[redacted] Woomera and Land of Parrots Matégot tapestries, microfade testing and colour measurement.

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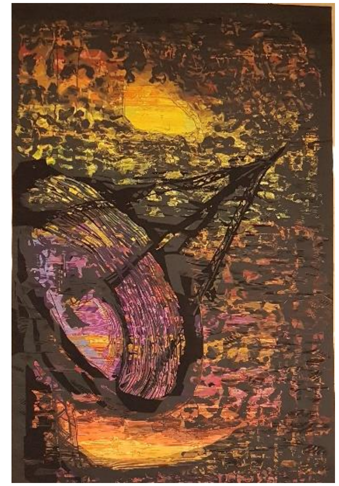
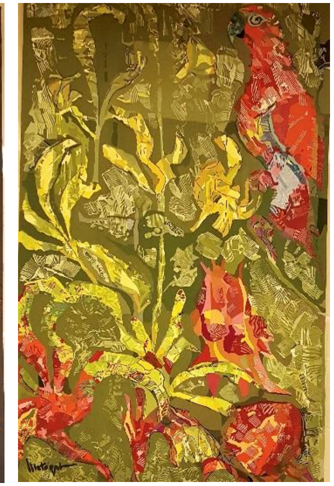
18/7/22





1 Results

1.1 Microfade Testing

Eleven areas of the Woomera tapestry (W) and five from Land of Parrots (P) whose locations are provided in Figures 1 & 4 were assessed as containing dyes of lightfastness equivalent to BW4 or worse (Tables 1 & 2, Figures 2 & 3 and 5 & 6). Some of these, particularly the pinks, were visibly faded (Figure 8). The rest were more lightfast than BW4. The least lightfast example was a pink dyed yarn (W17, pale pink) at BW1-BW2 which is well within the range of lightfastness (BW1 or worse to BW3) for colourants described in the CIE standard for museum lighting as having "high responsivity to light" for museum purposes (CIE 2004). The phrase "*for museum purposes*" applies to UV-free light levels in the 50-100 lux range. On the basis of a single daytime measurement, average light levels in the [redacted] foyer are likely to be in the 100-200 lux range and relatively UV-free. The [redacted] is undertaking systematic light logging to estimate annual cumulative exposures. Pink and pinkish-dyed yarns were generally, but not invariably (see W31a and P2), the least lightfast, followed by a bright yellow (W24 & P3) found in both tapestries.

According to their reflection spectra, it is very likely that several different pink dyes were used to create pink colours - including several likely rhodamine-based dyes or dye mixtures and a probable anthraquinone (a group that includes synthetic alizarin, madder and lac). See section 3. Pink Dyes (Figures 14-18). A portion of the MFT response will be a result of photochemical bleaching of thermally yellowed wool substrate (Endnote 3), however judging by the response of the pale-yellow dye P11 (Figure 7), wool bleaching probably only contributes about 0.15ΔE - all other things being equal.

1.2 Colour Measurement

The actual fading of the dyes over 50 years (Tables 3, 4 & 5) supports the MFT predictions (Tables 1 & 2) for the colours evaluated using both approaches (grey boxes in Table 1). The most obvious anomaly is that the order of lightfastness of the pinks W15 and W17 predicted by MFT are reversed between MFT and direct measurement.

This may be due to different reciprocity behaviour during accelerated testing (Endnote 1), or to direct measurement of the fading of pinks being complicated by the mixing of different pink dyed yarns with different lightfastness as observed in W15 and W31, Figure 12). Direct measurement averages the colour within the instrument's $6mm^2$ aperture, whereas MFT was carried out on single yarns.

Approximate blue wool equivalent lightfastness ratings (BWE) In Table 5 have been calculated from Michalski's data for the ISO BWs adopted by the CIE in *CIE157-2004*, *control of damage to museum objects by optical radiation* (CIE 2004) in which they are expressed as cumulative exposures in megalux hours (Mlux h) required to induce a just noticeable fade (JNF=1.6ΔE). See Figure a, Appendix. Lightfastness in Mlux h/JNF was calculated from the data in Table 4 under three different average light level scenarios (100, 150 & 200 lux averages, or 15, 20 and 30 Mlux h/year averages) based on a single daytime reading of 200 lux in the [redacted] lobby June 2022, which also showed relatively low UV. These ratings are compared to the MFT BWE ratings in the final column of Table 5. The best fit is for the 30 Mlux h/year assumption, however all three assumptions result in satisfactory risk predictions.

The stability of W14 (purple) and W27 (black/grey), both evaluated using MFT and direct measurement, indicate that it is likely most of the dyes with similarly low fading rates according to MFT in Figures 2 & 4 have lightfastnesses in the BW5 range (30 Mlux h/JNF), where 30 Mlux h represents an upper estimate for cumulative exposure during the past 50 years (Table 5).

2 Methods

2.1 Sampling for MFT

Approximately 10mm long samples were cut from loose threads where individual yarns were introduced or terminated on the rear of the Woomera and Land of Parrots tapestries. The locations, which are given in Figures 1 & 4, were chosen to include areas of colour which appeared faded to the eye, and also and also colours from which large or prominent areas of the tapestry were comprised. It was necessary to be selective because of the large number of potential tests involved in comprehensive testing. This selectivity means the results are biased towards those of low lightfastness. Three or four fibres were usually included with each sample.

2.2 MFT Testing

Microfade testing (MFT) was carried out on single yarns flattened between two glass microscope slides. ISO Blue Wool fading fabrics (BWs) used as internal fading standards were similarly prepared. MFT testing was carried out at about double the usual 5-6 Mlux intensity to extend the effective detection limit beyond BW4. This was because the tapestries are on permanent display at somewhat higher light levels than normal controlled museum gallery display conditions. Colour change was calculated from L*a*b* values according to the CIEDE2000 equation, although CIELab results are also provided in Tables 1 & 2 (Endnote 2). Thirty-one samples were tested from the Woomera tapestry and a further fifteen from the Land of Parrots. Replicates were carried out where dyes appeared to be less lightfast than BW4.

2.3 Colour Measurements

Colour measurements from 10 locations on the front (50 year exposed) and rear (unexposed) of the Woomera tapestry were carried out to assess the extent of light-fading over its 50-years on display (Table 3). The tapestry was suspended on a loom roller for access. The locations were chosen to include some of the least lightfast dyes as assessed by MFT, some of the most lightfast, and also colours from which large or prominent areas of the tapestry are comprised. The instrument used was an Xrite – eXact™ handheld spectrometer, illuminant D65, specular reflectance excluded, $6mm^2$ aperture. The colour measurements consisted of ten replicates, each independently positioned within the single-coloured area of interest. The statistical significances of the colour difference measurements were assessed using the "mean colour distance from the mean" (MCDM) method recommended by Billmeyer in which a difference is considered significant if MCDM/ΔE<0.5 (Berns 2000). All colour differences measured were statistically significant.

The front and rear colours were reconstructed in Photoshop from their rear L*a*b* values and ΔL*, Δa* Δb* (rear/front) values (Figure 8). The colours reconstructed from the rear L*a*b* values did not match the visual appearance of the sampled yarns particularly well, and in Figure 9 the starting colours were adjusted in Photoshop to match their appearance more closely and then "faded" using the same measured colour differences. This provides a somewhat better visual indication of the extent of current and projected future fading, assuming the tapestries are left in place for an additional 50 years.

3 Pink dyed yarns (Figures 10-19)

Six distinct spectra were found among the pink samples taken from the Woomera and Land of Parrots tapestries (Figures 10 – 13). In two cases a single area of pink (W15, W31) contained yarns dyed with two different dyes. The W15 dyes had similar fading rates according to MFT however 31a darker and 31b lighter had greatly different fading rates (Figures 12 & 13). It is possible to see the result of the differential fading on the exposed side.

Most of the dyes probably contain rhodamine (Figures 14-18), however the most lightfast (e.g. W16, Figure 19) share secondary spectral features with anthraquinones like alizarin or madder etc. which also have fading rates in the BW3-BW4 range. Any of the pink areas could contain yarns individually dyed with different dyes (e.g. W15, W31) and/or yarns dyed with mixtures of dyes. Differences in mordanting could also explain some of the fading-rate and possibly spectral differences. It should also be noted that different tint strengths result in different fading rates even for the same dye. This is partly because human colour and colour difference perception is optimised for mid-range lightness and chroma (Figure 14).

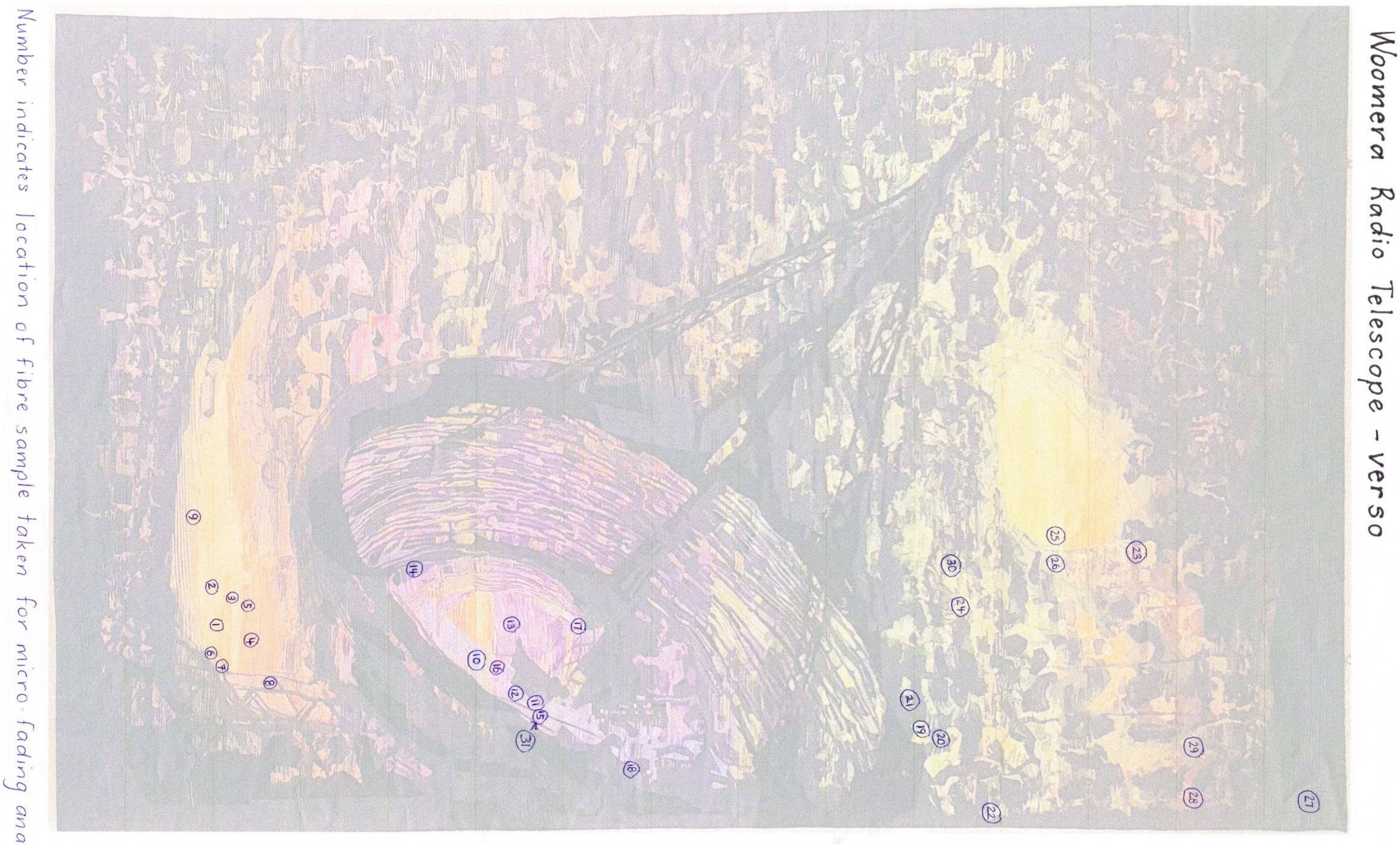


Figure 1. Woomera, microfade test sampling positions. Samples taken from rear (largely unexposed to light).

