

834 Additional Files

Figure S1 The four paintings from the *Laudario* used to create the training dataset for the 1D-CNN model. (a) *The Nativity with the Annunciation to the Shepherds*, Master of the Dominican Effigies, c. 1340, miniature on vellum, National Gallery of Art, Washington, D.C., Rosenwald Collection, 1949.5.87, (b) *The Ascension of Christ*, Pacino di Bonaguida, about 1340, Tempera and gold leaf on parchment. The J. Paul Getty Museum, Los Angeles, Ms. 80a (2005.26), verso, (c) *The Martyrdom of Saint Lawrence*, Pacino di Bonaguida, about 1340, Tempera and gold leaf on parchment. The J. Paul Getty Museum, Los Angeles, Ms. 80b (2006.13), verso (d) *Christ and the Virgin Enthroned with Forty Saints*, Master of the Dominican Effigies, c.1340, miniature on vellum, National Gallery of Art, Washington, D.C., Rosenwald Collection, 1959.16.2. Digital images of (b) and (c) courtesy of the Getty's Open Content Program.

Table S1 Summary of per class accuracy for the 1D-CNN model. The 25 pigment/mixture classes and their total class size is given along with the per class accuracy using 10-fold cross validation.

Figure S2 The average reflectance spectra for each of the pigment labeled classes in the training dataset used for the 1D-CNN model.

Figure S3 The pigment labeled map created by using a lower threshold (0.85) in the 1D-CNN model.

Table S2 Summary of analyses, the *Pentecost*. Note that the RIS features listed are those identified by an expert user following manual data exploration. When available, fiber optic reflectance spectroscopy (FORS) and Raman analysis may provide additional information about the total chemical composition of each area. However, not all pigments identified are discernible in the RIS data cube on which the 1D-CNN is applied. Therefore, a simplified "pigment class" column notes the materials that should be identified in the paint by this technique.

Table S3 Summary of analyses, *Saint Peter Enthroned*. Note that the RIS features listed are those identified by an expert user following manual data exploration. When available, fiber optic reflectance spectroscopy (FORS) analysis may provide additional information about the total chemical composition of each area. However, not all pigments identified are discernible in the RIS data cube on which the 1D-CNN is applied. Therefore, a simplified "pigment class" column notes the materials that should be identified in the paint by this technique.



(a)



(b)

