Burrup Peninsula Aboriginal Petroglyphs: Colour Change & Spectral Mineralogy 2004–2009

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Note: Since the Colour Change and Spectral Mineralogy report of 2009, CSIRO Exploration and Mining has changed name to Earth Science and Resource Engineering (CESRE).

1. COLOUR MEASUREMENT

1.1 Introduction

In response to tender number 34DIR0603 issued by WA DoIR and additional measurement agreements, CSIRO Materials Science and Engineering (CMSE) measured the colour of selected petroglyphs on the Burrup Peninsula over a period of six years. The requirements stipulated by the project were the measurement of relocatable sample points on petroglyphs annually for the measurement period.

An alternative technique for in situ monitoring of degradative change through colour measurement has been reported by Mirmehdi *et al.* [1], who undertook a pilot study designed for monitoring and modelling the deterioration of paint residues in a cave environment through digital image comparisons with a reference image. The template-matching technique was considered unsuitable and impractical for the Burrup study because:

- Template matching, as described by Mirmehdi *et al.* [1], would require the collection of digital images with repeatable and controlled spectral illumination, angle of incidence and collection. Burrup petroglyphs are located in remote, exposed locations, and it would not be possible to control the colour temperature and angle of the ambient lighting easily without blocking all the ambient daylight, or collecting images in the night with the ambient moon and starlight removed.
- The effect of metamerism in relation to the reference template and rock surface has not been accounted for. It is well known that surfaces appearing similar in colour under one set of illumination conditions can appear dramatically different with another spectral illuminant or angle of incidence. The reference template is a glossy (laminated) smooth surface, while the rocks in this study are significantly rougher.

Portable, hand-held spectrophotometry was identified as a suitable technique. It has been recognised as a repeatable way of recording colour in units of standard CIE chromaticity coordinates, in many contexts including archaeological situations [2]. CIE chromaticity coordinates are an internationally recognised numerical system of permanently and objectively describing the colour of a surface or material as a point in three-dimensional L*a*b* colour space, identifying a tristimulus value (L*a*b*) for each sample point.

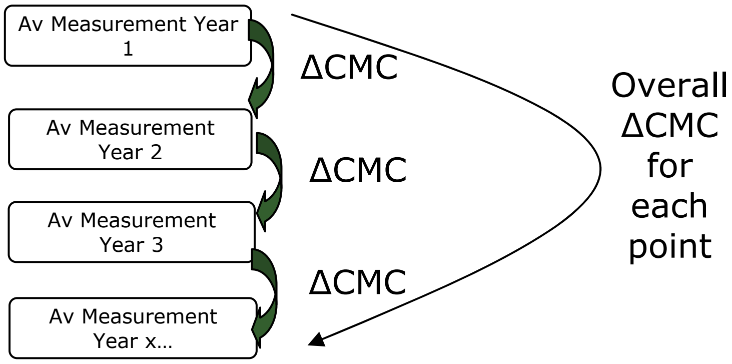
1.2 Experimental Methodology

The difference between two colours measured instrumentally is ΔE. It derives from the German word – *Empfindung* – which means a difference in sensation. A ΔE value of zero represents an exact match. It is the standard CIE colour difference method, and measures the distance between the two colours, calculated in 3D L*a*b* colour space. In this way, colour difference can be evaluated through measuring the tristimulus values of points over time, and calculating to evaluate the colour difference with time. This enabled the colour contrast between an engraving and a rock surface to be monitored to evaluate whether it is decreasing.

The difference between two colours, ΔE, can be evaluated using the 1976 CIE colour difference formula [3]. In CIE L*a*b* space, the difference is:

$$\Delta E^*ab = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{0.5}$$

This was used to evaluate the colour change of single points between consecutive years over which the monitoring occurred, viz.:



The instrument used for colour measurement is a portable spectrophotometer (BYK-Gardner[1]) with inbuilt spectral illuminants: CIE illuminant A, D65 and F2 (see Fig. 1 and Table 1). A CIE standard illuminant represents an aimed spectral power distribution of a theoretical real light source. For example, CIE illuminant A is a mathematical representation of tungsten halogen (incandescent), and CIE illuminant D65 is a mathematical representation of a phase of daylight, recommended by the CIE if daylight is of interest. F illuminants are similar to fluorescent light sources.

It is essential to use an artificial light source for reproducibility and determination of colour change, as the fluctuations in the natural daylight spectrum due to time of day, season and weather, means naturally illuminated measurements would be inconsistent and unreliable.

The geometry of the measuring head on the spectrophotometer is designed to exclude light on flat surfaces. However, as rock surfaces are not always flat, a collar of black fabric was used when necessary for the complete exclusion of natural light.

Figure 1: Portable spectrophotometer used for colour measurements.

[1] Spectrophotometer website: http://www.bykgardner.com/englisch/products.php?lv3=2.

Table 1: Portable spectrophotometer specifications

Repeatability	Inter-Instrument Agreement	Color System	Color Differences	Indices	Spectral Interval
0.01 ΔE, 1σ	0.02 ΔE, 1σ	CIELab/Ch; Lab(h); XYZ; Yxy; RxRyRz	ΔE; ΔE(h); ΔEFMC2; ΔE94; ΔECMC; Component differences	YIE313; YID1925; WIE313; CIE; Berger; Color strength; Opacity; Metamerism	20 nm
Observer	**Language**	**Power Supply**	**Operating Temperature**	**Illuminants**	**Spectral Range**
2º; 10º	English; German; French; Italian; Spanish; Japanese	4 AA alkaline; NiCd or MH	50 to -110 ºF (10 to -42 ºC)	A; C; D50; D55; D65; F2; F6; F7; F8; F10; F11	400 - 700 nm
Geometry	**Aperture**	**Humidity**			
45/0	4 mm	< 85% relative humidity, non-condensing / 35 ºC (95 ºF)			

1.2.1 Sampling protocol

The sites for monitoring (see Table 2) were determined by the Rock Art Management Committee, and the final decision for a representative petroglyph at each site (each site contains one or more petroglyphs) was determined in consultation with the Committee's Technical Advisor and nominated representatives of the local indigenous communities. Respecting the cultural laws of the traditional owners for the entitlement of access, the selected petroglyphs were firstly evaluated for their suitability for scientific study, including aspect (e.g. elevation and direction of exposure).