	CIE76			CIE2000							
Colour	BW Range	BW Equivalent	ΔE76	BW Range	BW Equivalent	ΔE2000	ΔL*	Δa*	Δb*	ΔC	Δh
BW1			11.30			4.15	3.66	-5.16	9.36	-10.06	5.72
BW2			6.70			1.66	1.32	-2.41	6.11	-6.32	2.26
BW3			1.81			0.84	0.85	-0.99	1.25	-1.55	0.42
BW4			0.86			0.32	0.00	0.72	-0.46	0.64	-0.67
W1 orange	>BW4	>BW4	0.48	>BW4	>BW4	0.19	-0.05	-0.02	-0.47	-0.46	-0.16W
W2 yellow	>BW4	>BW4	0.16	>BW4	>BW4	0.14	0.05	0.06	-0.14	-0.14	-0.37
W3 medium orange	>BW4	>BW4	0.44	>BW4	>BW4	0.24	-0.14	0.02	-0.41	-0.34	-0.29
W4 medium dark orange	>BW4	>BW4	0.36	>BW4	>BW4	0.20	-0.17	-0.06	-0.31	-0.30	-0.14
W5 dark orange	>BW4	>BW4	0.42	BW4	4.0	0.31	0.19	-0.27	0.26	-0.02	0.44
W6 brown	>BW4	>BW4	0.21	>BW4	>BW3	0.11	-0.04	-0.14	-0.15	-0.19	0.12
W7 dark brown	>BW4	>BW4	0.50	BW4	4.0	0.31	-0.14	-0.26	-0.41	-0.46	-0.42
W8 reddish brown	>BW4	>BW4	0.23	>BW4	>BW4	0.09	0.02	-0.13	-0.19	-0.22	-0.02
W9 green	>BW4	>BW4	0.06	>BW4	>BW4	0.04	0.01	0.05	-0.03	-0.03	-0.07
W10 blue	BW4-BW3	3.3	0.92	BW3-BW4	3.6	0.51	0.08	0.57	-0.71	0.70	-1.49
W11 purple	>BW4	>BW4	0.17	>BW4	>BW4	0.09	-0.01	0.05	-0.16	0.12	0.25
W12 light purple	>BW4	>BW4	0.32	>BW4	>BW4	0.21	0.05	0.11	-0.30	0.23	0.82
W13 medium purple	>BW4	>BW4	0.30	>BW4	>BW4	0.19	-0.17	-0.04	-0.24	0.08	0.38
W14 dark purple	>BW4	>BW4	0.16	>BW4	>BW4	0.10	-0.03	-0.13	0.08	-0.16	0.05
W15 bright pink	BW3-BW2	2.95	2.03	BW3	3.1	0.77	-0.23	-1.93	-0.61	-2.00	-0.47

Table 1. Woomera, colour change during microfade testing (MFT) summary. See last page for CIELAB diagram and Endnote 2 for a discussion of CIE76 vs CIE2000 results. Red results are as or less lightfast than BW4 (ctd. next page). Dyes in grey boxes are the colours measured back (unexposed) and front (exposed) using the X-rite spectrometer (Figure**).

	CIE76			CIE2000							
Colour	**BW Range**	**BW Equivalent**	**ΔE76**	**BW Range**	**BW Equivalent**	**ΔE2000**	**ΔL***	**Δa***	**Δb***	**ΔC**	**Δh**
BW1			11.30			4.15	3.66	-5.16	9.36	-10.06	5.72
BW2			6.70			1.66	1.32	-2.41	6.11	-6.32	2.26
BW3			1.81			0.84	0.85	-0.99	1.25	-1.55	0.42
BW4			0.86			0.32	0.00	0.72	-0.46	0.64	-0.67
W16 dark pink	>BW4	>BW4	0.48	BW4	4.0	0.29	-0.20	-0.25	-0.36	-0.31	-0.47
W17 pale pink	BW3-BW2	2.2	5.57	BW2-BW1	1.7	2.45	-1.03	-5.32	-1.29	-5.47	0.34
W18 dark blue	>BW4	>BW4	0.35	>BW4	>BW4	0.19	-0.10	0.29	-0.16	0.25	-0.45
W19 green	>BW4	>BW4	0.37	>BW4	>BW4	0.19	-0.08	0.16	-0.33	-0.35	0.25
W20 blue green	>BW4	>BW4	0.33	BW4	4.0	0.34	-0.05	0.24	-0.22	-0.03	-2.33
W21 medium green	>BW4	>BW4	0.54	BW4	4.0	0.31	-0.03	0.26	-0.47	-0.53	0.10
W22 pale green	>BW4	>BW4	0.38	BW4	4.0	0.30	-0.29	0.12	-0.20	-0.21	-0.24
W23 red	>BW4	>BW4	0.35	>BW4	>BW4	0.23	-0.22	-0.09	-0.25	-0.21	-0.18
W24 bright yellow	BW4-BW3	3.5	1.16	BW3-BW4	3.5	0.58	-0.24	0.71	-0.89	-1.03	-0.83
W25 yellow-green	>BW4	>BW4	0.24	>BW4	>BW4	0.15	0.17	0.05	-0.16	-0.17	-0.04
W26 mustard brown	>BW4	>BW4	0.13	>BW4	>BW4	0.13	0.13	-0.02	-0.04	-0.04	0.02
W27 black	>BW4	>BW4	0.19	>BW4	>BW4	0.22	0.05	0.14	-0.12	0.15	2.66
W28 reddish brown	>BW4	>BW4	0.34	>BW4	>BW4	0.22	-0.19	-0.17	-0.22	-0.27	-0.15
W29 dark brown	>BW4	>BW4	0.22	>BW4	>BW4	0.18	0.01	0.05	-0.22	-0.17	-0.60
W30 dark green	>BW4	>BW4	0.27	>BW4	>BW4	0.21	-0.11	0.12	-0.21	-0.24	0.24
W31a pink darker	BW3-BW2	2.6	3.59	BW3-BW2	2.4	1.31	0.11	-3.53	-0.62	-3.59	0.00
W31b pink lighter	>BW4	>BW4	0.38	>BW4	>BW4	0.25	-0.08	-0.07	-0.36	-0.20	-0.73

Table 1. ctd.

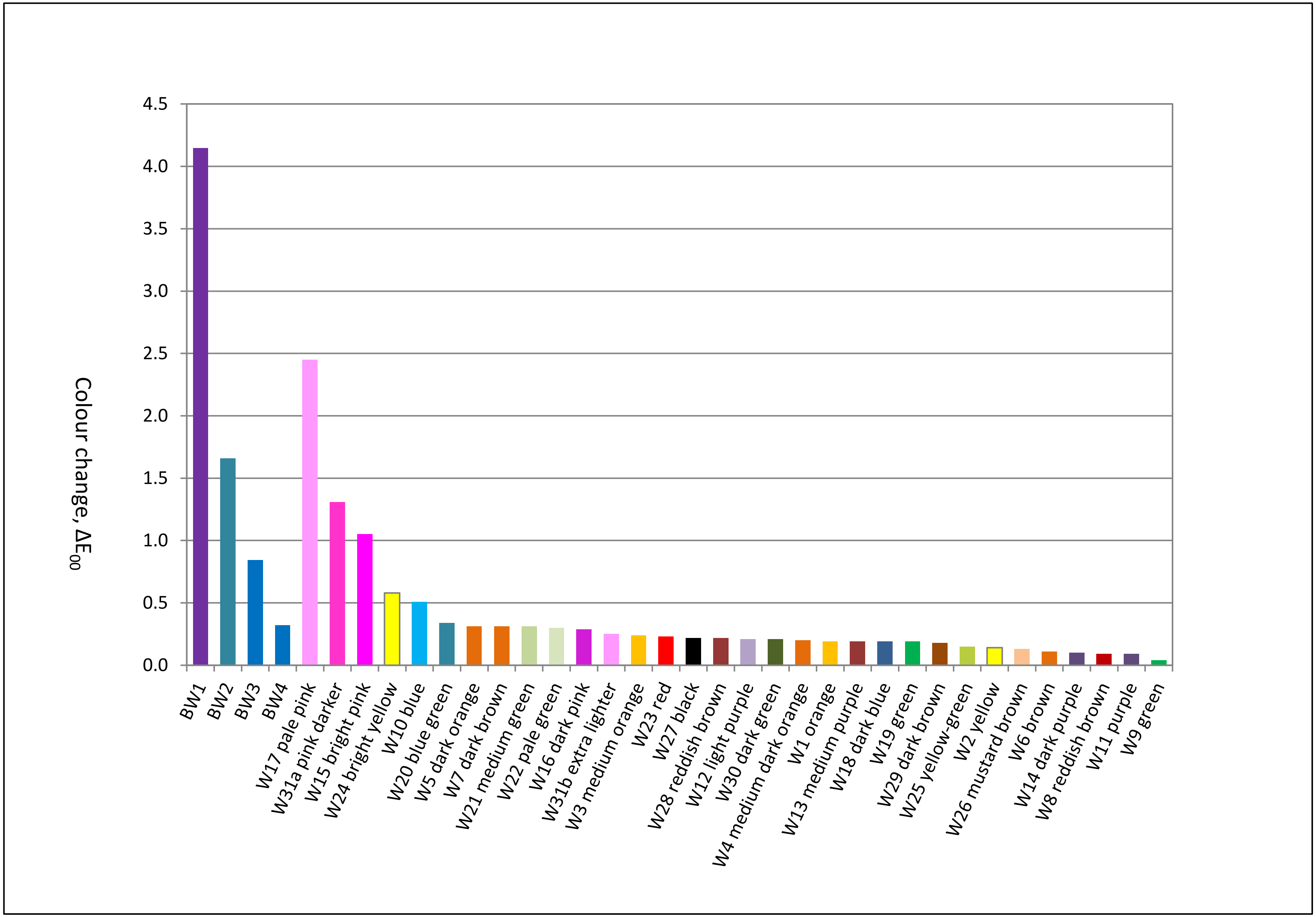


Figure 2. Woomera, colour change compared to ISO Blue Wools as determined by MFT.

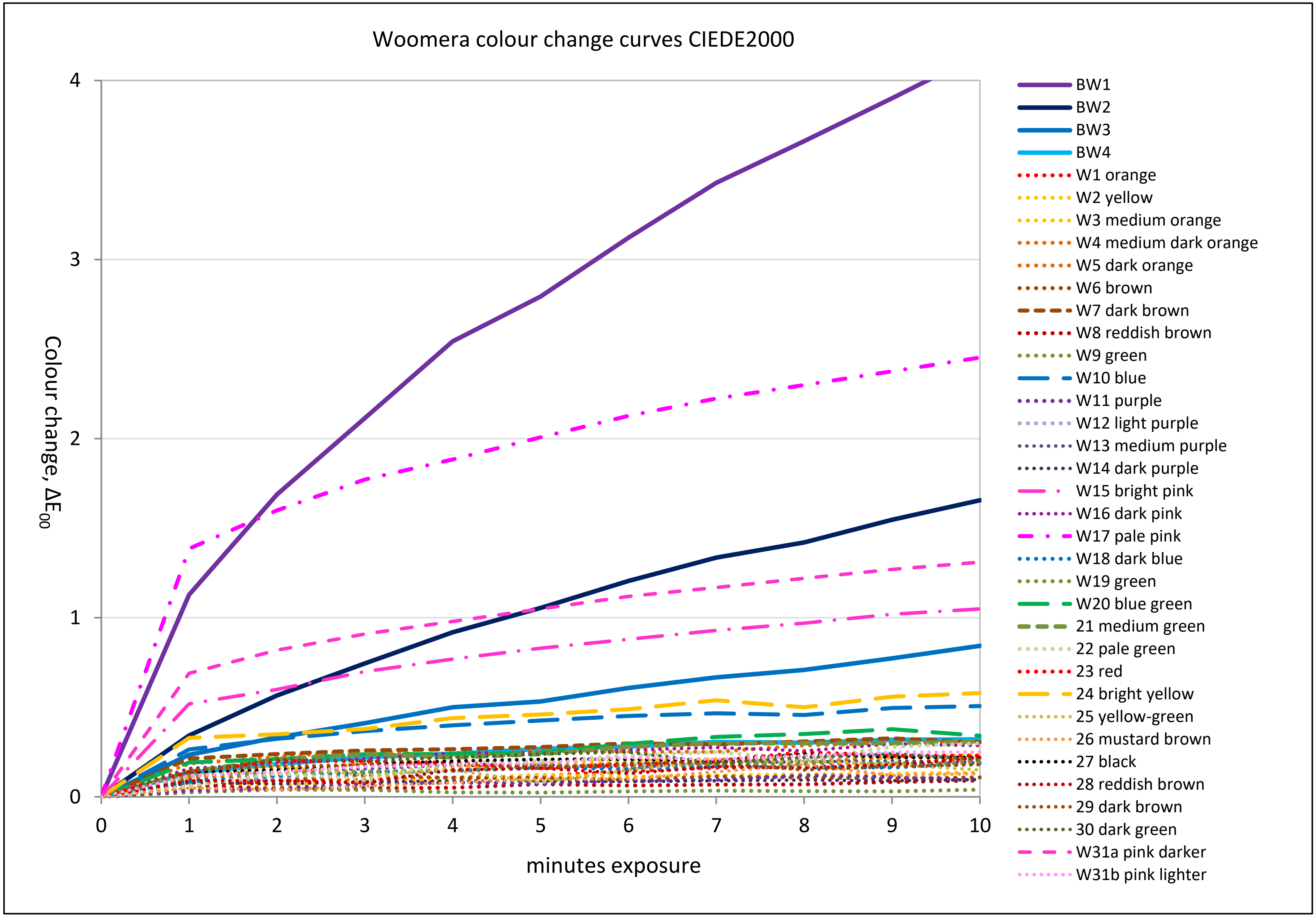


Figure 3. Woomera, fading curves during MFT

Figure 4. Land of Parrots, microfade test sampling positions. Samples taken from rear (largely unexposed to light).