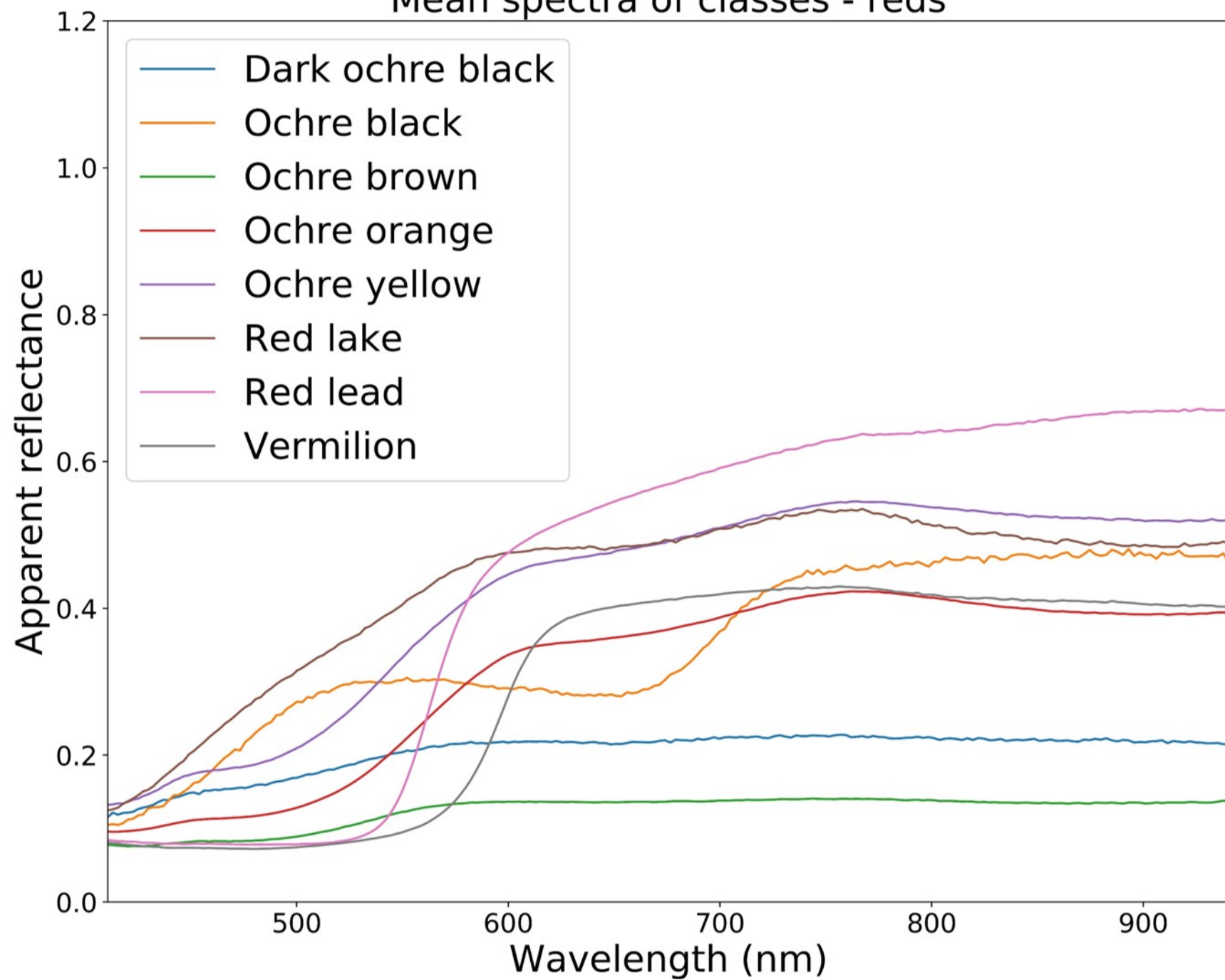


(c)

