.51		
G785	4.10	48.51		
G788	6.65	31.80		
G791	4.42	44.33		
G937	4.41	45.88		
G941	2.90	45.75		
G942	6.42	49.14		
G944	5.98	51.24		
TS1	5.15	69.80	saprolite	[43]
I1	4.79	49.25	limonitic laterites	[69]
I2	4.94	51.75		
I3	4.75	51.40		
I4	5.01	49.44		
3106	2.70	76.10	Fe-Ni-laterites	[54]
3107	1.90	77.20		
3108	1.70	76.90		
3110	2.00	76.90		
3112	2.30	76.30		
3114	2.30	72.10		
9603	12.20	42.60		
9605	6.50	54.50		
9607	8.20	62.60		
9609	10.80	51.10		

DC-+UL 92401 (Moa Bay)	14.52	68.03	Fe-Ni-laterites from the Punta Gorda ore deposit (Moa Bay) and from the Loma Caribe ore deposit (Falcondo). DC (duricrust); UL (upper limonite); LL (lower limonite)	[51]
MN17 DC-UL (Moa Bay)	15.00	65.81		
LL 92402 (Moa Bay)	9.59	66.75		
LL92405 (Moa Bay)	9.16	71.83		
MN3 LL (Moa Bay)	8.26	69.13		
MN3 LL (Moa Bay)	7.98	68.66		
LC -11 -001 DC+UL (Loma Caribe)	31.82	40.10		
LC-1 UL (Loma Caribe)	14.16	55.97		
UL (Loma Caribe)	9.72	65.55		

Table S6. Bauxite and Fe-Ni-laterite mineralogy as detected by the XRD analyses of exploitation samples.

	Bauxite minerals	(common)	Fe-Ni-laterite minerals
1		Goethite	
2		Hematite	
3		Quartz	
4		Calcite	
5	Diaspore		Chromite
6	Kaolinite		Montmorillonite
7	Anatase		Talc
8	Allophane		Antigorite
9	Gibbsite		Chrysotile
10			Lizardite
11			Chlorite