	CIE76			CIE2000							
Colour	BW Range	BW Equivalent	$\Delta E76$	BW Range	BW Equivalent	$\Delta E2000$	ΔL^*	Δa^*	Δb^*	ΔC	Δh
BW1			13.8			3.9	3.0	-6.1	12.0	-12.8	6.3
BW2			7.8			1.5	1.2	-3.8	6.7	-7.2	3.1
BW3			2.3			0.6	-0.3	-1.3	1.8	-2.2	0.5
BW4			0.9			0.3	0.0	0.7	-0.5	0.6	-0.7
P1 red	>BW4	>BW4	0.8	BW3-BW4	3.7	0.4	-0.1	-0.8	-0.2	-0.7	0.6
P2 pale pink	>BW4	>BW4	0.3	>BW4	>BW4	0.2	0.1	-0.1	-0.2	-0.2	-0.3
P3 bright yellow	BW4-BW3	3.9	1.0	BW3-BW4	3.3	0.5	-0.3	0.7	-0.7	-0.8	-0.8
P4 main green	>BW4	>BW4	0.4	>BW3	>BW4	0.2	-0.1	0.1	-0.3	-0.3	0.1
P5 faded green	>BW4	>BW4	0.4	BW4	4.0	0.3	-0.1	0.1	-0.4	-0.4	0.0
P6 bright magenta (pink)	BW3-BW2	2.8	3.2	BW2-BW1	1.9	1.8	-1.5	-2.4	-1.6	-2.4	-0.9
P7 dark magenta	>BW4	>BW4	0.8	>BW3	3.0	0.6	-0.3	0.0	-0.8	-0.2	-1.2
P8 warm yellow	>BW4	>BW4	0.3	>BW4	>BW4	0.1	0.0	0.0	-0.3	-0.3	0.1
P9 peach	>BW4	>BW4	0.4	>BW4	>BW4	0.2	0.0	-0.3	-0.3	-0.4	-0.2
P10 mustard yellow	>BW4	>BW4	0.6	>BW4	>BW4	0.2	0.0	-0.2	-0.5	-0.6	0.2
P11 pale yellow	>BW4	>BW4	0.2	>BW4	>BW4	0.1	0.1	0.0	-0.1	-0.1	0.1
P12 greenish yellow	>BW4	>BW4	0.4	>BW4	>BW4	0.1	0.0	0.0	-0.3	-0.3	0.1
P13 pale peach	>BW4	>BW4	0.7	>BW4	>BW4	0.3	0.0	-0.1	-0.7	-0.7	-0.1
P14 rust red	>BW4	>BW4	0.3	>BW4	>BW4	0.1	0.0	-0.1	-0.3	-0.3	-0.1
P15 orange pink	>BW4	>BW4	0.7	>BW4	>BW4	0.3	0.1	-0.7	-0.2	-0.6	0.5

Table 2. Land of Parrots. colour change summary. See last page for CIELAB diagram and Endnote 2 for a discussion of CIE76 vs CIE2000 results.