Table 2. Details of the sites for colour and spectral mineralogy measurements (site 3 is not included in this study)

Site	Site name	Coordinates (GDA 94, Zone 50)	
1	Dolphin Island	484,975	7,738,503
2	Gidley Island	482,166	7,740,857
4	Woodside	477,398	7,721,980
5	Burrup Rd	475,959	7,719,771
6	Water Tanks	477,698	7,720,137
7	Deep Gorge	477,956	7,717,987
8	King Bay South	474,082	7,717,229

Three sampling 'spots' on each selected petroglyph were identified, and in each spot two areas were monitored (i.e. six sampling points per petroglyph):

- An area classified as 'engraving' – defined by the graffito lines or pecking marks that constitute the image.
- An area classified as 'background' – a section of the adjacent rock surface unmarked by the petroglyph.

Measurements based on the average of a minimum of seven readings were recorded at each sampling point.

A sampling area was chosen on the criteria that it had relatively uniform colour over a minimum area of 20 mm, so that comparative measurements could be made with fibre optic reflectance spectroscopy, performed concurrently by CSIRO Earth Science and Resource Engineering (CESRE).

1.3 Results and Discussion

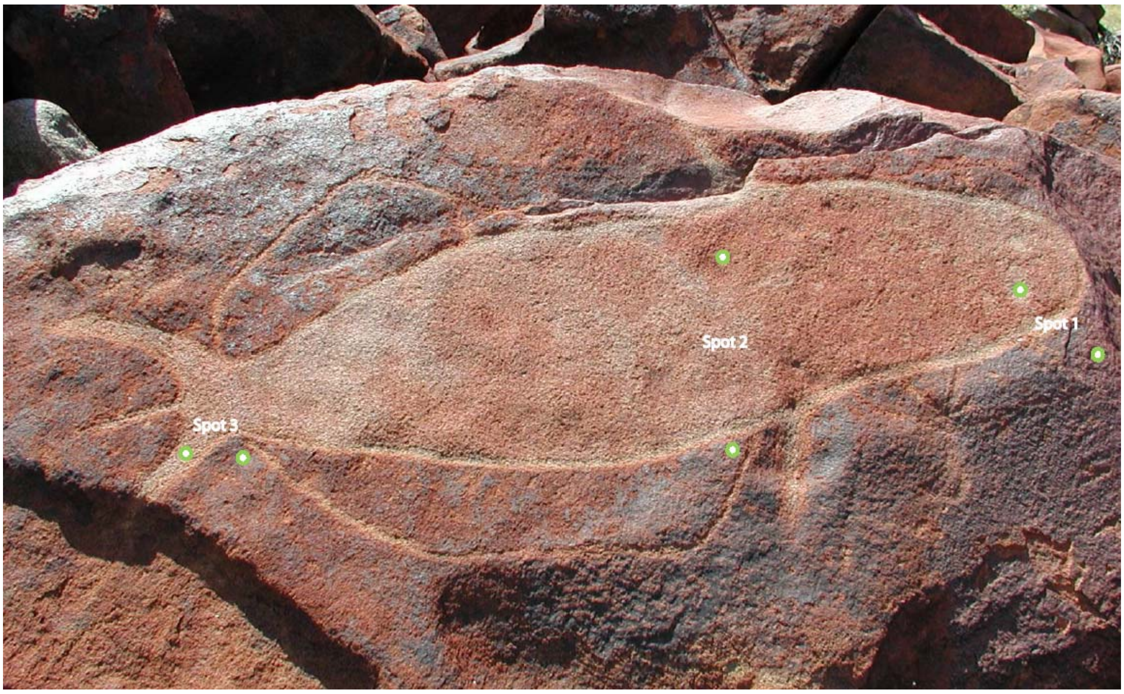
1.3.1 Year to year colour differences

The following pages present photographs of the monitored petroglyphs at each site, showing the sampling points of engravings and background rock, and the colour measurements that were recorded at these points each year.

The original intention was to take an average of seven colour measurements (L*a*b*) at each sample point. However, when in the field, it became apparent that additional measurements would be useful to statistically evaluate the variability of measurements, so for many sample points there are more than one set of average measurements.

In the second year of colour measurements, 21 independent measurements were taken at each sample point (3 times the originally intended 7 measurements), to reduce sample variance introduced by surface inhomogeneity or roughness, and by systematic error. For clarity, the raw data has not been included here, but averages of the data are presented with the colour difference measurements calculated with the standard CIE methods.