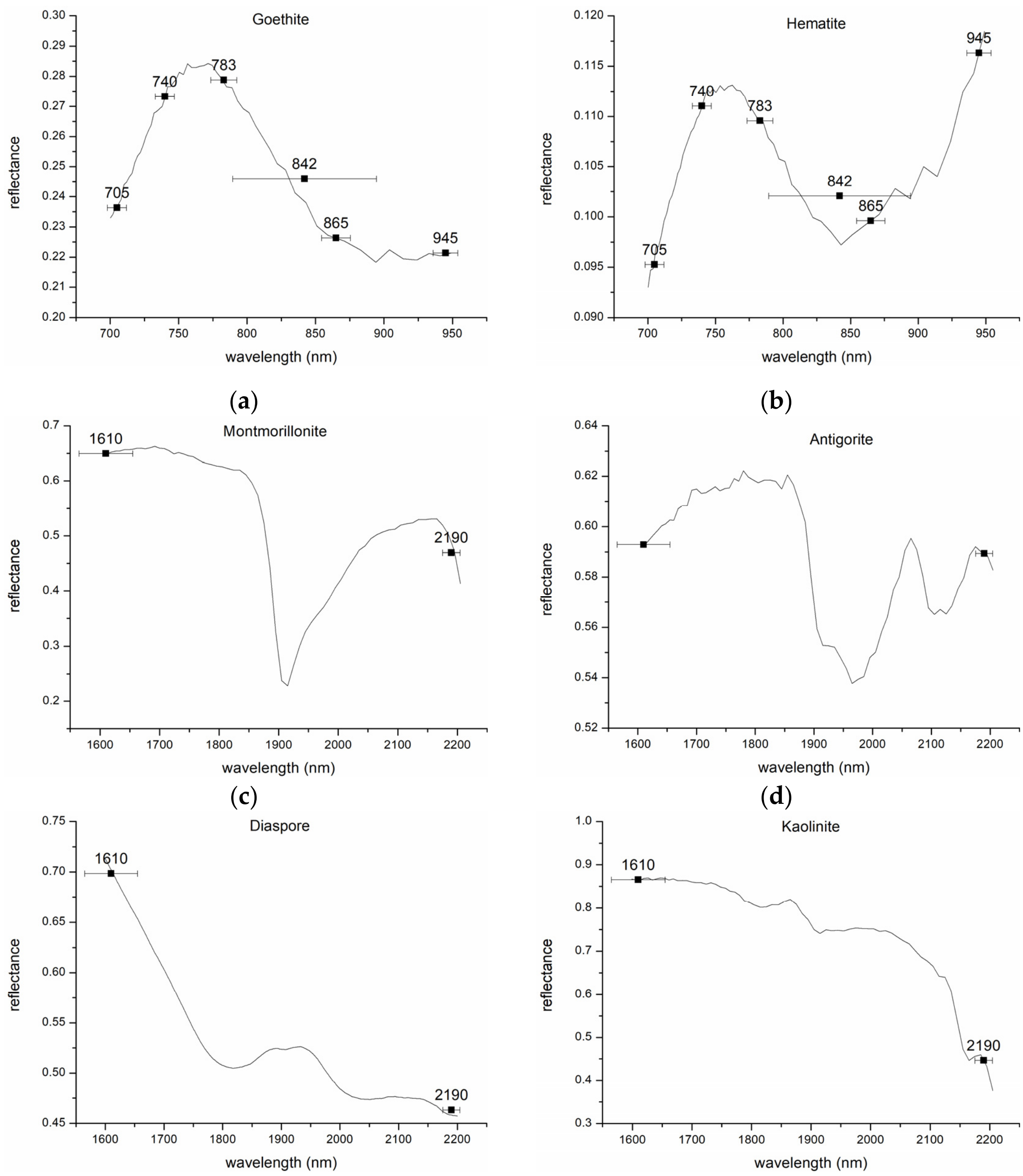
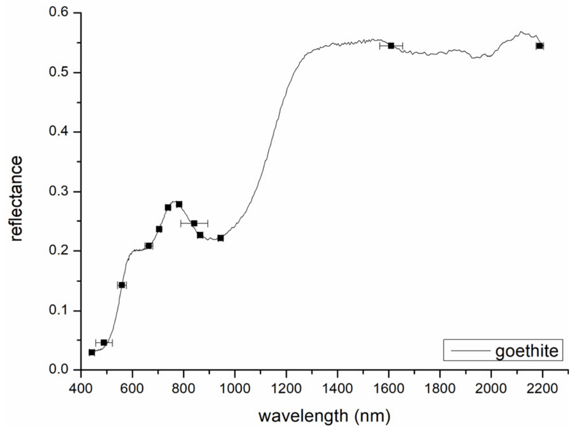


Figure S4. Examples of spectral features of characteristic Fe-Ni-laterite/bauxite minerals, namely (**a**) goethite and (**b**) hematite (common to both lithologies); (**c**) montmorillonite and (**d**) antigorite (in Fe-Ni-laterites); (**e**) diapore and (**f**) kaolinite (in bauxites) retrieved from the United States Geological Survey Spectral Library version 7 [77]; (**a**) and (**b**) show the reflectance feature observed within 700-900nm, which is typical of ferric iron minerals, such as goethite and hematite, and corresponds to the spectral bands from $b5$ to $b8A$; (**c**) and (**f**) show the slope drop between 1600 and 2200 nm in non-ferric mineral spectral signatures, mainly Al-OH bearing minerals, such as diaspore, kaolinite and montmorillonite. In each plot, the continuous line is part of each mineral's original spectral signature, the square black points correspond to the wavelength center of each Sentinel-2 spectral band and the horizontal margins correspond to each band's spectral bandwidth. The y-axis scale was chosen not to be uniform for the four plots in order to enhance the specific spectral features.

Minerals common to both ores



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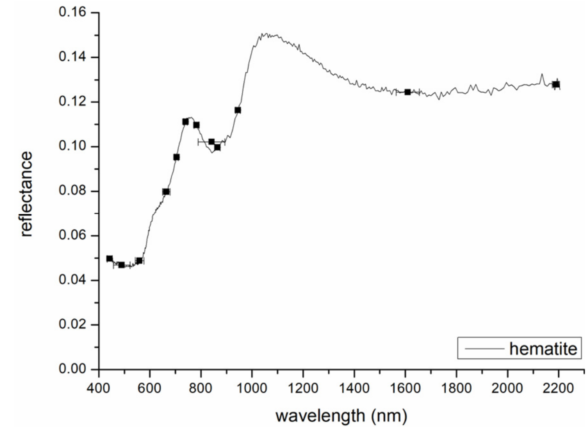