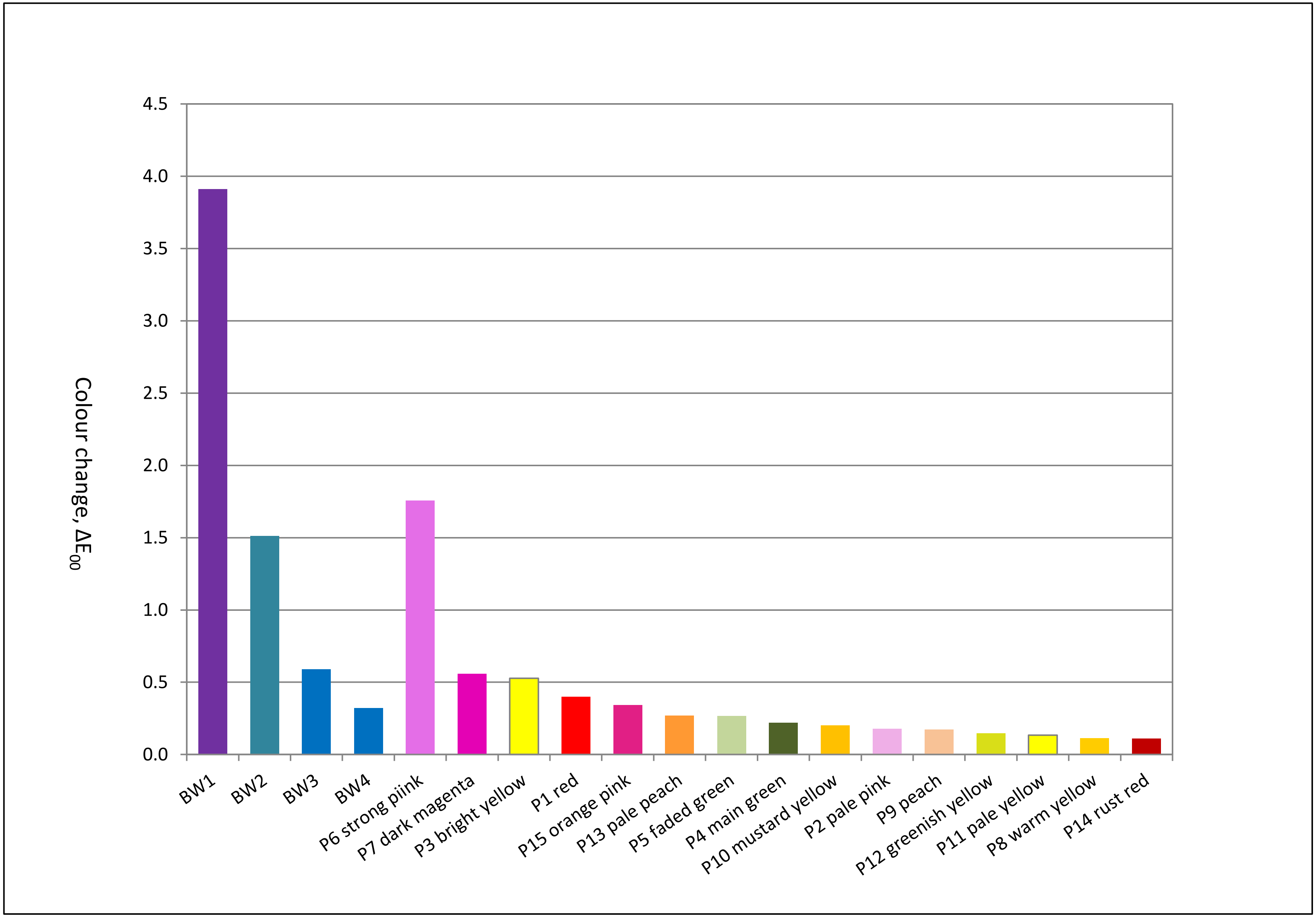


Figure 5. Land of Parrots, relative colour change rates , CIE2000

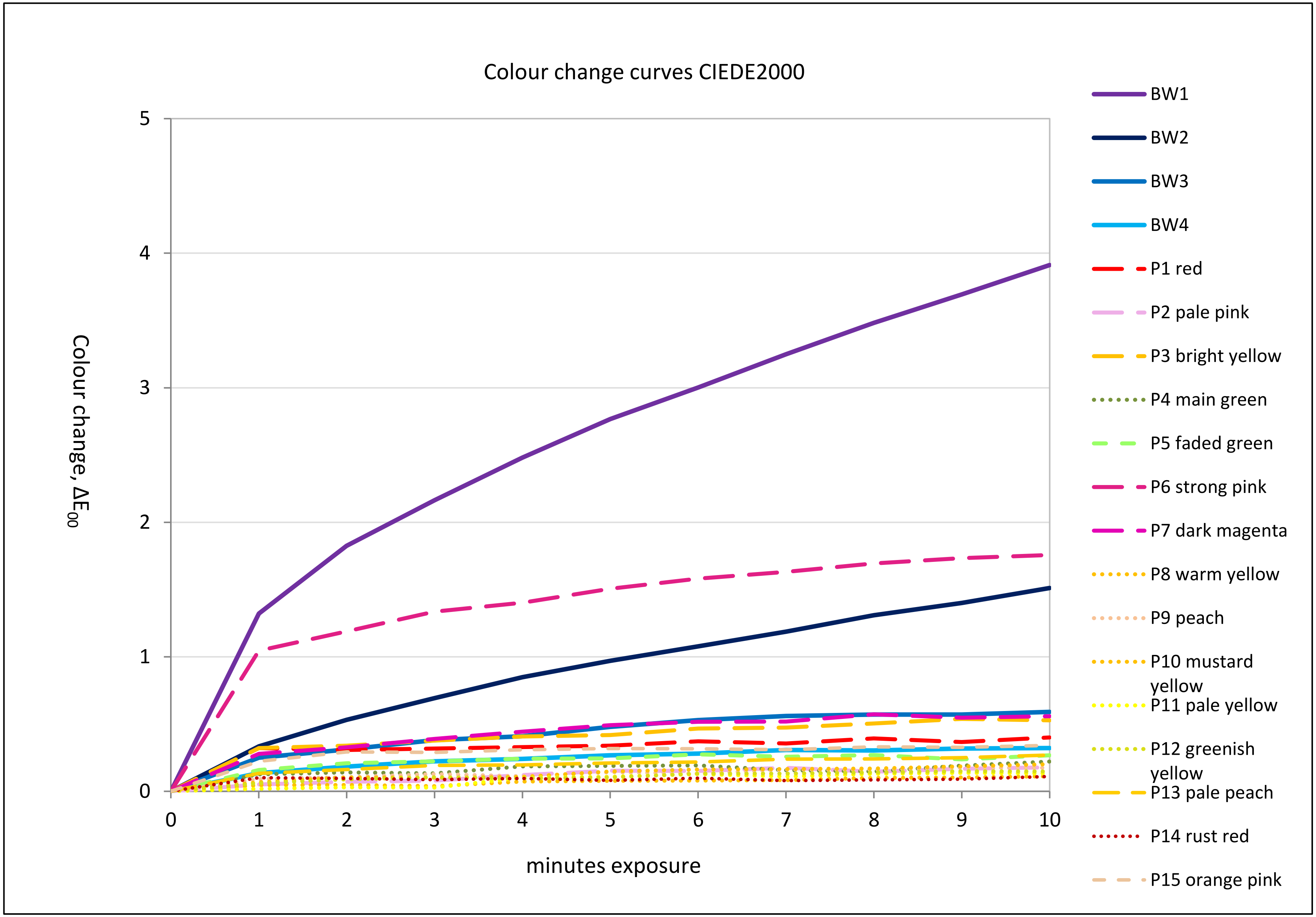


Figure 6. Land of Parrots colour change curves, CIE2000

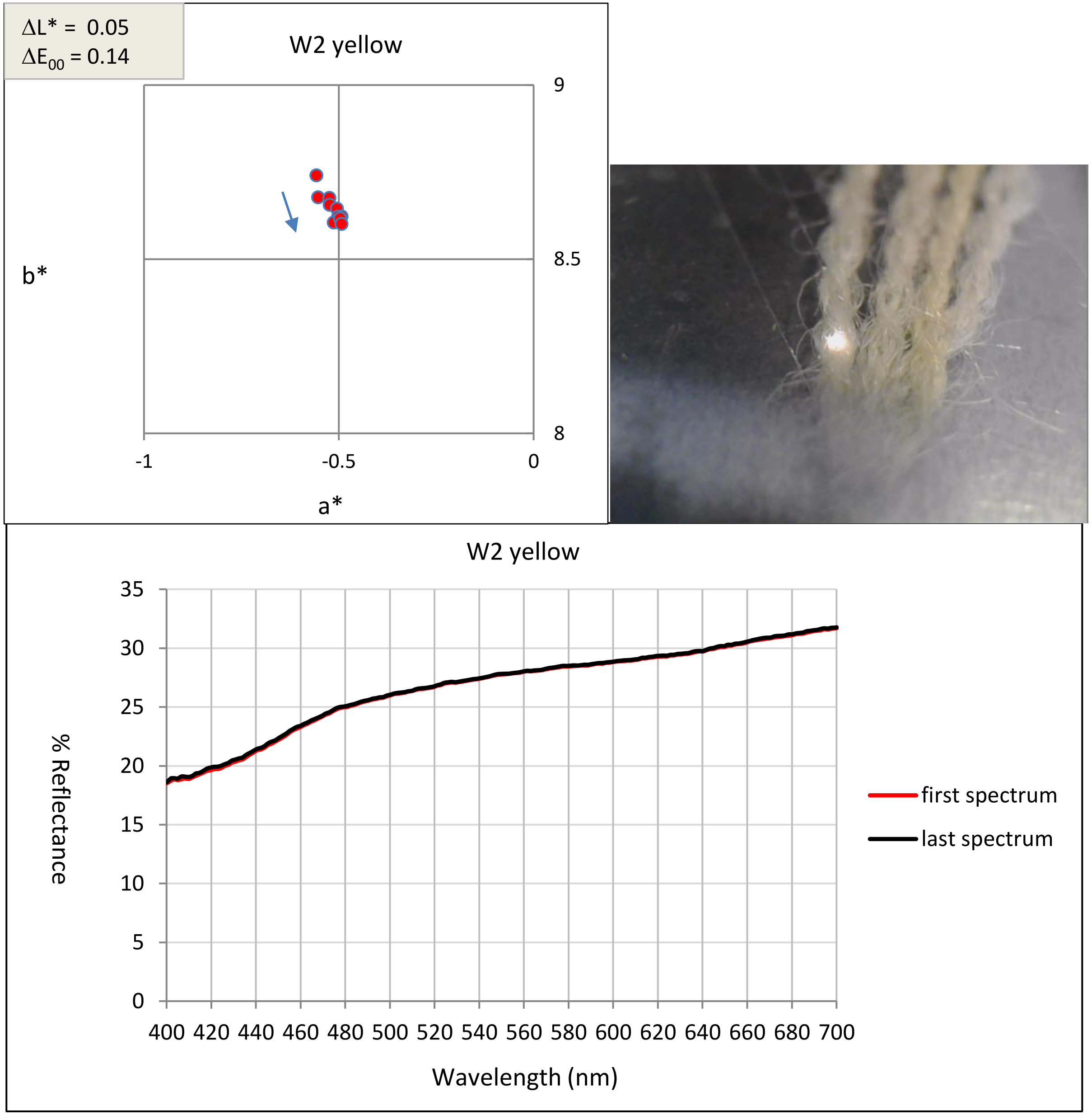


Figure 7. Probable maximum extent of yellow(ed) wool bleaching during MFT

W2 warm yellow

W5 dark orange

W15 & 31 bright pink

W17 pale pink

W16 dark pink (magenta)

W24 bright yellow

W27 grey (black)

Figure 8. front and rear colour measurement locations except W14 & W4. Front photographs flipped on horizontal axis.

Colour measurements											
	Front (unexposed)				Back (exposed)						
Dye	**L***	**a***	**b***	**MCDM**	**L***	**a***	**b***	**MCDM**	**ΔL***	**Δa***	**Δb***
W15 bright pink	37.65	50.50	3.69	1.74	49.22	36.59	8.44	0.80	11.57	-13.91	4.75
W24 bright yellow	68.90	-2.13	60.57	0.99	67.98	1.37	43.52	0.54	-0.92	3.50	-17.05
W5 dark orange	36.84	49.86	31.31	0.24	43.17	48.30	28.43	0.40	6.33	-1.56	-2.88
W17 pale pink	60.14	15.66	1.97	0.24	63.95	8.72	2.59	0.76	3.81	-6.94	0.62
W16 dark pink	29.97	40.83	3.24	0.17	36.52	36.06	2.75	0.37	6.55	-4.77	-0.49
W2 warm yellow	56.76	33.04	48.59	0.54	61.00	26.33	38.92	0.45	4.24	-6.71	-9.67
W10 blue	37.94	-5.78	-22.37	0.58	41.24	-2.41	-21.24	0.48	3.30	3.37	1.13
W4 medium dark orange	47.87	48.35	41.51	0.57	51.06	42.68	34.20	0.54	3.19	-5.67	-7.31
W14 purple	18.87	10.74	-12.52	0.36	21.32	10.47	-12.89	0.30	2.45	-0.27	-0.37
W27 grey/black	17.18	-0.58	0.68	0.45	17.83	-1.46	0.74	0.29	0.65	-0.88	0.06

Table 3. Colour measurements from the back (unexposed) and front (exposed) areas of the Woomera tapestry.

Colour Difference (ΔE_{00}) between front (exposed) and back (unexposed) after ~50 years on display			
Dye	**ΔE_{00}**	**MCDMt**	**MCDMt/ΔE**
W15 bright pink	12.17	1.91	0.16
W24 bright yellow	6.57	0.75	0.11
W5 dark orange	5.71	0.46	0.08
W17 pale pink	5.65	0.79	0.14
W16 dark pink	5.56	0.41	0.07
W2 warm yellow	5.15	0.70	0.14
W10 blue	4.31	0.75	0.17
W4 medium dark orange	4.21	0.78	0.19
W14 dark purple	1.75	0.47	0.27
W27 grey/black	1.31	0.54	0.41

Table 4. Colour differences between back (unexposed) and front (exposed) areas of the Woomera tapestry. The colour difference ΔE_{00} is considered statistically significant if MCDMt/ΔE < 0.5. Multiply MCDMt/ΔE by 100 for a measure of systematic error (%).

Approximate BWE lightfastness (BWE = Blue Wool Equivalent) of various dyes based on fading during ~50 years compared to MFT BWE											
		100 lux av. Illumination 8 hrs/day			150 lux			200 lux			
		15Mlux h			22Mlux h			30Mlux h			
Dye (order of fading)	**JNF**	**Mlx hr/JNF**	**BWE**	**BW range**	**Mlx hr/JNF**	**BWE**	**BW range**	**Mlx hr/JNF**	**BWE**	**BW range**	**MFT BWE**
W15 bright pink	7.60	2.0	2.5	BW2-BW3	2.9	3.0	BW3	3.9	3.1	BW3	3.1
W24 bright yellow	4.10	3.7	3.1	BW3-BW4	5.4	3.3	BW3-BW4	7.3	3.6	BW3-BW4	3.5
W5 dark orange	3.57	4.2	3.2	BW3-BW4	6.2	3.5	BW3-BW4	8.4	3.8	BW4	4.0
W17 pale pink	3.53	4.2	3.2	BW3-BW4	6.2	3.5	BW3-BW4	8.5	3.8	BW4	1.7
W16 dark pink	3.47	4.3	3.2	BW3-BW4	6.3	3.5	BW3-BW4	8.6	3.8	BW4	4.0
W2 warm yellow	3.22	4.7	3.2	BW3-BW4	6.8	3.5	BW3-BW4	9.3	3.9	BW4	>BW4
W10 blue	2.69	5.6	3.4	BW3-BW4	8.2	3.7	BW4	11.1	4.1	BW4	3.6
W4 medium dark orange	2.63	5.7	3.4	BW3-BW4	8.4	3.8	BW4	11.4	4.1	BW4	4
W14 dark purple	1.09	13.7	4.2	BW4-BW5	20.2	4.5	BW4-BW5	27.5	4.9	BW5	>BW4
W27 grey/black	0.82	18.3	4.4	BW4-BW5	26.9	4.8	BW4-BW5	36.6	5.1	BW5	>BW4

Table 5. Approximate blue wool equivalent lightfastness ratings (BWE) based on three different light intensity scenarios and the results from Tables 3 & 4 for relatively UV-free illumination. The BW stability data in Mlux h/JND is provided in Figure a, Appendix. These are compared to the MFT BWE ratings from Table 1 in the final column. The estimated light level range, and therefore cumulative exposure over 50 years, was based on a single daytime reading of 200 lux in June 2022 which also showed low UV. Year-round electronic logging currently being undertaken will better characterise cumulative light exposures.

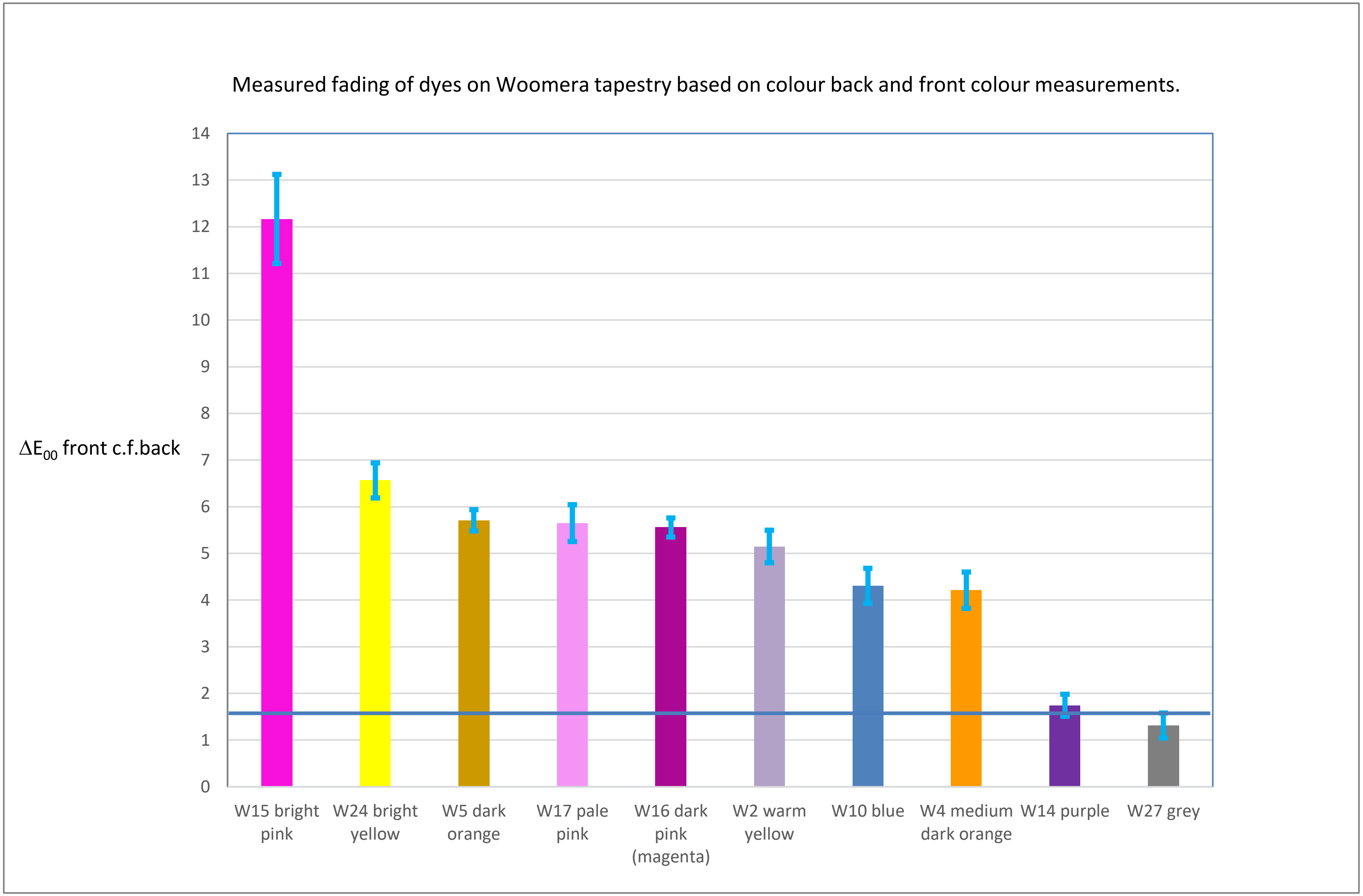


Figure 7. Measured colour differences back and front of the same dyed areas (Table 4). A just noticeable (or perceptible) fade (JNF) is approximately 1.6ΔE, represented by the horizontal blue line. Where a direct contrast is available, it is possible for most young healthy people to distinguish between shades that differ by roughly this amount. JNF estimates in the literature range from 1.6 to 2.0.