Site 1: Dolphin Island

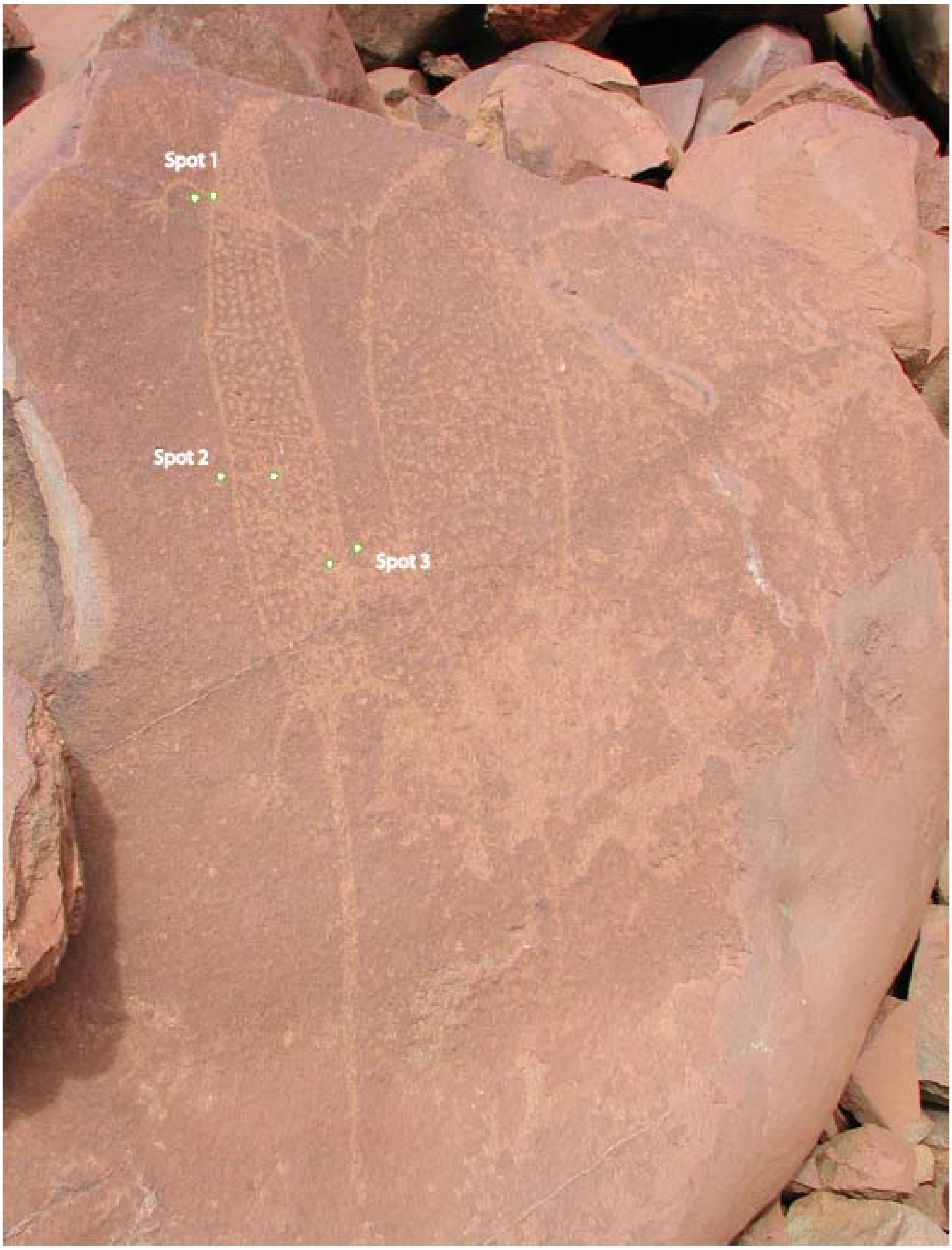


Sample	Colour scale			Colour difference* ΔE (change from previous year)
	L*	a*	b*	
Site 1 Spot 1 Engraving				
Average 2009	23.16	8.65	15.49	6.53
Average 2008	19.10	4.54	12.45	2.34
Average 2007	17.16	5.71	13.03	2.40
Average 2006	16.791	3.833	11.593	3.040
Average 2005	14.970	6.081	12.525	2.155
Average 2004	14.315	8.080	12.995	
Site 1 Spot 1 Background				
Average 2009	25.92	8.30	9.84	5.06
Average 2008	29.91	11.10	11.22	1.72
Average 2007	28.24	10.69	11.14	1.16
Average 2006	28.969	10.287	10.332	1.842
Average 2005	27.662	11.255	11.196	2.243
Average 2004	29.867	11.200	10.787	3.52
Site 1 Spot 2 Engraving				
Average 2009	10.63	8.73	10.46	5.84
Average 2008	14.96	11.17	13.53	3.52
Average 2007	12.13	9.76	11.98	4.89
Average 2006	8.372	8.216	9.257	1.838
Average 2005	7.911	9.837	9.991	0.690
Average 2004	8.427	9.620	9.587	
Site 1 Spot 2 Background				
Average 2009	32.98	12.58	14.21	7.82
Average 2008	26.35	9.51	11.43	6.11
Average 2007	20.96	7.06	9.92	8.54
Average 2006	28.819	10.210	11.064	7.881
Average 2005	20.984	9.460	11.461	6.744
Average 2004	27.657	10.350	11.870	
Site 1 Spot 3 Engraving				
Average 2009	29.66	11.14	13.26	5.43
Average 2008	32.98	11.15	17.56	6.37
Average 2007	26.72	10.16	16.94	3.60
Average 2006	23.218	10.682	16.272	3.159
Average 2005	25.669	12.246	17.506	3.024
Average 2004	28.672	12.117	17.175	
Site 1 Spot 3 Background				
Average 2009	16.66	3.83	2.99	8.07
Average 2008	15.14	7.48	10.02	4.29
Average 2007	19.09	8.97	10.76	6.43
Average 2006	13.069	7.302	9.247	2.429
Average 2005	11.449	8.754	10.328	2.437
Average 2004	13.417	7.983	9.113	