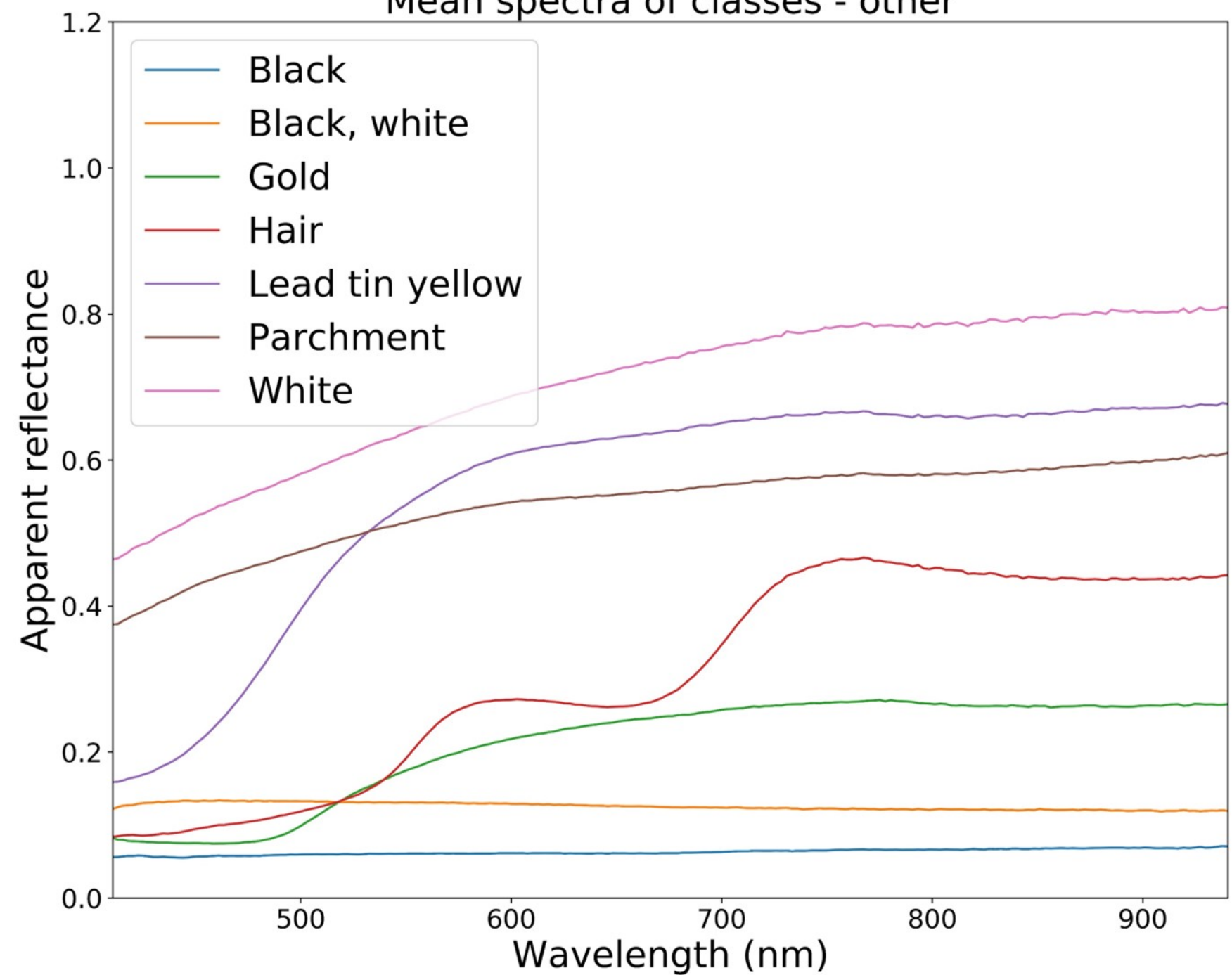


(d)