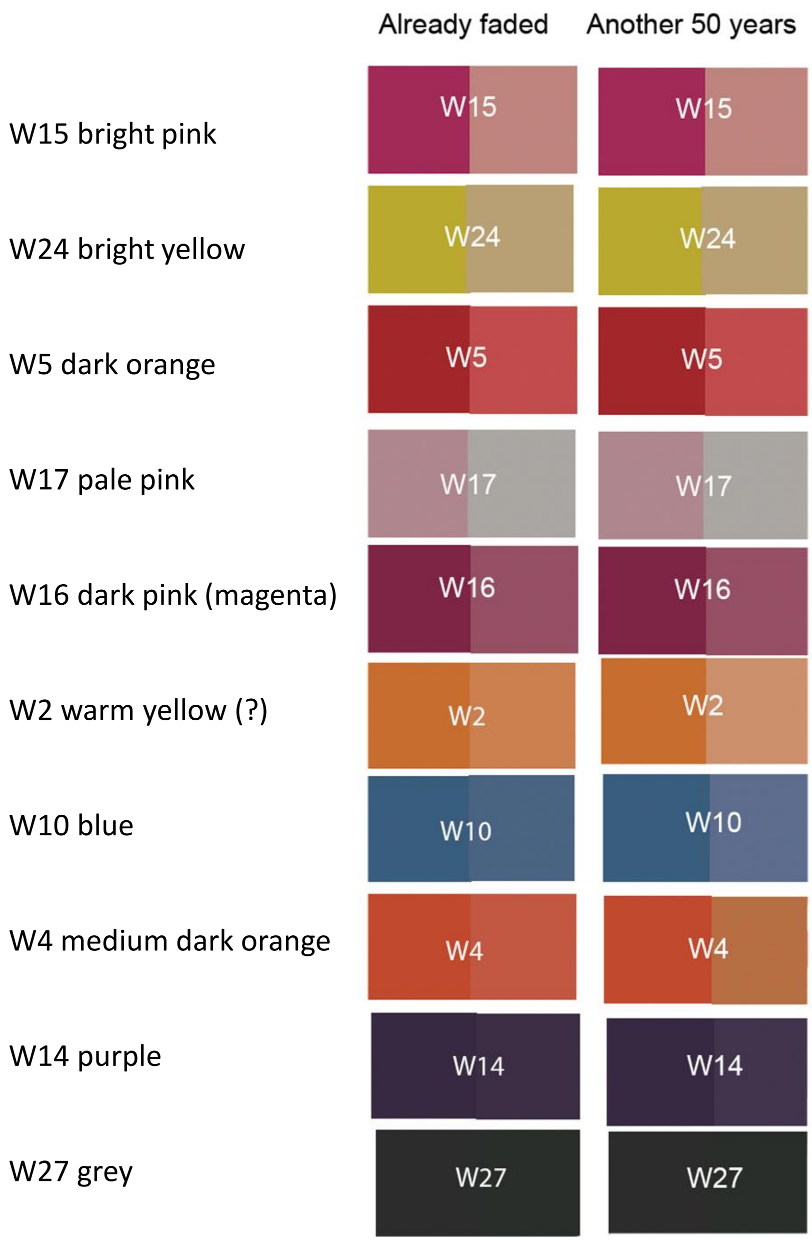


Figure 8. Rear (unexposed) and front colours from colour measurements, future fading calculated from measured Δ(L*a*b*) rear v.s front.

Figure 9. Initial colours matched from yarn samples by eye, current and future fading calculated from Δ(L*a*b*) rear v.s front.

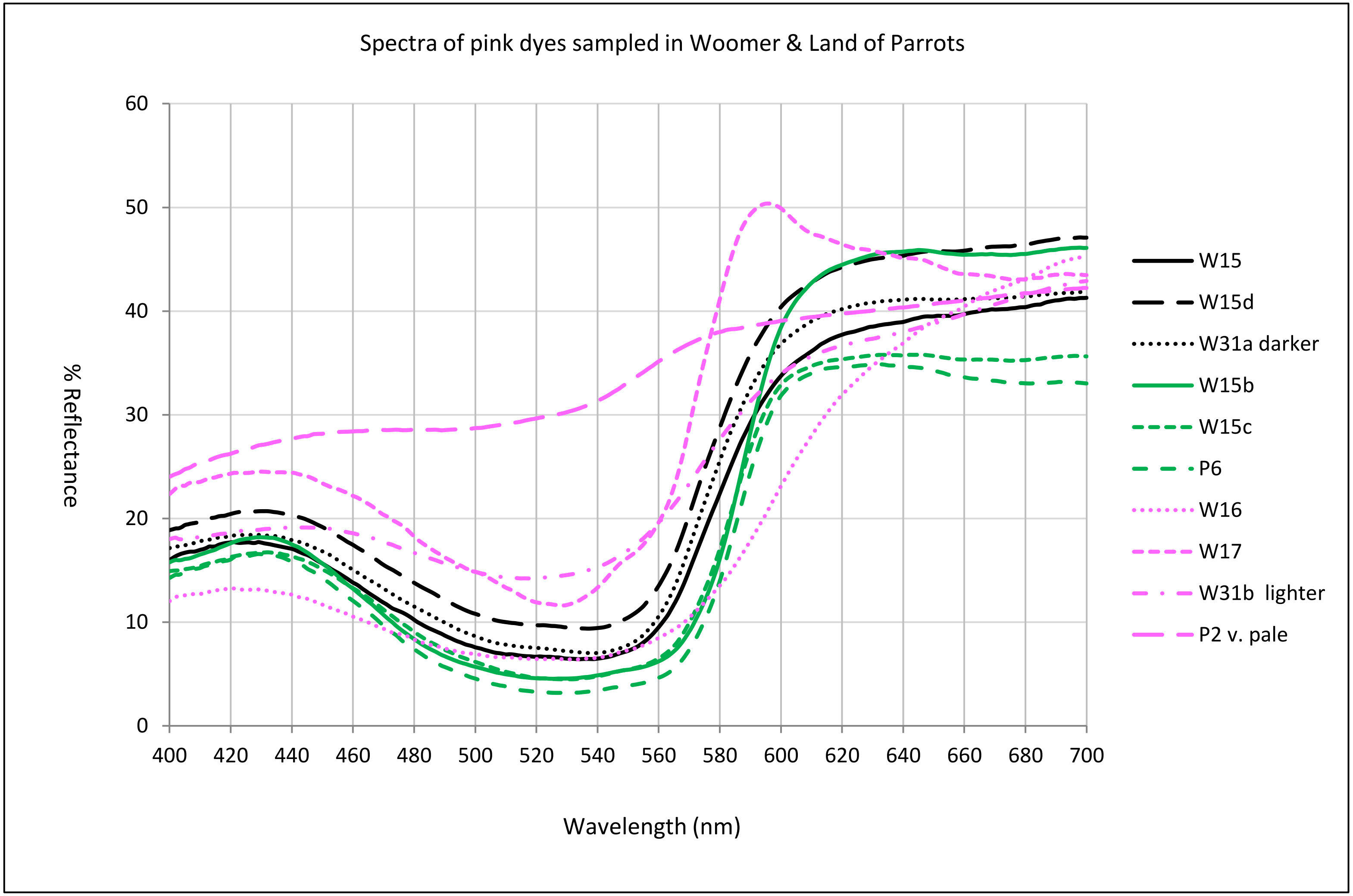
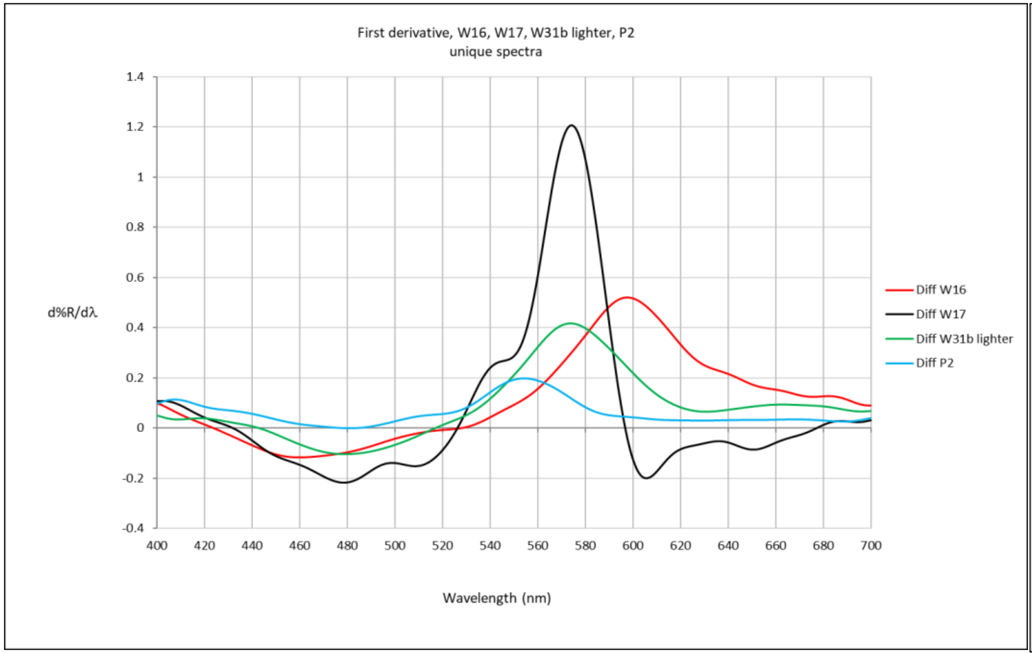


Figure 10. There are 6 distinct pink spectra, some with quite different fading rates (see Figures 11 & 12 below). W31 contains two differently dyed yarns, as does W15.



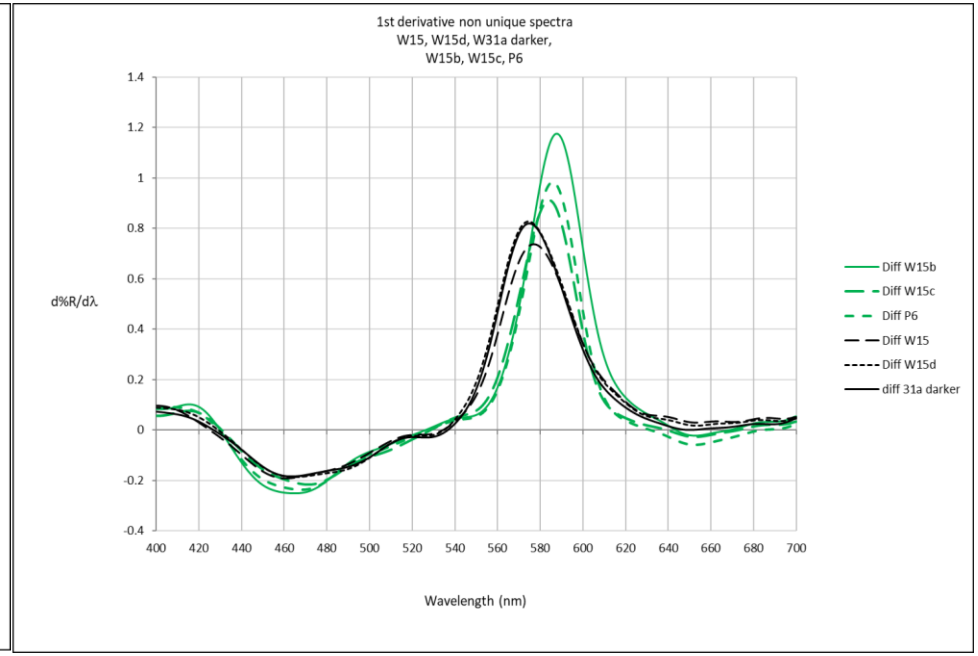


Figure 11. First derivatives of pink dyes d%R/dλ, where λ = wavelength in nm. Differentiating spectra highlights spectral differences and similarities. The pink dyes sampled fall into a total of 6 different spectral types: four individual dyes W16, W17, W31b, P2 represented by a single example each (left); and two groups each containing three dyes 15b, 15c, P6 and W15, 15d, 31a (right). W31a (dark) and W31b (light) are different.

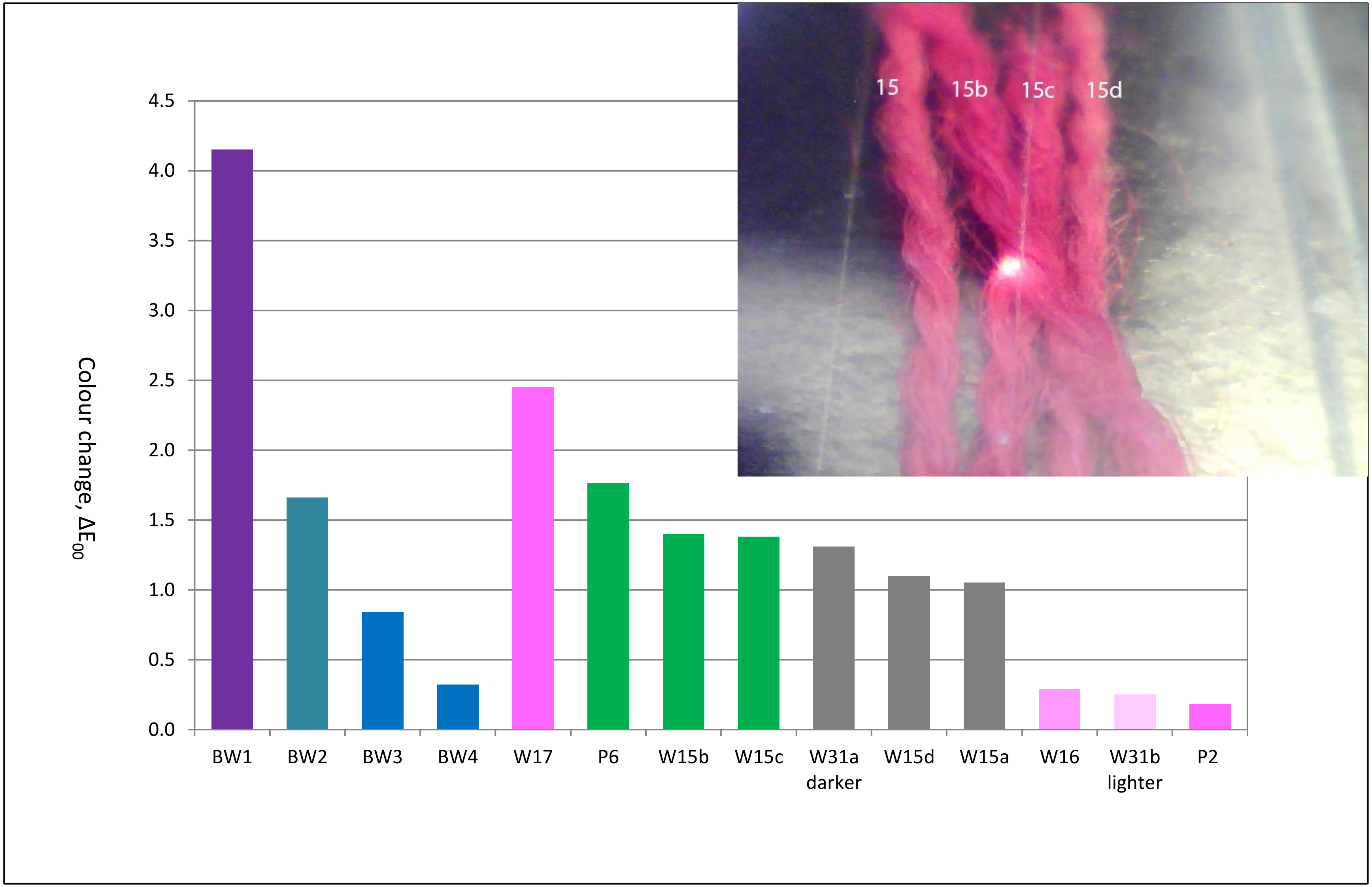


Figure 12. The fading rates of the 6 distinct pink yarns, 4 of them unique (pink bars) and two groups of three each (grey) and 3 (green). Insert = the four yarns from W15 which represented two different dyes.