Site 2: Gidley Island

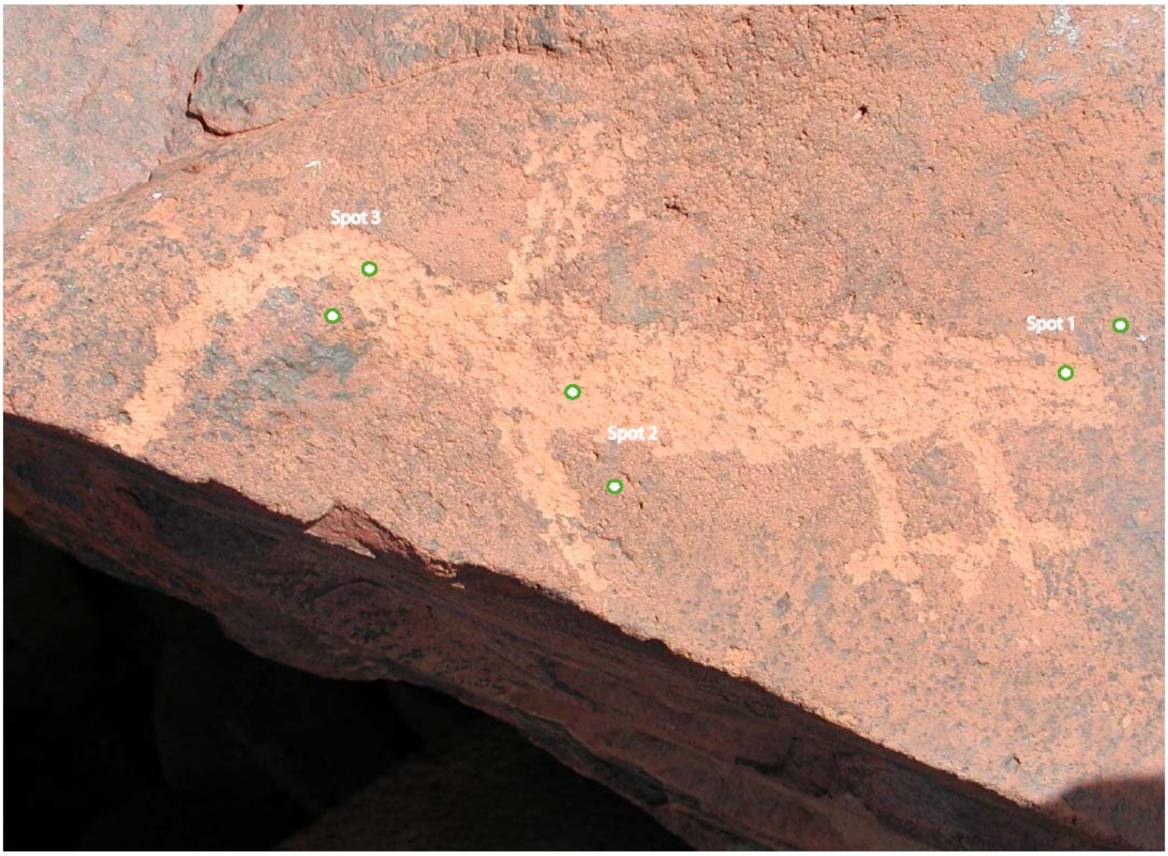
Sample	Colour scale			Colour difference* ΔE (change from previous year)
	L*	a*	b*	
Site 2 Spot 1 Engraving				
Average 2009	32.61	9.04	16.92	2.16
Average 2008	32.99	7.11	16.02	2.23
Average 2007	31.06	7.44	14.96	3.72
Average 2006	34.104	7.790	17.069	1.620
Average 2005	33.581	9.261	17.502	2.292
Average 2004	31.900	8.957	15.975	
Site 2 Spot 1 Background				
Average 2009	20.86	8.15	11.79	8.30
Average 2008	28.91	9.53	13.25	4.47
Average 2007	25.42	7.93	10.97	1.86
Average 2006	26.536	9.159	11.817	2.138
Average 2005	27.010	9.883	13.772	4.626
Average 2004	22.505	9.000	13.197	
Site 2 Spot 2 Engraving				
Average 2009	37.76	12.22	17.95	4.57
Average 2008	34.87	9.18	19.76	1.18
Average 2007	33.90	9.84	19.67	0.81
Average 2006	34.100	9.113	19.374	1.724
Average 2005	34.018	10.670	20.110	3.302
Average 2004	31.013	10.153	18.840	
Site 2 Spot 2 Background				
Average 2009	28.25	9.65	7.76	4.96
Average 2008	26.94	11.35	12.23	1.85
Average 2007	26.14	10.73	10.68	1.40
Average 2006	26.990	11.490	11.491	2.086
Average 2005	26.424	12.705	13.089	2.889
Average 2004	25.803	10.770	11.037	
Site 2 Spot 3 Engraving				
Average 2009	29.69	10.57	17.75	1.73
Average 2008	28.87	9.67	18.98	7.70
Average 2007	36.55	9.48	19.57	3.78
Average 2006	33.042	10.817	20.022	0.824
Average 2005	33.224	10.556	19.262	5.569
Average 2004	27.683	10.563	18.697	
Site 2 Spot 3 Background				
Average 2009	21.15	11.97	16.85	1.43
Average 2008	21.35	11.54	15.50	6.66
Average 2007	16.10	8.75	12.49	2.70
Average 2006	15.815	10.243	14.722	6.402
Average 2005	21.395	12.573	16.824	2.678
Average 2004	18.823	12.247	16.153	

Site 4: Woodside



Sample	Colour scale			Colour difference* ΔE (change from previous year)
	L*	a*	b*	
Site 4 Spot 1 Engraving				
Average 2009	23.68	9.59	9.95	8.75
Average 2008	25.82	13.03	17.71	0.80
Average 2007	25.59	13.62	18.20	0.64
Average 2006	25.363	13.070	17.961	2.44
Average 2005	23.266	14.259	18.341	1.17
Average 2004	22.717	13.835	17.400	
Site 4 Spot 1 Background				
Average 2009	28.57	11.86	10.62	7.40
Average 2008	21.72	10.97	13.27	2.43
Average 2007	19.29	10.98	13.27	1.55
Average 2006	20.706	11.129	13.876	2.03
Average 2005	19.219	12.502	14.019	1.12
Average 2004	20.102	12.057	13.498	
Site 4 Spot 2 Engraving				
Average 2009	23.02	9.73	9.48	6.45
Average 2008	20.38	11.12	15.20	4.42
Average 2007	16.11	10.67	14.17	1.78
Average 2006	14.474	10.110	13.720	2.25
Average 2005	14.546	11.918	15.053	1.26
Average 2004	14.560	10.857	14.375	
Site 4 Spot 2 Background				
Average 2009	28.05	10.69	10.42	5.76
Average 2008	26.04	12.48	15.51	1.96
Average 2007	24.40	12.56	14.44	3.67
Average 2006	27.783	13.465	15.515	1.65
Average 2005	26.268	13.657	16.129	0.35
Average 2004	26.523	13.902	16.106	
Site 4 Spot 3 Engraving				
Average 2009	26.03	11.03	11.87	6.51
Average 2008	24.53	12.51	18.03	5.04
Average 2007	19.69	11.91	16.76	4.84
Average 2006	24.307	12.431	18.130	2.61
Average 2005	23.421	14.489	19.478	1.83
Average 2004	22.407	13.675	18.185	
Site 4 Spot 3 Background				
Average 2009	31.64	11.83	10.81	7.28
Average 2008	25.79	12.62	15.06	2.75
Average 2007	27.83	13.88	16.41	2.02
Average 2006	28.758	13.100	14.793	4.00
Average 2005	25.298	13.833	16.654	1.99
Average 2004	26.325	13.300	15.035	