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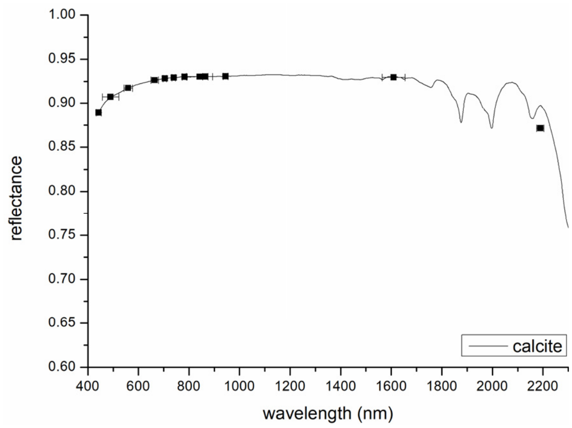
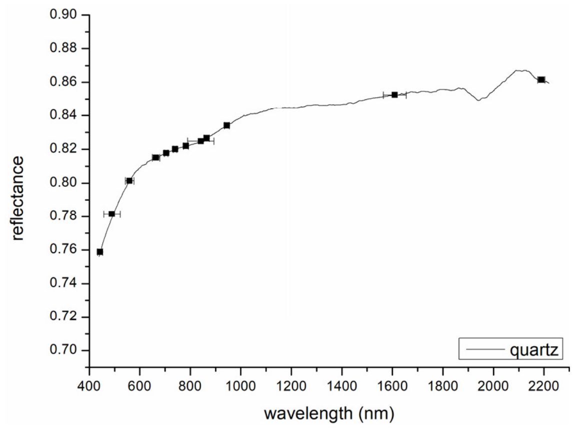
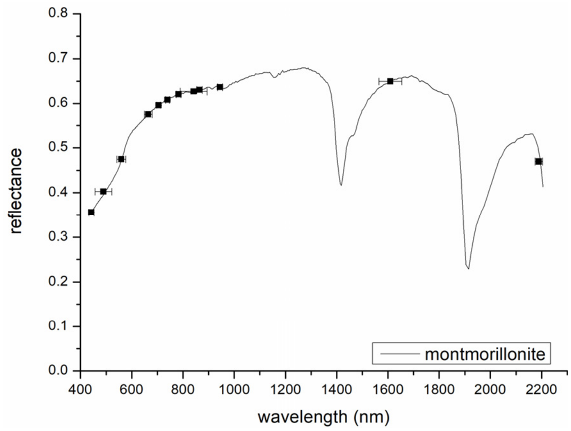


(**c**)

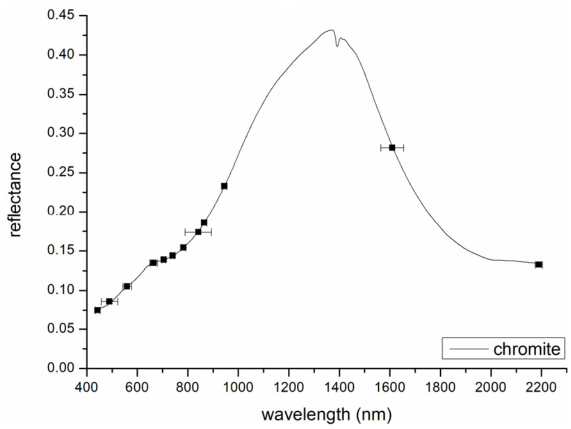


(**d**)