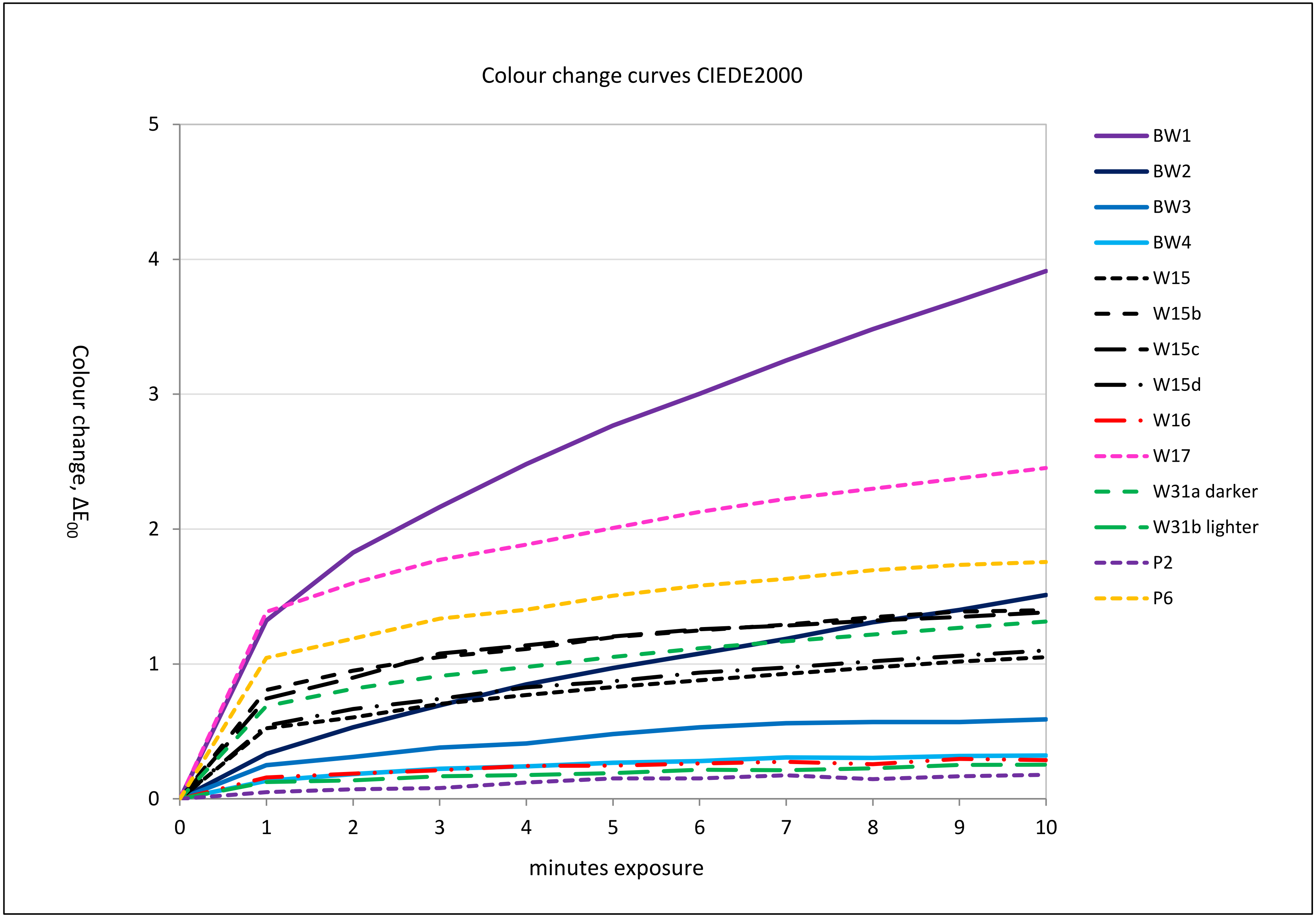


Figure 13. Fading curves of pink yarns

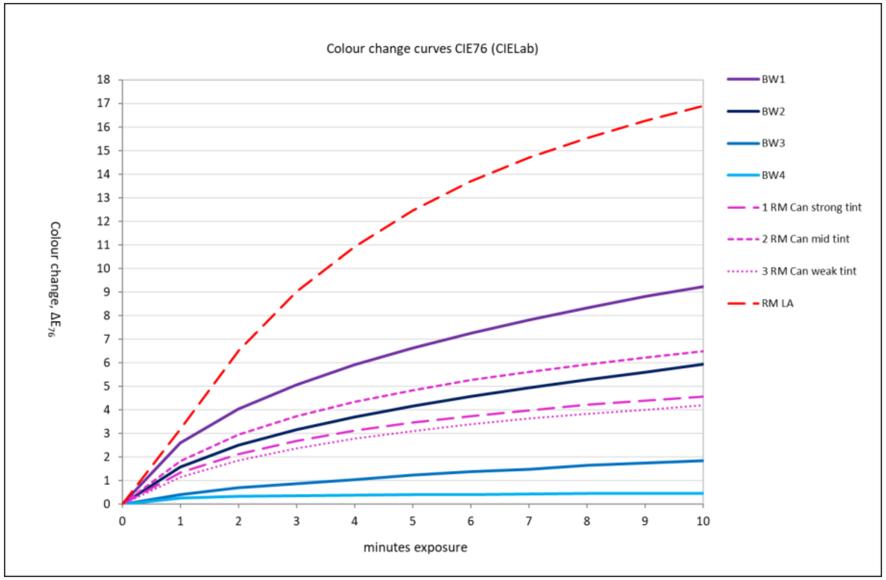
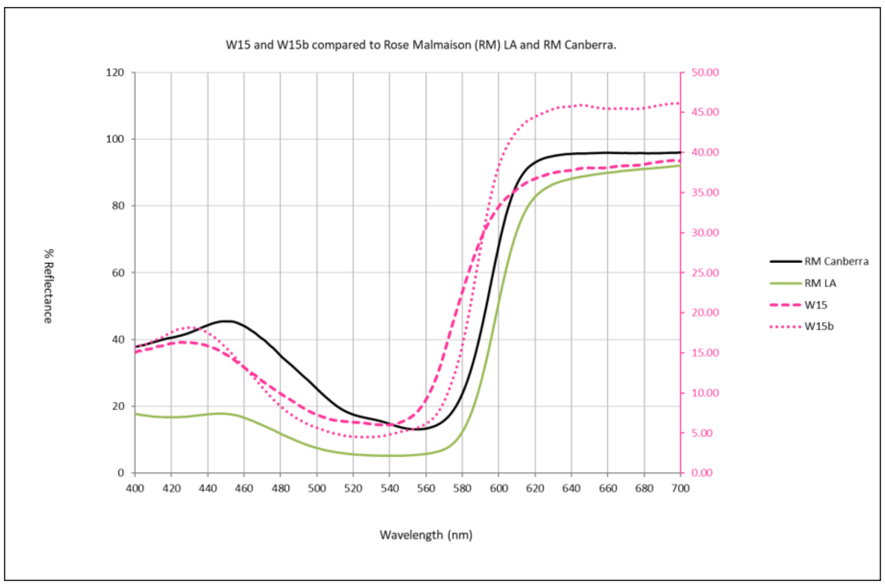


Figure 14. W&N Rose Malmaison designers' gouache (discontinued) from identical tubes, one bought in Los Angeles and the other in Canberra in the same year (2009). Both colours looked the same but had two different spectra (bottom) and wildly different fading rates (upper). Not also that different shades of the same dye fade at somewhat different rates (.

W&N were contacted for comment but could offer no explanation. It is very likely their quality control consisted only of colour measurement rather than chemical identification or chromatography to identify mixtures or substitution.



The spectra of Winsor & Newton Rose Malmaison from Los Angles (RM LA) is almost identical to that of W15

591	Rose Malmaison	1	C	T	Bl	Rhodamine/alumina lake, Strontium toner	PR173, PR48:3	45160, 15865

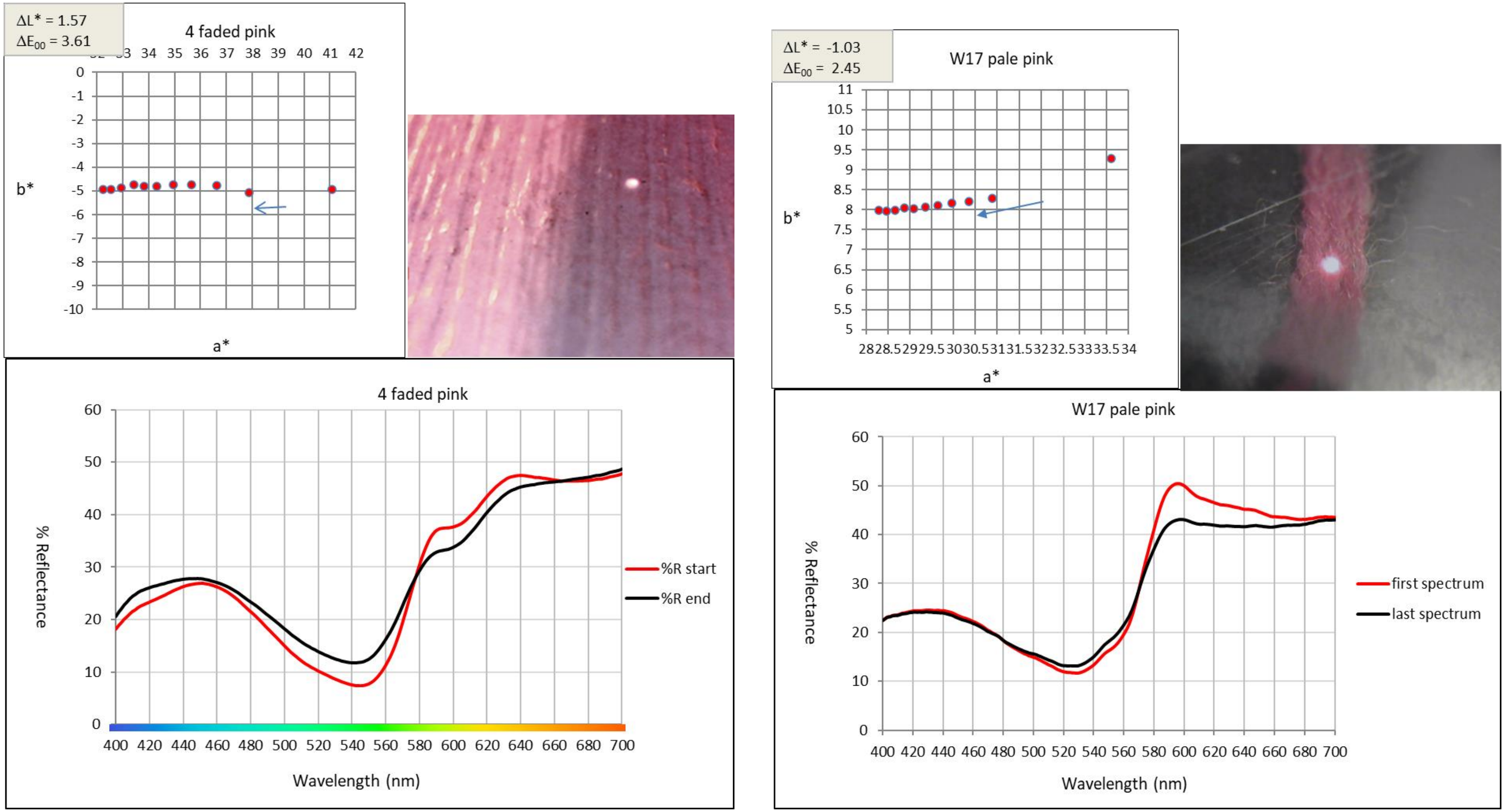


Figure 15. Rhodamine 4, the less lightfast pink rhodamine paint from the Guggenheim Mel Ramos painting (left), and W17 (right) there are enough spectral and fading pattern similarities to conclude that W17 is more likely than not a rhodamine. Eosin is another theoretical possibility, however it fades more rapidly than the Ramos and W17 pinks and has a distinctive a* b* fading pattern not seen in the tapestry samples.