Site 5: Burrup Rd

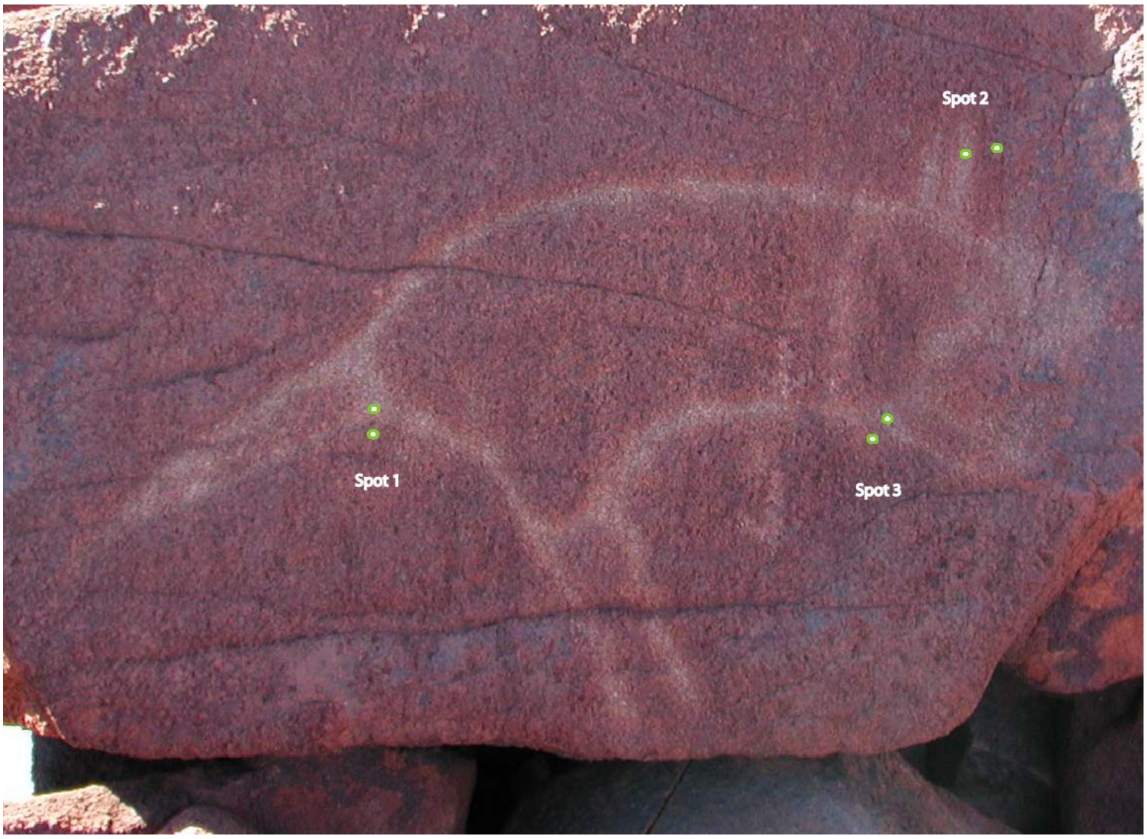


Sample	Colour scale L*	a*	b*	Colour difference* ΔE (change from previous year)
Site 5 Spot 1 Engraving				
Average 2009	30.53	14.37	14.95	5.90
Average 2008	26.73	14.82	19.44	1.84
Average 2007	27.80	15.74	20.62	6.52
Average 2006	21.817	13.581	19.187	2.327
Average 2005	22.227	15.496	20.444	4.383
Average 2004	18.897	14.243	17.883	
Site 5 Spot 1 Background				
Average 2009	32.27	10.89	10.89	7.71
Average 2008	27.57	13.69	16.32	2.04
Average 2007	29.04	13.18	15.00	3.63
Average 2006	29.526	10.882	12.221	6.280
Average 2005	27.381	14.453	16.920	5.132
Average 2004	22.937	12.893	14.883	
Site 5 Spot 2 Engraving				
Average 2009	27.07	16.05	20.08	5.60
Average 2008	22.31	13.93	18.02	2.87
Average 2007	19.47	13.54	18.22	8.99
Average 2006	27.517	16.197	21.235	4.858
Average 2005	22.761	16.798	22.020	1.682
Average 2004	22.987	16.777	20.353	
Site 5 Spot 2 Background				
Average 2009	29.61	14.65	16.28	1.23
Average 2008	29.94	13.70	15.58	1.53
Average 2007	29.02	14.63	16.37	2.33
Average 2006	27.191	13.759	15.230	3.609
Average 2005	29.526	15.277	17.526	
Average 2004		No 2004 measurements		
Site 5 Spot 3 Engraving				
Average 2009	32.41	15.64	20.83	4.53
Average 2008	34.14	18.58	23.81	3.57
Average 2007	37.22	18.98	25.58	2.97
Average 2006	35.584	17.401	23.667	7.253
Average 2005	28.452	17.505	22.352	9.243
Average 2004	36.880	20.007	25.207	
Site 5 Spot 3 Background				
Average 2009	33.38	14.61	14.44	12.40
Average 2008	21.32	11.77	14.06	7.48
Average 2007	16.96	7.26	9.99	17.27
Average 2006	32.635	13.272	14.071	6.717
Average 2005	26.136	14.016	15.598	1.000
Average 2004	25.305	13.748	15.110	