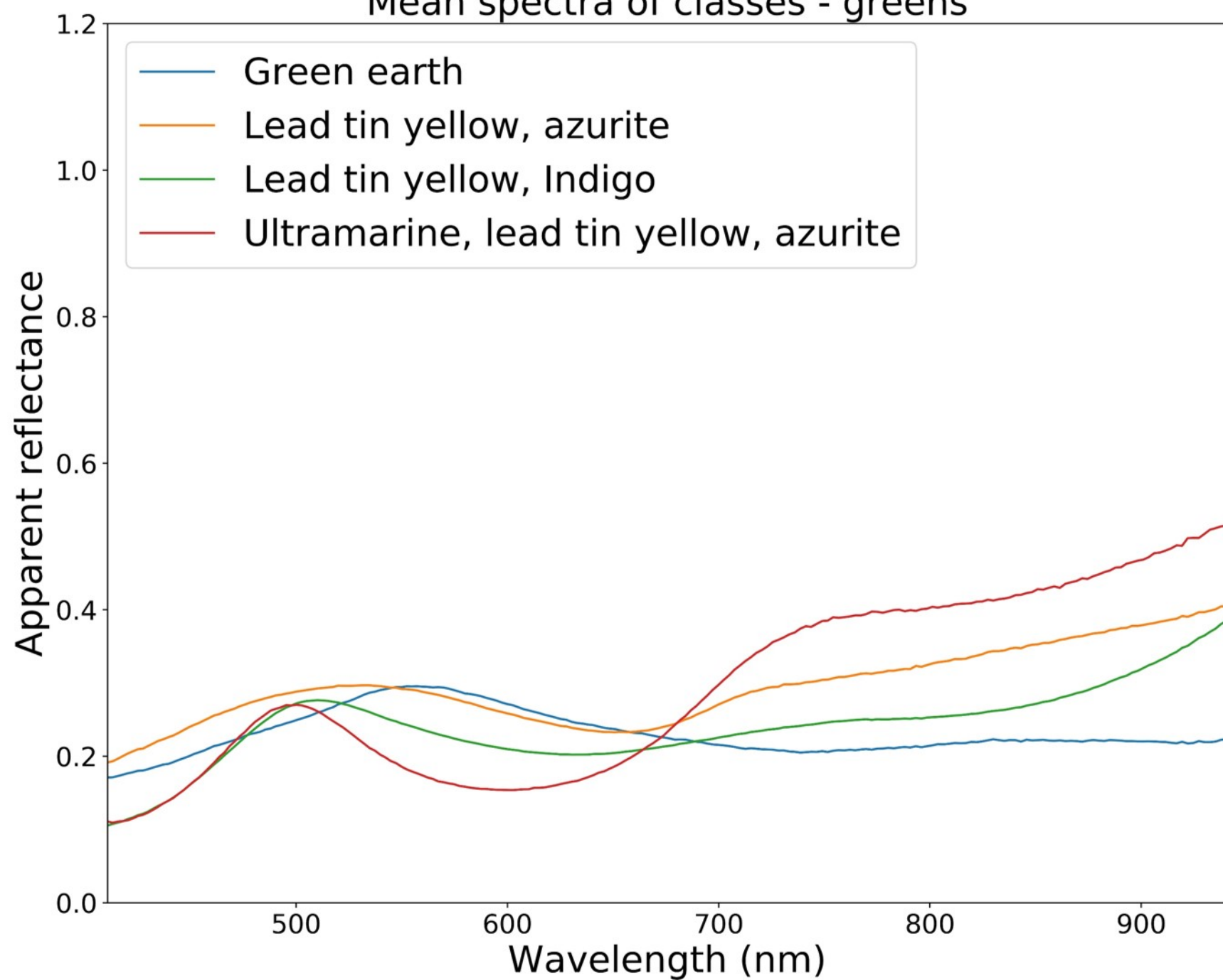
Mean spectra of classes - reds



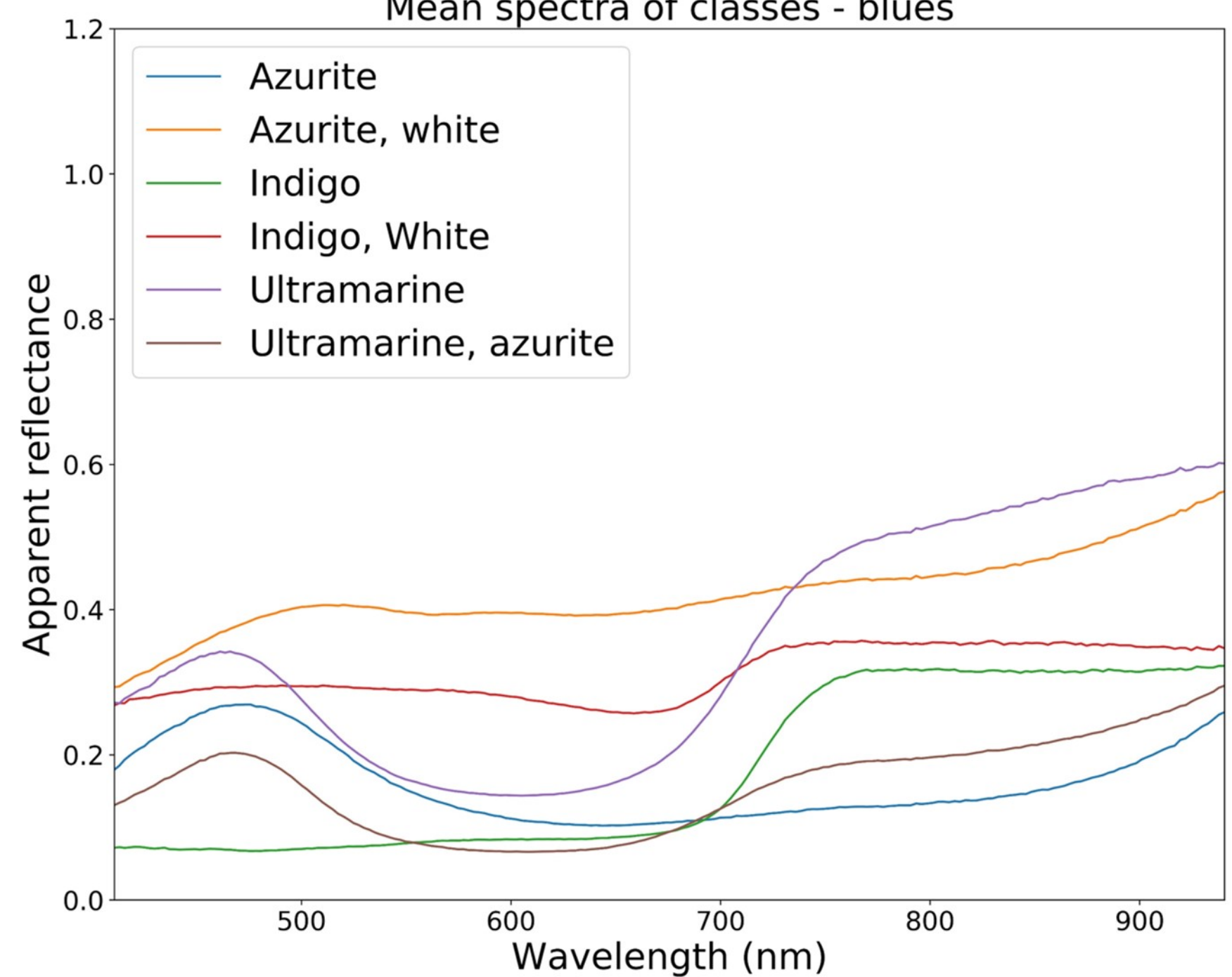
Mean spectra of classes - other

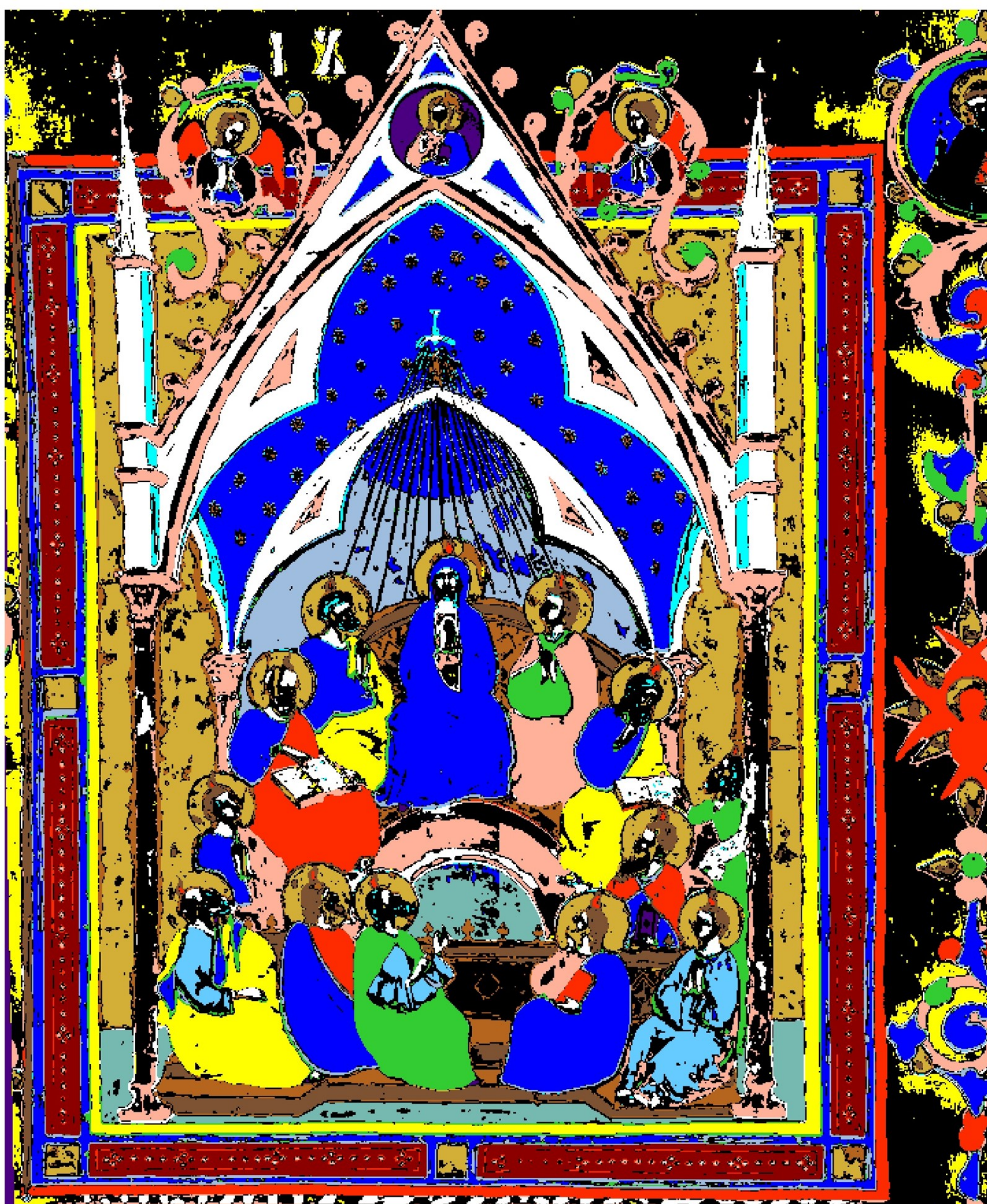


Mean spectra of classes - greens



Mean spectra of classes - blues





Class	1D-CNN pigment map
	Lead tin yellow (LTY)
	Red lead
	Vermilion
	Ochre brown
	Ochre orange
	Gold
	Green earth
	LTY, azurite
	Black
	Azurite
	Azurite, white
	Red lake
	Ultramarine, azurite
	White
	Indigo
	Unclassified

Pigment Labels	Accuracy (%)	Total class size
Azurite	100	2047
Azurite, white	100	260
Black	95	94
Black, white	94	130
Dark Ochre Black	100	343
Gold	100	37
Green earth	100	40
Hair	99	166
Indigo	96	55
Indigo, white	100	66
Lead tin yellow, indigo	100	1208
Lead tin yellow	100	978
Lead tin yellow, azurite	100	3495
Ochre black	100	234
Ochre brown	98	801
Ochre orange	98	731
Ochre yellow	89	43
Red lead	100	1030
Ultramarine	100	1324
Ultramarine, Azurite	100	982
Ultramarine, lead tin yellow, azurite	100	48
Vermilion	98	152
White	100	769
Parchment	100	1054
Red lake	100	596
Average accuracy	98.7	16683