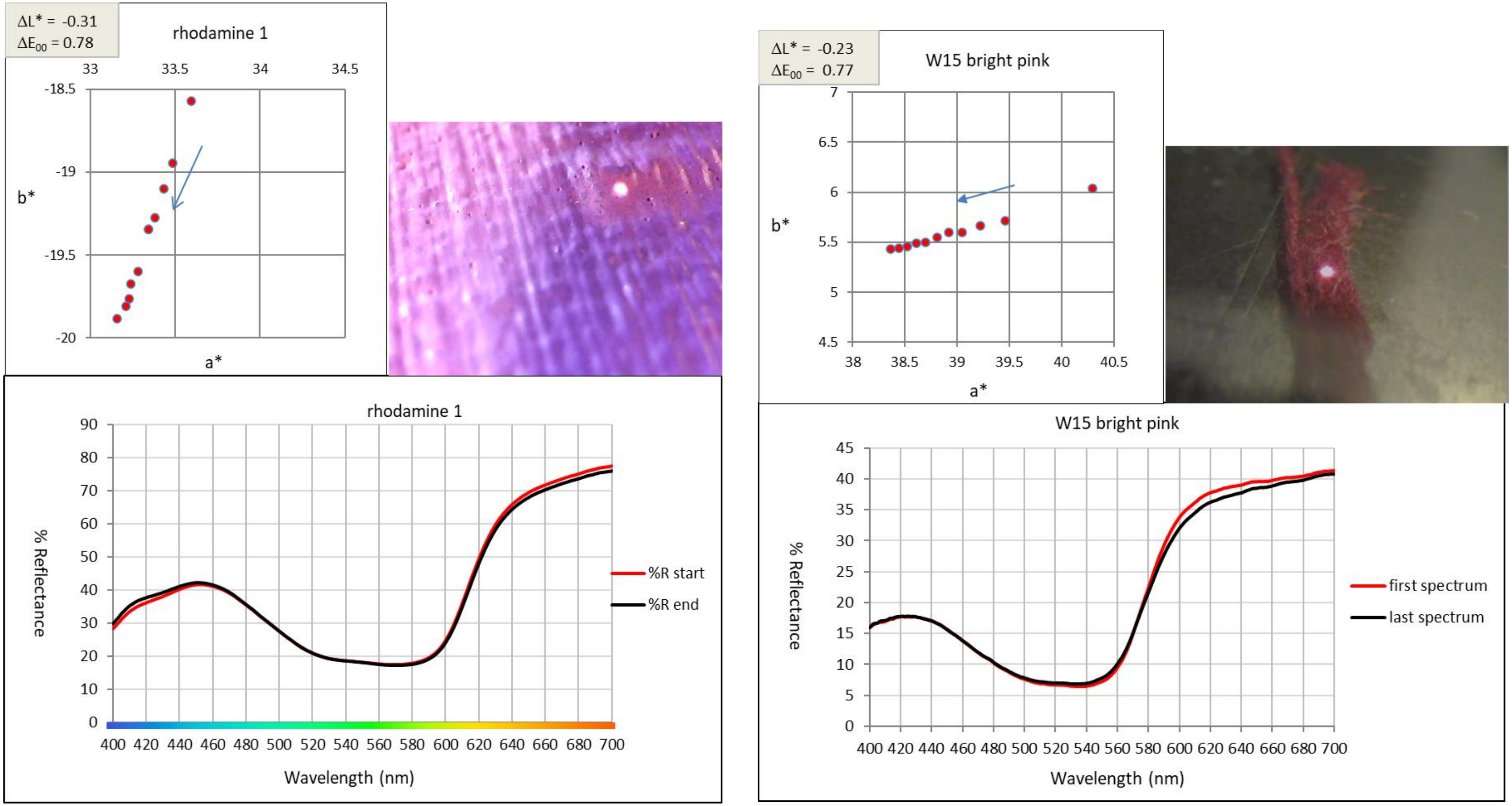


Figure 16. Spectral and fading pattern similarity between Woomera W15 and Rhodamine 1 from the Guggenheim Mel Ramos painting which was positively identified as containing a rhodamine dye.

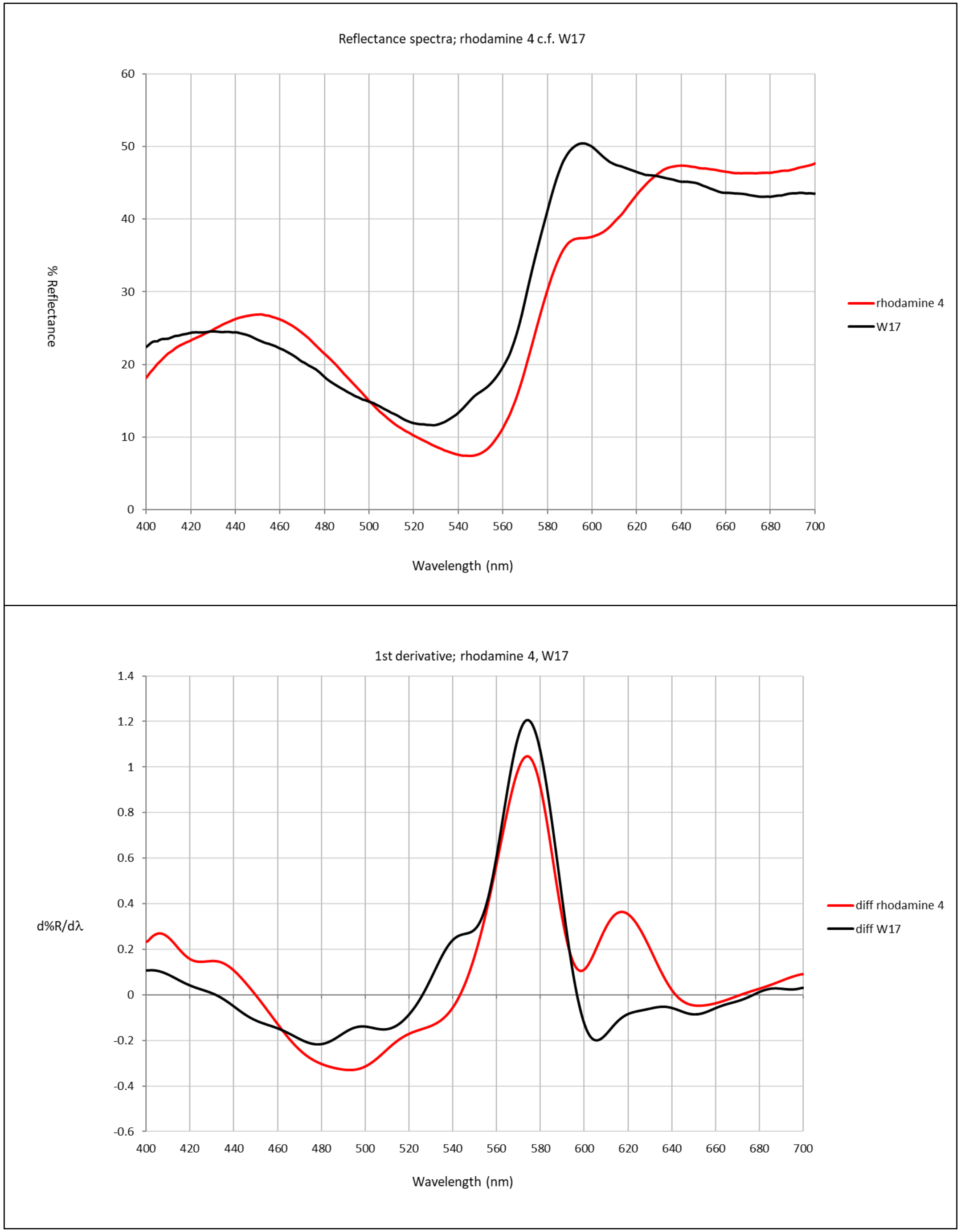


Figure 17. Upper, visible reflectance spectra of rhodamine from Mel Ramos painting (Guggenheim) compared to that of W17. First differentials below. They are not exactly the same but along with the fading data they share enough features to conclude that P17 (and therefore other pinks in the tapestries) probably includes rhodamine dyes.

The same applies to rhodamine 1 from the Mel Ramos painting and tapestry samples W15 and P6 in Figure 17.

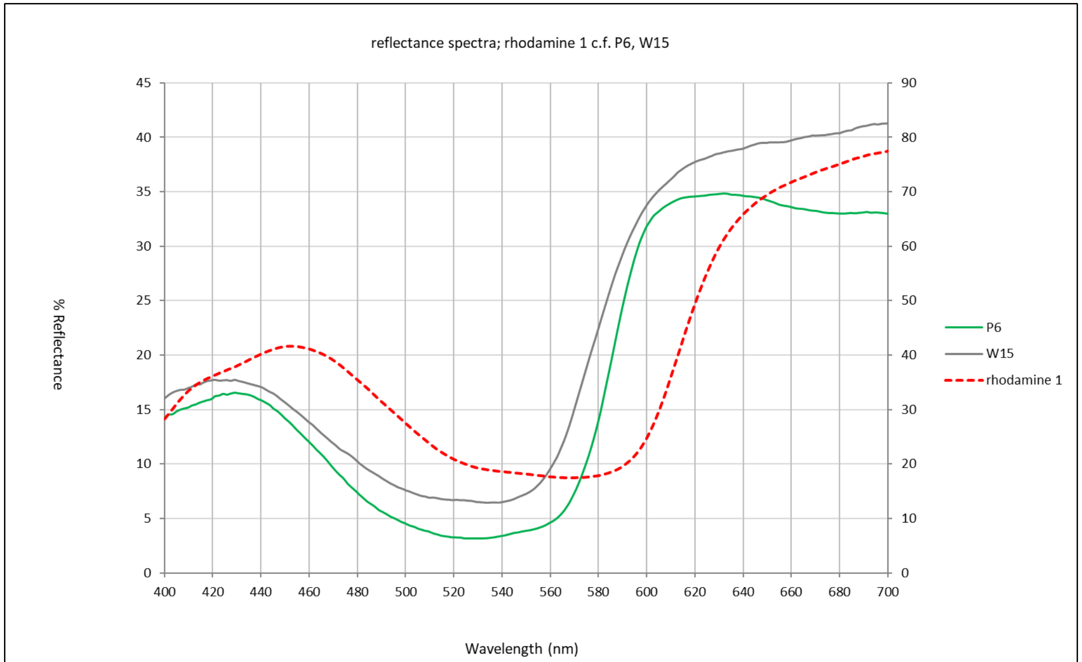
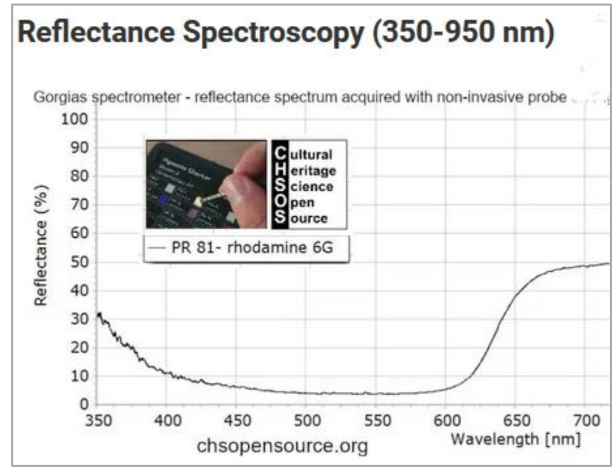
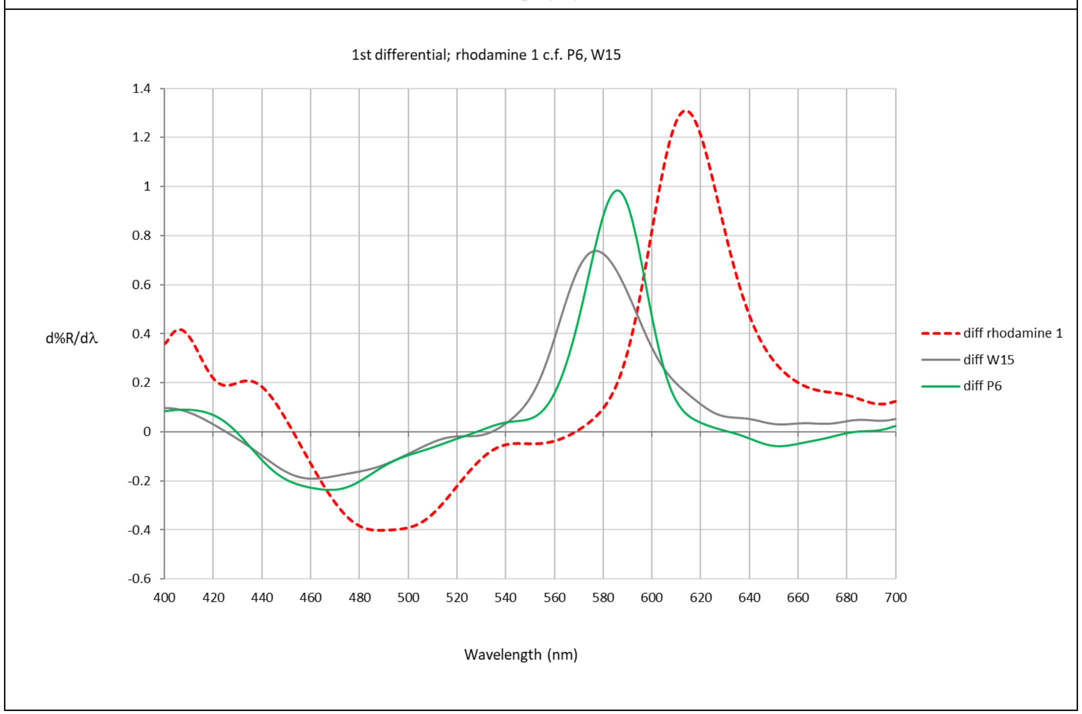