Site 6: Water Tanks

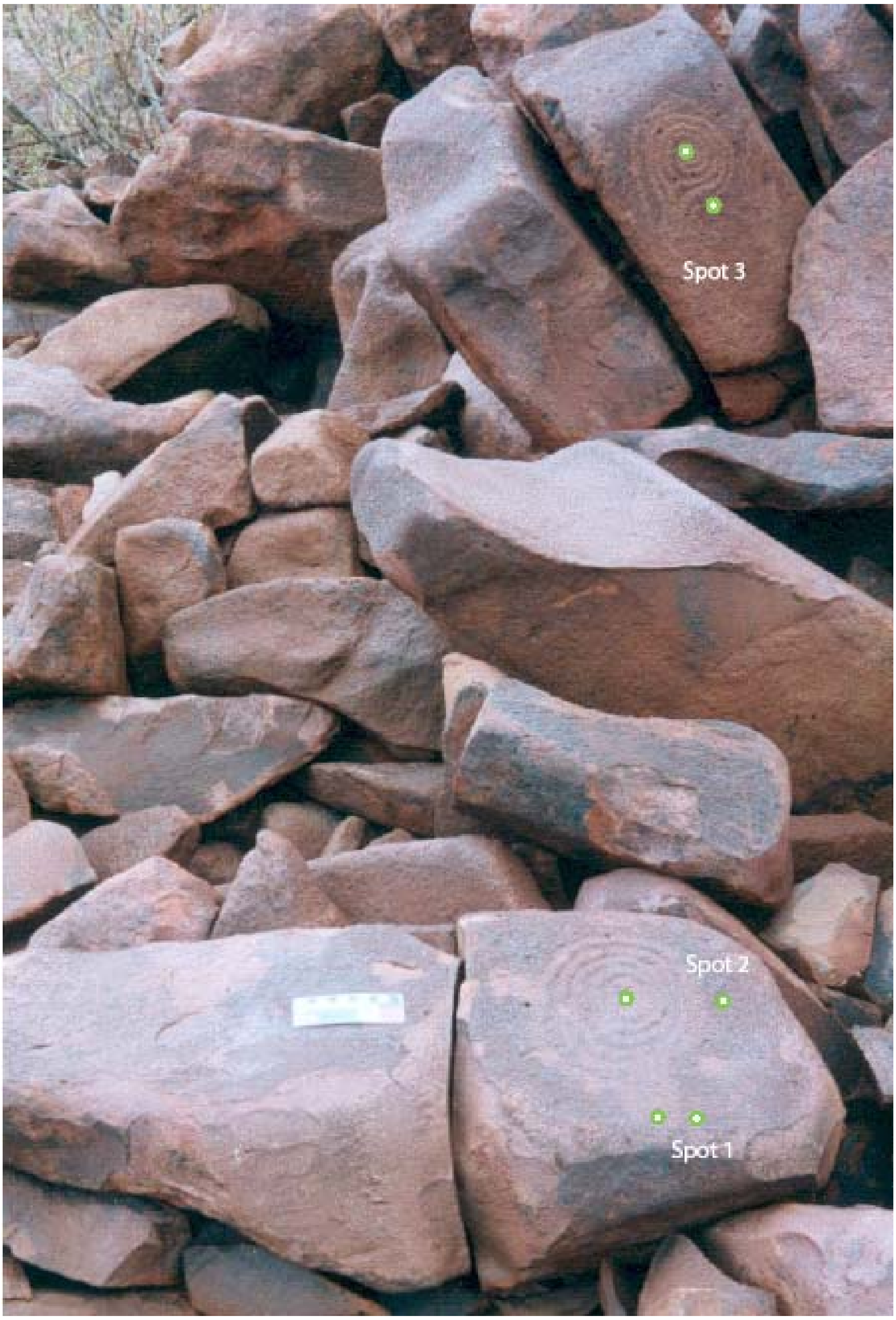
Sample	Colour scale L*	a*	b*	Colour difference* ΔE (change from previous year)
Site 6 Spot 1 Engraving				
Average 2009	36.92	9.15	16.20	2.89
Average 2008	34.15	9.73	16.80	0.39
Average 2007	34.37	9.96	17.03	2.87
Average 2006	36.833	11.279	17.686	1.281
Average 2005	35.712	11.564	18.236	5.557
Average 2004	30.200	12.270	18.250	
Site 6 Spot 1 Background				
Average 2009	32.87	11.35	16.97	3.15
Average 2008	35.94	11.71	17.55	2.16
Average 2007	36.95	13.32	18.57	0.45
Average 2006	36.891	13.761	18.506	3.020
Average 2005	34.044	12.800	18.204	2.852
Average 2004	36.865	13.220	18.245	
Site 6 Spot 2 Engraving				
Average 2009	32.77	10.83	16.95	1.96
Average 2008	34.14	9.62	16.25	1.14
Average 2007	33.69	10.43	16.91	0.71
Average 2006	33.471	11.103	16.806	2.282
Average 2005	31.249	11.241	17.305	2.534
Average 2004	33.733	11.010	16.867	
Site 6 Spot 2 Background				
Average 2009	36.32	11.73	16.12	0.90
Average 2008	36.20	12.05	16.95	1.27
Average 2007	35.20	11.95	16.18	0.79
Average 2006	35.899	11.981	15.826	1.085
Average 2005	34.858	11.901	16.122	1.724
Average 2004	35.273	13.077	17.313	
Site 6 Spot 3 Engraving				
Average 2009 *(bird droppings may interfere with measurement)*	42.59	4.52	11.28	9.74
Average 2008	35.59	9.61	15.75	1.51
Average 2007	34.18	10.03	16.08	0.86
Average 2006	33.494	10.260	15.616	2.564
Average 2005	34.969	11.453	17.340	1.536
Average 2004	36.387	11.087	16.877	
Site 6 Spot 3 Background				
Average 2009	36.35	12.40	14.14	3.08
Average 2008	36.53	12.29	17.21	2.03
Average 2007	35.56	13.65	18.37	3.81
Average 2006	36.029	11.186	15.506	3.311
Average 2005	35.594	13.396	17.932	1.455
Average 2004	36.883	12.767	17.693	

Site 7: Deep Gorge



Sample	Colour scale L*	a*	b*	Colour difference* ΔE (change from previous year)
Site 7 Spot 1 Engraving				
Average 2009	29.88	10.13	12.33	7.44
Average 2008	26.36	12.19	18.55	12.38
Average 2007	16.41	8.35	12.26	3.56
Average 2006	12.887	8.466	11.741	17.84
Average 2005	28.131	14.485	18.789	23.706
Average 2004	7.100	8.550	9.600	
Site 7 Spot 1 Background				
Average 2009	26.97	12.31	11.51	11.26
Average 2008	16.18	9.78	13.47	1.42
Average 2007	16.65	11.04	13.94	3.34
Average 2006	19.853	12.009	14.061	2.998
Average 2005	17.038	12.990	13.743	1.409
Average 2004	17.075	13.260	15.125	
Site 7 Spot 2 Engraving				
Average 2009	16.83	6.31	4.78	9.37
Average 2008	11.93	10.08	11.82	1.14
Average 2007	12.71	10.43	12.58	10.65
Average 2006	5.497	5.663	6.360	6.800
Average 2005	11.021	8.560	9.069	8.746
Average 2004	3.510	6.440	5.120	
Site 7 Spot 2 Background				
Average 2009	22.90	9.59	8.28	5.64
Average 2008	19.81	10.19	12.97	3.72
Average 2007	16.62	12.07	13.37	1.25
Average 2006	17.849	11.886	13.475	3.490
Average 2005	14.556	12.925	12.967	10.143
Average 2004	24.650	12.010	13.360	
Site 7 Spot 3 Engraving				
Average 2009	10.35	1.54	1.53	7.56
Average 2008	3.00	1.90	3.26	0.51
Average 2007	2.62	2.16	3.03	15.06
Average 2006	12.774	9.354	11.517	15.86
Average 2005	2.004	2.419	2.168	
Average 2004	No 2004 measurements			
Site 7 Spot 3 Background				
Average 2009	15.85	4.81	3.12	8.28
Average 2008	12.77	7.70	10.24	3.50
Average 2007	9.63	7.07	8.84	11.61
Average 2006	19.218	11.734	13.457	8.593
Average 2005	11.268	10.207	10.576	8.875
Average 2004	18.440	13.300	14.790	