visible paint color	RIS endmember color	RIS endmember features (manual work-up)†	FORS features	XRF (point and/or scanning modalities)§	Raman	Overall paint composition	Pigment class (likely to be observable in RIS datacube)
yellow		R _{inf} 488 nm, R _{inf} 689 nm, refl hump 738 nm, abs weak 806 nm;		Pb, Sn, Sr, K		lead tin yellow type II	lead tin yellow II +?
yellow		R _{inf} 488 nm, R _{inf} 689 nm,	R _{inf} 490 nm, R _{inf} 689 nm, hump ~725 nm; 1944 nm abs, 2044 , 2181 nm	Pb, Sn, Fe, K, Ca/Sr	lead tin yellow type II, vermilion	lead tin yellow type II with trace vermilion	lead tin yellow II
orange-red		R _{inf} 564 nm	--	Pb, C, Cu, Fe	red lead	red lead	red lead
orange-red		R _{inf} 558 nm, turns up at ~850 nm	--	Pb, Cu, Ca	--	--	red lead, azurite
bright red		R _{inf} 602 nm, weak abs 806 nm	--	Hg, S; Pb in the white dots, Fe, (Cu)	vermilion, lead white	vermilion with lead white accents	vermilion
dark brown		abs 485 nm, R _{inf} 457 nm, refl max 757 nm, abs 916 nm	abs ~478 nm, R _{inf} 556 nm, R _{max} 775 nm, abs 905 nm	Fe, Pb , Zn, Cu, S	goethite, lead white	iron earth pigment(s), lead white	ochre (goethite)
light brown		similar to above but offset	--	Pb, Fe, Mn, Zn, Sr	--	iron earth, lead white	ochre (goethite), white
gold		refl ramps 400-478 nm and rounds up (convex (0.3-0.85 %)) broad abs 820 nm	--	Au, Pb (Ca/Sr, Fe, S)	--	gold leaf, iron earth bole, calcium gesso	gold leaf
mint green		R _{max} 542 nm, sh 487 nm, abs 743 nm, w refl at 850 nm, weak abs 919 nm	R _{max} 539 nm, sh 485 nm, abs 750nm, R _{max} 846-855 nm, slow rise at 1100 nm, broad abs at 1443 nm, 1942 nm, 2042 , 2182 nm, weak abs 2352, ~2300, and ~1500 nm	Fe, Pb, K, Cu, Ca/Sr, Mn	--	lead white, iron earth pigment(s), trace azurite	green earth, white
dark green		R _{max} 525 nm, broad abs 702 nm	R _{inf} 472-480 nm, R _{max} 525-539 nm, broad abs 680-800 nm with rise to 1329 nm, 1939 nm, 2043, 2181 nm	Pb, Cu, Sn, Fe, Ca/Sr	calcite, lead tin type yellow II, ultramarine	copper green, lead tin yellow type II, ultramarine, calcite	copper green, lead tin yellow
khaki green		R _{inf} 471 nm, R _{max} 524 nm, abs 638 nm, rise, weak abs 803 nm	R _{inf} 476, R _{max} 536-548 nm, abs 642-667 with R _{inf} 695-704, broad abs ~750 nm with rise to 1300 nm, 1939 nm, 2043, 2181 nm	Pb, K, Sn, Cu, Fe, Ca/Sr	calcite, lead tin type yellow II, ultramarine	calcite, lead tin type yellow II, ultramarine, some azurite /copper green and indigo also possible	lead tin yellow, ultramarine/indigo, copper green
black		Refl < 5.2 % +/- 0.4%	--	Ca, K, Sr	carbon black	carbon or bone black	black
dark blue		R _{max} 460 nm, broad abs 638 nm, rapid rise begins at ~860 nm	R _{max} 459 nm, abs 1499, 2287, 2356, 2045 nm; abs 2180 nm, abs 2212	Cu, Pb, Zn, Mn, K, Fe, Ca/Sr (Au)	azurite, lead white, calcite	azurite, with some lead white; gold accents in area behind Virgin	azurite
blue		R _{inf} 444 nm, R _{max} 507 nm, narrow abs 567 nm, broad abs ~600 nm , small peak at 748 nm	R _{max} 491 nm, broad abs 600 nm, broad sh. 731 nm, abs 2286, 2354 nm. Abs 2044, 2181 nm	Pb, Cu, Ca/Sr, Fe, Zn	azurite, ultramarine, lead white, calcite	azurite, ultramarine, lead white, calcite	azurite, ultramarine, white
pink		abs 560 nm (stronger in some areas), vw abs 802 nm	--	(Cu), Pb, Ca/Sr, Fe, Zn	lead white, calcite, gypsum, vermilion	organic red colorant, lead white, calcite, gypsum, trace vermilion	unknown red lake, white
pale blue		R _{max} 483 nm, strong abs 633 nm, shoulder 748 nm, rapid rise after 811 nm	R _{max} 485nm sh. 736 nm; abs 1499, 2287, 2356, 2045 nm; abs 2180 nm, weak abs 2212	Pb, Cu, Ca/Sr, Mn, Zn, Fe	azurite, ultramarine, calcite, lead white	azurite, ultramarine, calcite, lead white	azurite, ultramarine, white
white		convex rise with vw abs at ~485 nm, 800 nm	abs ~478 nm, R _{inf} 556 nm, R _{max} 775 nm, abs 905 nm	Pb, Zn, Mn, Cu, Fe, Ca/Sr, (Au)	lead white, carbon vermilion	lead white, sometimes with small amounts of carbon or vermilion	white, weak ochre (goethite)

† R_{inf} = inflection point, reflection spectrum; R_{max} = local reflection maximum ; refl = reflection; abs = absorption