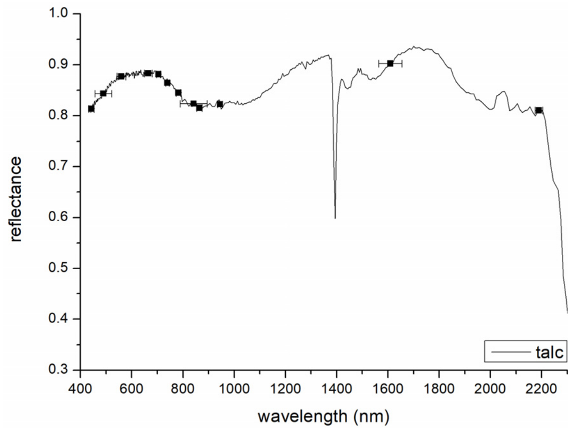
Minerals only within Fe-Ni-laterites



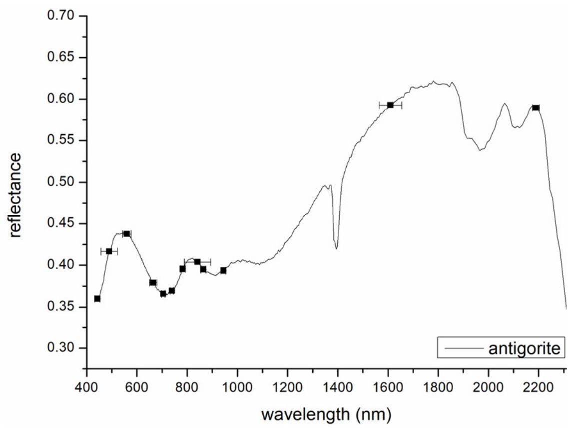
(**e**)



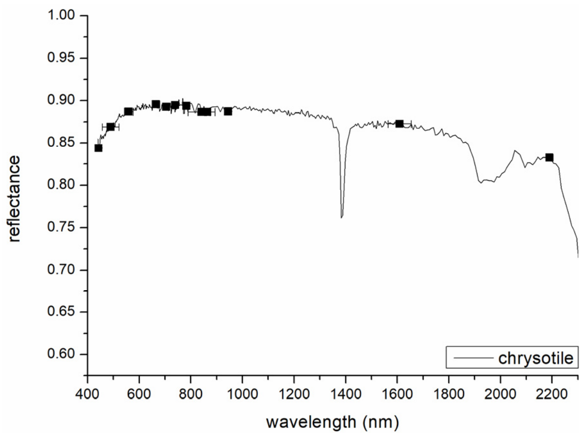
(**f**)



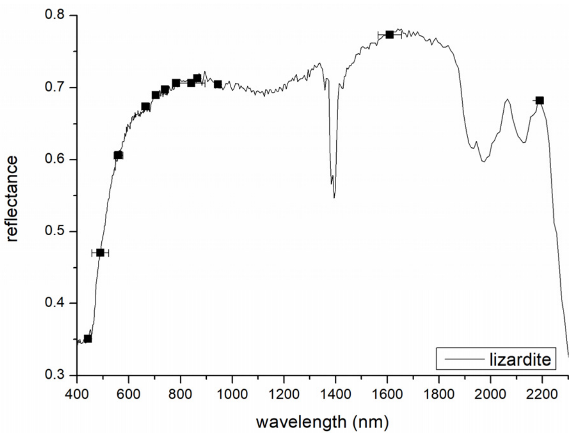
(**g**)



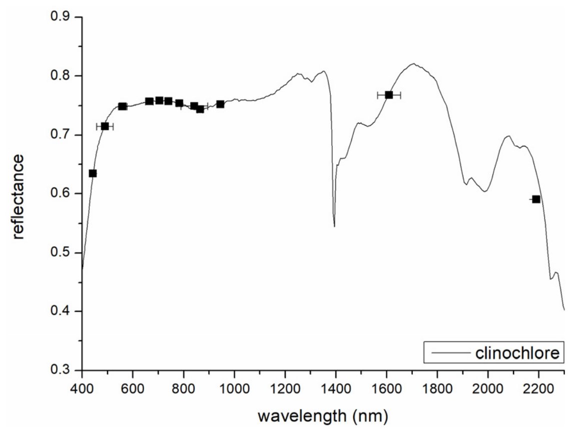
(**h**)



(**i**)

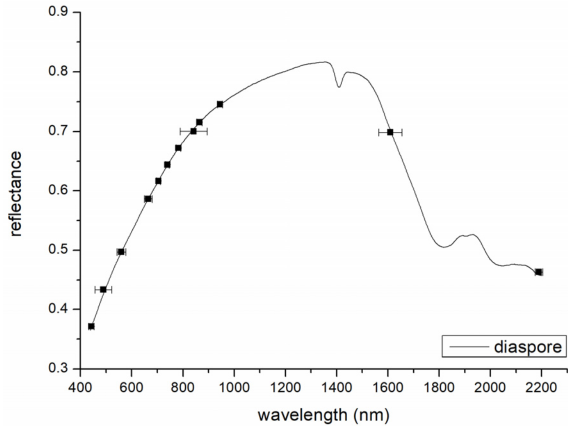


(**j**)