Site 8: King Bay South



Sample	Colour scale			Colour difference* ΔE (change from previous year)
	L*	a*	b*	
Site 8 Spot 1 Engraving				
Average 2009	24.60	10.00	12.76	3.16
Average 2008	26.57	11.35	14.83	2.79
Average 2007	29.05	12.58	14.52	2.18
Average 2006	28.282	13.426	16.376	2.529
Average 2005	25.770	13.711	16.325	5.591
Average 2004	31.260	14.748	16.120	
Site 8 Spot 1 Background				
Average 2009	29.34	11.67	11.67	0.91
Average 2008	29.92	11.55	12.36	0.88
Average 2007	29.10	11.46	12.04	2.78
Average 2006	26.481	10.545	12.129	2.538
Average 2005	27.101	12.558	13.544	1.305
Average 2004	27.412	11.905	12.457	
Site 8 Spot 2 Engraved				
Average 2009	21.72	11.25	13.16	0.88
Average 2008	21.89	10.90	13.95	3.44
Average 2007	24.74	12.68	14.67	7.81
Average 2006	17.800	9.770	12.591	10.323
Average 2005	27.283	13.235	14.744	6.389
Average 2004	20.940	12.580	14.337	
Site 8 Spot 2 Background				
Average 2009	26.27	9.90	11.87	1.30
Average 2008	27.22	10.60	12.42	1.03
Average 2007	26.40	11.17	12.17	1.13
Average 2006	25.809	10.272	11.829	2.566
Average 2005	23.693	11.525	12.561	2.213
Average 2004	25.867	11.687	12.180	
Site 8 Spot 3 Engraved				
Average 2009	23.13	12.46	16.79	1.95
Average 2008	21.31	11.85	17.11	0.66
Average 2007	20.69	11.97	16.92	2.31
Average 2006	22.845	12.463	17.591	6.205
Average 2005	16.794	12.227	16.237	5.260
Average 2004	21.715	13.400	17.680	
Site 8 Spot 3 Background				
Average 2009	21.24	13.06	16.51	5.50
Average 2008	26.73	13.08	16.21	5.03
Average 2007	22.36	11.92	14.01	1.47
Average 2006	22.568	12.529	15.330	1.618
Average 2005	24.033	13.194	15.497	3.192
Average 2004	26.977	13.087	14.267	

The averaged colour change for each site is presented in Table 3, which is an overall average for each of the six spots measured on a petroglyph. The colour change average for southern sites for the first period (2004–05) was higher than the second period (2005–06), and was originally believed to be a consequence of improved experimental measurement practice. However, the colour change average for the period 2006–07 increased again, which suggests this represents the actual degree of experimental error.

Table 3: Averaged colour change for each site

Site	Averaged site-specific colour change					
	ΔE 08–09	**ΔE 07–08**	**ΔE 06–07**	**ΔE 05–06**	**ΔE 04–05**	**ΔE 04–09**
4	7.02	2.9	2.42	1.89	1.29	8.14
5	6.23	3.2	6.95	4.77	4.29	8.46
6	2.39	1.4	1.58	2.43	2.61	4.93
7	8.26	3.8	7.58	6.10	10.58	13.49
8	2.28	2.3	2.95	4.14	3.99	3.80
Overall southern sites average	**5.24**					
1	6.46	4.1	4.50	3.12	2.97	5.87
2	3.86	4.0	2.38	3.01	3.56	3.25
Overall northern sites average	**5.16**					

The six consecutive years of colour change measurements have allowed an examination of whether any trends are apparent at the sites, either individually or as a group, and whether the colour change measurements at the southern test sites are consistently or significantly different to those at the northern control sites.

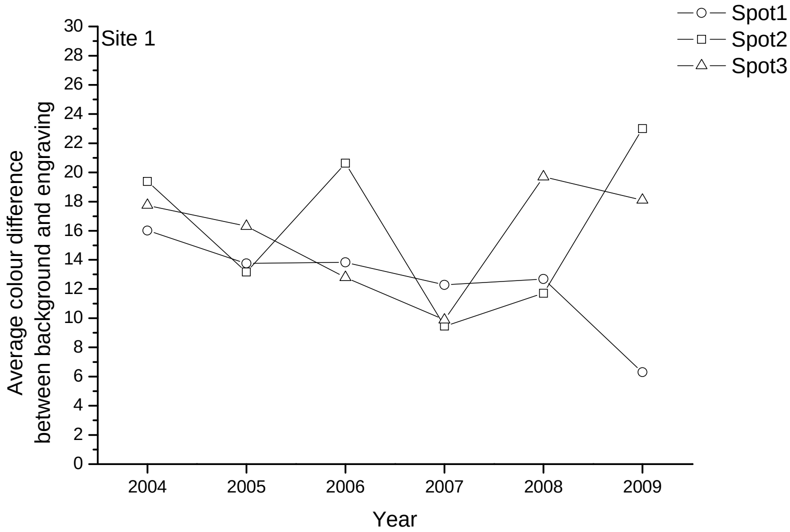
Considering the year to year ΔE values for 2004–09, which indicates the colour change over the five-year interval from 2004 to 2009, site 7 displayed the greatest year to year colour change, and this was consistent with the 2004–09 interval. For sites 4, 6 and 8 (southern), the colour change values for the interval 2004–07 were lower than northern sites 1 and 2. Considering the northern sites as the control sites, and the southern sites as test sites, they are not considered to be substantively different.

Where the colour difference appeared to have larger values overall (sites 5 and 7), this is believed to be partially due to the surface roughness of the rock, which influenced the placement of the spectrophotometer. At site 5, spot 3 there is a large patch of black patina which means that colour measurement is much more dependent on instrument placement at that spot. The site with the smoothest rock face (site 6), however, did not record the lowest colour change values so measurement repeatability is therefore dependent on more than just surface roughness. Site 4, which has relatively moderate surface roughness, recorded the lowest colour change value. This suggests that an additional factor such as sample area colour inhomogeneity is also responsible for influencing the spread of individual colour measurements. The overall average colour change measurements for Site 7 were calculated with the omission of 2004 values for spots 1 & 2 engraved since the consistent values for subsequent years suggest 2004 measurements for those points were anomalous.