Figure 18. Visible reflectance spectra, rhodamine 1 from Mel Ramos painting and tapestry samples W15 and P6. See also a reflectance spectrum of "rhodamine 6G" from an online database, similar to W15, W15a, W15d, W31a darker group. The position of the main "peak" in the differential spectra (actually the position of the maximum slope of the red reflectance area) varies with the colour. The secondary bumps around 540nm are more indicative.





1st differential spectra; rhodamine 1 from Mel Ramos painting, and tapestry samples P6 and W15.

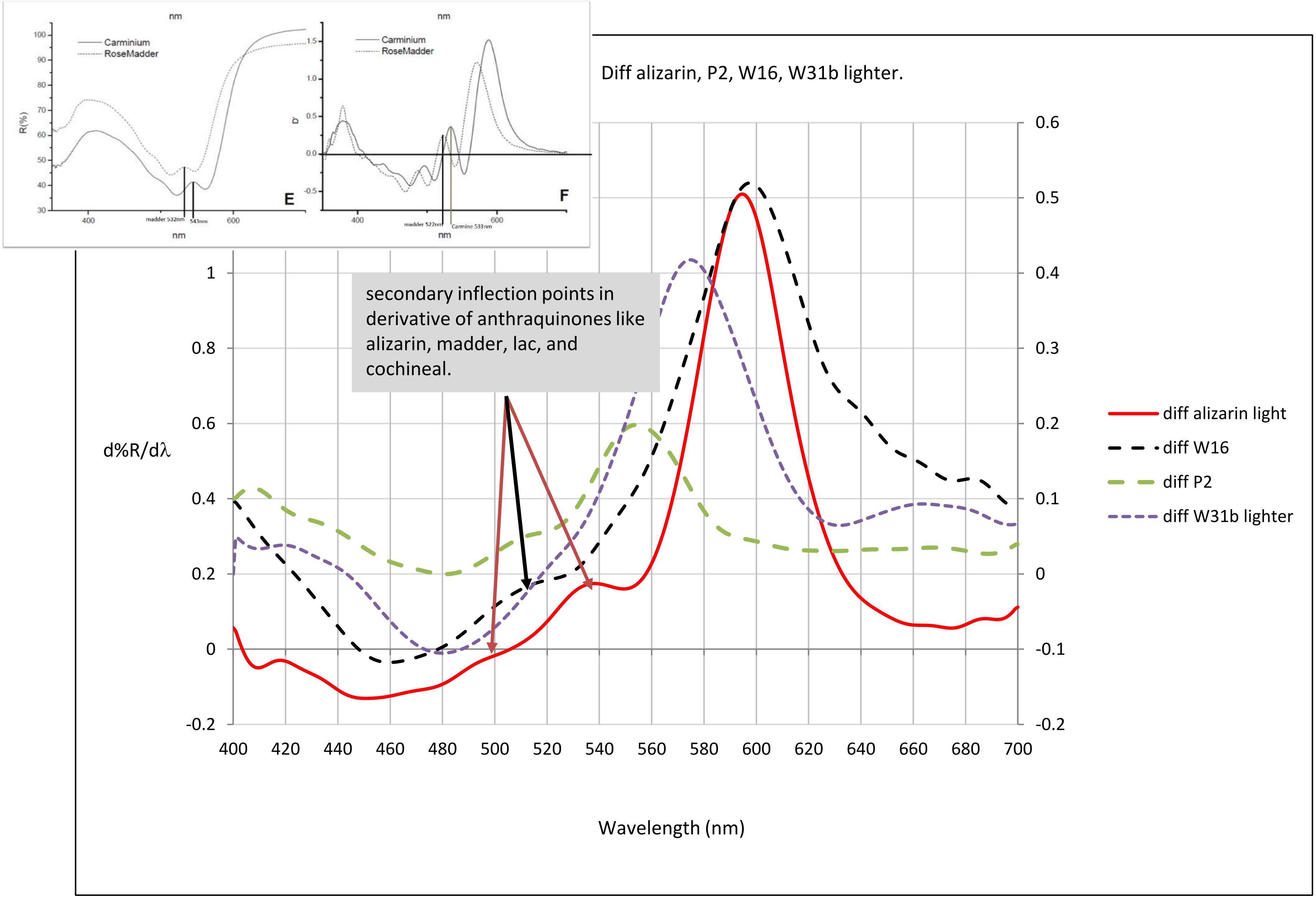


Figure 19. First differential spectrum of alizarin, W16, W31b and P2 indicating that anthraquinone dyes may have been used for the more lightfast pinks (and reds). Madder and alizarin on wool are usually more lightfast than BW3.

Notes & References

Endnote 1

Microfade testing is an accelerated test method and there are uncertainties surrounding the correlation between what is observed at very high intensities and what is likely to occur on display and during subsequent storage (Whitmore et al 2000). It is a semi-quantitative risk assessment tool rather than necessarily predictive. The results in this case apply only to UV-free light.

Endnote 2

For the purposes of this report colour change (ΔE) has been calculated using the CIE's 2000 (CIEDE2000) colour difference formula which replaced the earlier and much simpler 1976 (CIE76 or CIELAB) equation. There are many other colour difference equations, all of which will give different results - for example CMC, S-CIELAB, and a proposed I* (I-star) metric for photographs (McCormick-Goodhart 2007).

Michalski's estimates of how much exposure (megalux hours, Mlux h) will result in a just noticeable fade or difference (JNF or JND) for each of the BWs (CIE 2004) are themselves approximations with a maximum error of ± 1 BW step (Michalski 2010). Therefore absolute predictions of the response of a colourant to a particular exposure (mlx-h) are possibly uncertain to a similar extent. The most recent (unpublished) research by the CCI and GCI indicates that for BWs 2-5 Michalski's estimates are reasonable, but the lightfastness of BW1 is overestimated by as much as a factor of two or three (Druzik 2016).

Endnote 3

Microfading cannot predict post-exposure colour changes that may occur in undyed and unpigmented fibres and paper because only the immediate photochemical response is measured and not the effect of concurrent and subsequent thermal (oxidative) yellowing reactions (Feller 1994). Light exposure accelerates subsequent yellowing of paper via a thermal (non-photochemical or "dark") mechanism involving residual photochemical reaction products. Thermal discolouration depends heavily on temperature, chemical processing of fibres, pH, exogenous and endogenous pollutants, prior conservation treatments and so on. To further complicate matters, ultraviolet directly yellows, rather than bleaches, groundwood paper and most natural fibres like wool. For example the rapid discolouration of newspaper in sunlight is the result of UV (<400nm) yellowing outpacing visible (>400nm) light bleaching.

Endnote 4

The NMA assumptions (Ford BL & N Smith 2009) are based on those of the V&A Museum (Ashley-Smith et al 2002): that is works should last for at least 500 years in a coloured form; a Just Noticeable Difference (JND) = 1.6ΔE and 10 JNDs signal the effective end of coloured life for an object. This may sometimes be a conservative estimate because approximately 30ΔE represents complete fading, but for low chroma colours it seems reasonable. The absolute fading rates of the BWs are taken from CIE157 (2004), see Endnote 2. CIE157 recommends colourants less lightfast than BW3 be exposed only half as much as the V&A's 2 years/decade at 50lux recommendation.

The NMA further makes a judgement based on a significance test as to whether the object/collection is likely to be in strong demand for exhibition in the future (i.e. at higher risk of fading over time) and adjusts recommended exposures accordingly. Objects judged likely to be more in demand are treated more conservatively than objects which may rarely if ever displayed again (Ford BL & N Smith 2009) .

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Ashley-Smith, J, Derbyshire, A & B Pretzel 2002, The continuing development of a practical lighting policy for works of art on paper and other object types at the Victoria and Albert Museum, *Preprints of the 13th triennial meeting of the ICOM Committee for Conservation in Rio de Janeiro*, vol.1, pp. 3-8.

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Michalski, S., Canadian Conservation Institute (CCI), personal communication, 10th October 2010.

McCormick-Goodhart, M. 2007. *An introduction to the I* Metric*. Aardenburg Imaging and Archives.

Tse, S. 2016. Personal communication.

Whitmore, PM, Bailie, C & S Connors 2000, Micro-fading to predict the result of exhibition: progress and prospects, in *Tradition and Innovation: Advances in Conservation*, ed. A. Roy and P. Smith, pp. 200-205. London: IIC.

The Canadian Conservation Institute website has an excellent general introduction to light and museum collections: http://www.cci-icc.gc.ca/resources-ressources/agentsofdeterioration-agentsdedeterioration/chap08-eng.aspx

For a complete list of references to microfading and its applications see http://www.microfading.com/resources.html

Blue wool equivalent (BWE)	1	1.5	2	2.5	3	3.5	4
Lightfastness (Mlux h/JND)	0.2	0.6	1.0	1.8	3.0	5.5	10
Light level (lux)	up to 50 lux		50 - 80 lux*		50 - 80 lux*		lighting as required*
Display high significance	individually decided		2 years/decade		5 years/decade		period of exhibition
Display normal significance	individually decided (2 years/decade)		5 years/decade		period of exhibition		period of exhibition

*minimum consistent with good display

Figure (a) Appendix NMA lighting guideline

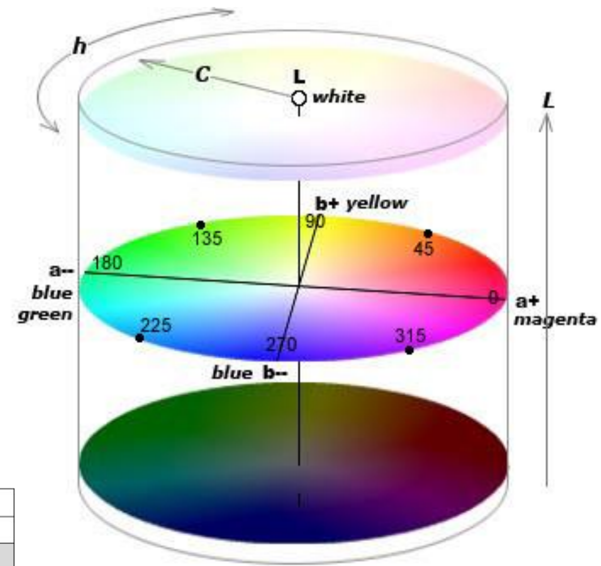
BW4-2 taken from Michalski's BWFS estimates from *Running A Museum, a practical handbook* ICOM 2004. *http://portal.unesco.org/culture/en/ev.php-URL_ID=36646&URL_DO=DO_TOPIC&URL_SECTION=201.html More recent estimates of BW1 put it at about 0.1-0.2 Mlux h/JND (UV-free), less lightfast than Michalski's estimate (Druzik 2016)*

Instrument Settings

Filtered xenon source, 0/45 orientation (Whitmore 2000)

Luminous flux (mlm)	~1000
Spot lux (megalux)	~ 10-12
Spot diameter (mm)	0.4
Colour difference equations	ΔE_{76} & ΔE_{00}

Figure (b) Appendix. Simplified L*a*b* colour space



L* a* b* and L C h are different ways of describing the same shift in CIELAB space

L* = Lightness
a* = red-green axis
b* = yellow-blue axis

C = vividness (chroma)
h = hue angle anticlockwise from red (0)