§ **Bold** indicates major species, normal text indicates minor species; *italics* indicate trace amounts; (parenthesis) indicates likely from nearby or reverse rather than primary paint color; Relative amounts are estimated as a guide based on peak intensity only.

visible paint color	RIS endmember color	RIS endmember features (manual work-up)†	FORS features	XRF (point and/or scanning modalities)§	Overall paint composition	Pigment class (likely to be observable in RIS datacube)
blue		R _{max} 467-476 nm (light 497 nm) abs 640 nm, Rincreases at 840 nm	R _{inf} 467 nm, abs 1497, 2289, 2352 nm	Cu, Pb (Hg, Fe, As)	Azurite, lead white, (from nearby: vermilion) iron earth	Azurite
white		broad increasing reflectance 400 to 950 nm	broad increasing reflectance 350 to ~1000 nm; weak abs at 1445 nm compared to vellum site	Pb	Lead white	white
yellow		1st dervative: R _{max} 488 nm, FWHM ~120 nm	R _{inf} 486 with sh. 558 (FWHM 160 asym.) (yellow), abs. 2310 (lipid?)	Pb, Hg (Fe, Cu)	Lead white, yellow lake (vermilion from music line reverse side)	yellow lake, white
red/orange		1st dervative: R _{max} 574-580, FWHM ~60 nm	<i>1st derivative, broad with peaks at ~564 and 589 nm, FWHM 66 nm</i>	Hg, Pb	Vermilion, red lead	Vermilion, red lead
green		R _{max} ~517-527nm, abs broad 640 nm, shallow abs 740 nm	R _{max} 520 (green color), R _{inf} 478 (yellow), abs. 647 with R _{inf} 703 (indigo?), broad abs. 600-900 with R _{inf} 959 & abs. 1497, 2284, 2352 (azurite)	Cu, Pb	azurite, organic yellow pigment	azurite, yellow lake
dark green		R _{max} ~510 to 518 abs broad 660 nm, R _{inf} 705 nm	R _{max} 513 (green color), R _{inf} 480 (yellow), abs. 657 with R _{inf} 710 (indigo?), broad abs. 600-900 with R _{inf} 956 & abs. 1496, 2285, 2352 (azurite)	Cu, Pb	indigo/ultramarine (I lean toward indigo), azurite, organic yellow pigment	indigo, yellow lake, azurite
red		1st dervative, R _{max} 602 nm, FWHM 45 nm	R _{inf} 600 nm, FWHM 42 nm	--	vermilion	vermilion
purple		1st dervative 598 nm, FWHM 82 nm, asym	abs. 555 with R _{inf} 597 (FWHM 82 asym.) (red lake), abs. 1450 (lead white)	Ca, S (Si, K, Fe, Cu, Pb)	Red lake, purple lake, azurite, iron earth, lead white	red lake, white
dark green		1st dervative R _{max} 723 or 707 nm FWHM 46 or 56 nm		--		indigo
light pink		1st dervative 590-592.5 nm, FWHM 53 nm, asym	abs. 555 with R _{inf} 590 (FWHM 58 asym.) (red lake), abs. 1449 (lead white)			red lake, white
			abs. 555 with R _{inf} 590 (FWHM 58 asym.) (red lake), abs. 1449 (lead white)	Pb, (Hg, Cu, Ca, Fe)		red lake, white
gold		1st dervative R _{max} 514 nm, FWHM ~70 nm		Au, Ca, Fe, Hg (Cu)	Gold, bole, vermilion	gold leaf
		1st dervative R _{max} 530 nm, FWHM ~50 nm	R _{inf} 533 (FWHM 105 asym.)	S, Sn, Fe, Cu, Zn, Pb (Si), Ca	Mosaic Gold with lead white decorations	mosaic gold

† R_{inf} = inflection point, reflection spectrum; R_{max} = local reflection maximum ; refl = reflection; abs = absorption

§ **Bold** indicates major species, normal text indicates minor species; *italics* indicate trace amounts; (parenthesis) indicates likely from nearby or reverse rather than primary paint color;

Relative amounts are estimated as a guide based on peak intensity only.