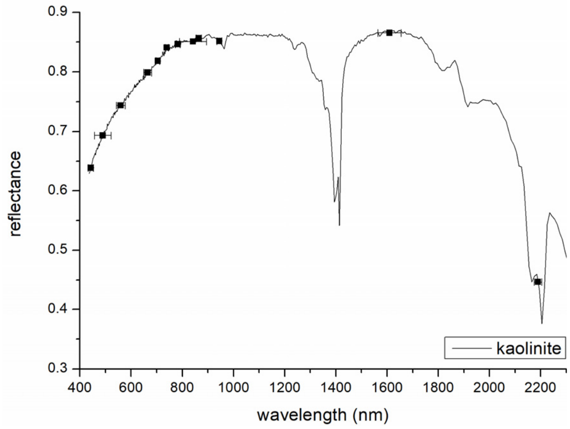


(**k**)

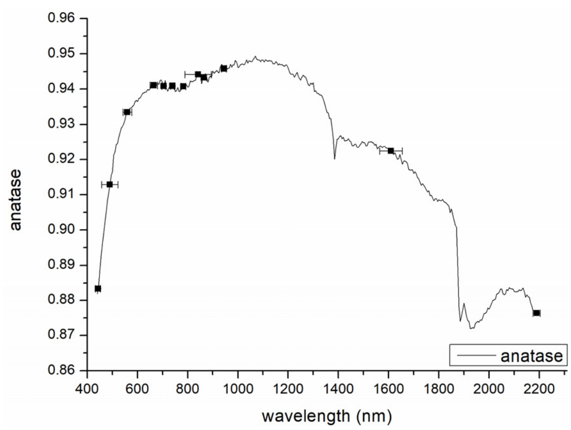
Minerals only within bauxites



(l)



(m)



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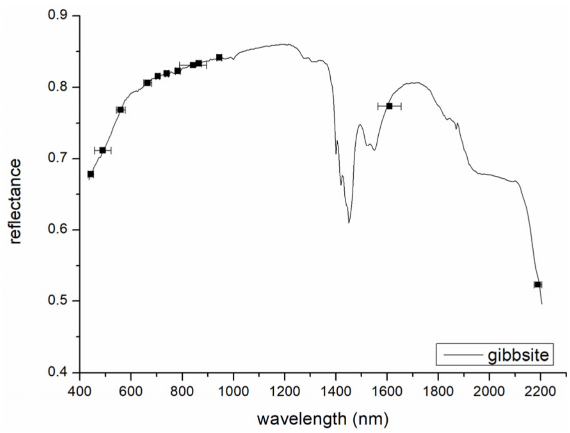
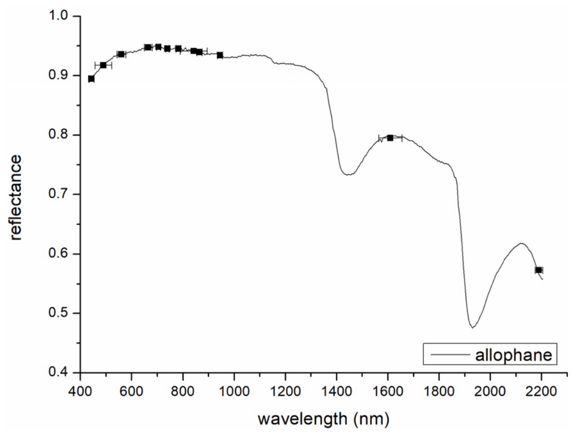


(o)



(p)

Figure S5. Original spectral signatures of bauxite/Fe-Ni-laterite minerals, as retrieved from the USGS Spectral Library Version 7 [77]. The spectra were resampled to the Sentinel-2 spectral bands using ENVI 5.5 software. In each plot, the continuous line corresponds to each mineral's original spectrum, the square black points correspond to the wavelength center of each Sentinel-2 spectral band and the horizontal margins correspond to each band's spectral bandwidth. The x-axis corresponds to wavelength (in nm) and y-axis to the corresponding reflectance values. The y-axis scale is not uniform to all plots for clarity purposes..