1.3.2 Background – engraving colour difference

Table 4: Colour difference between background and petroglyph

Spot 1	**Site 1**	**Site 2**	**Site 4**	**Site 5**	**Site 6**	**Site 7**	**Site 8**
Average 2009	6.3	12.9	5.4	5.6	4.7	3.7	5.1
Average 2008	12.7	5.5	6.4	3.4	2.8	11.6	4.2
Average 2007	12.3	6.9	8.4	6.3	4.5	3.2	2.7
Average 2006	13.8	9.3	6.5	10.7	2.6	8.2	5.4
Average 2005	13.8	7.6	6.2	6.3	2.1	12.3	3.3
Average 2004	16.0	9.8	5.0	5.2	6.7	12.3	6.0
Spot 2							
Average 2009	23.0	14.2	5.2	4.8	3.8	7.7	4.9
Average 2008	11.7	11.1	5.8	8.0	3.3	8.0	5.6
Average 2007	9.5	11.9	8.5	9.8	2.3	4.3	3.4
Average 2006	20.6	10.9	13.8	6.5	2.8	15.6	8.1
Average 2005	13.2	10.5	11.9	8.3	3.9	6.8	4.5
Average 2004	19.4	9.4	12.5		2.6	23.4	5.5
Spot 3							
Average 2009	18.1	8.7	5.8	6.5	10.4	6.6	2.0
Average 2008	19.7	8.5	3.2	17.5	3.2	13.3	5.6
Average 2007	9.9	21.7	8.4	28.1	4.5	10.3	3.4
Average 2006	12.8	18.0	5.6	10.9	2.7	7.1	2.3
Average 2005	16.3	12.2	3.5	7.9	2.1	14.7	7.3
Average 2004	17.7	9.4	5.0	16.6	1.9		6.3


Site 1
Spot1
Spot2
Spot3
Average colour difference between background and engraving
Year
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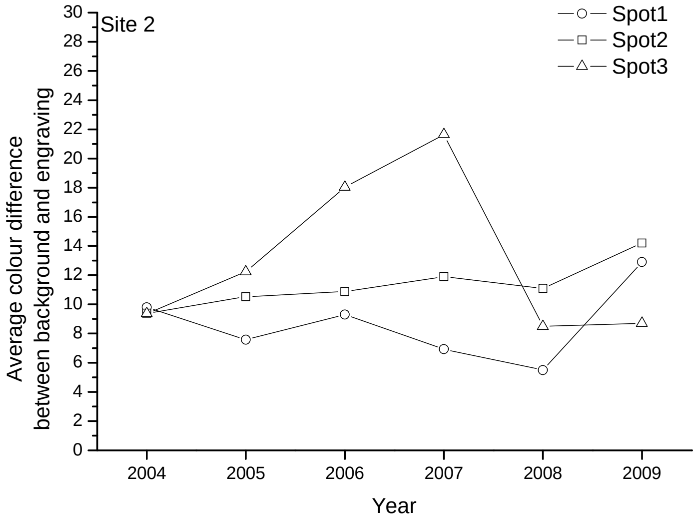
2005
2006
2007
2008
2009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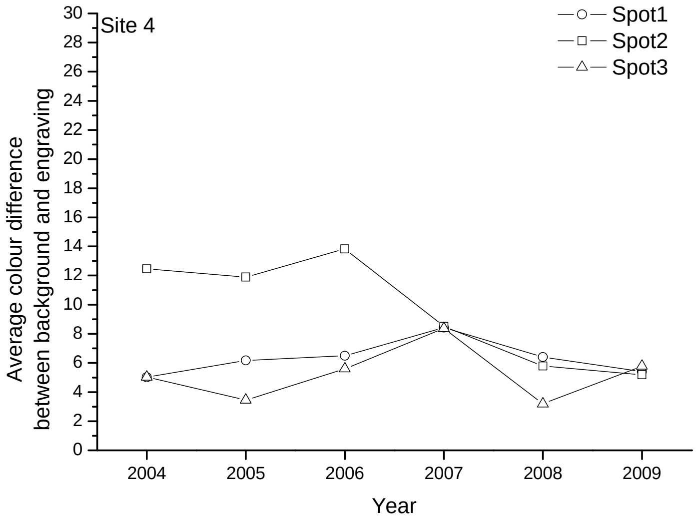
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Average colour difference between background and engraving
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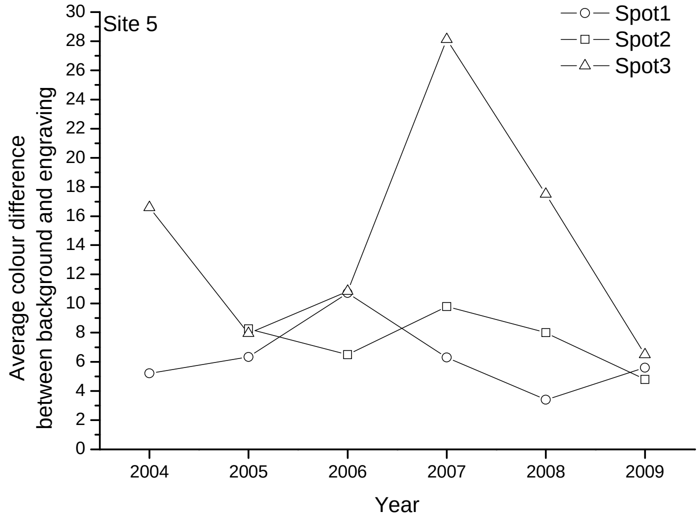
2008
2009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Spot3
Average colour difference between background and engraving
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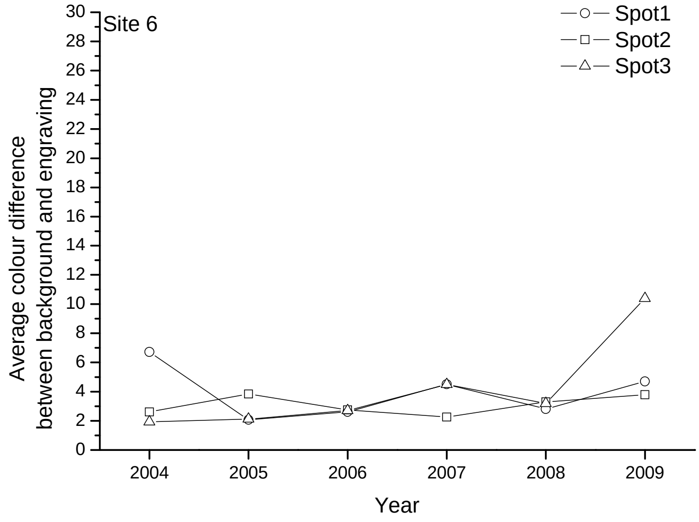
2004
2005
2006
2007
2008
2009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Average colour difference between background and engraving
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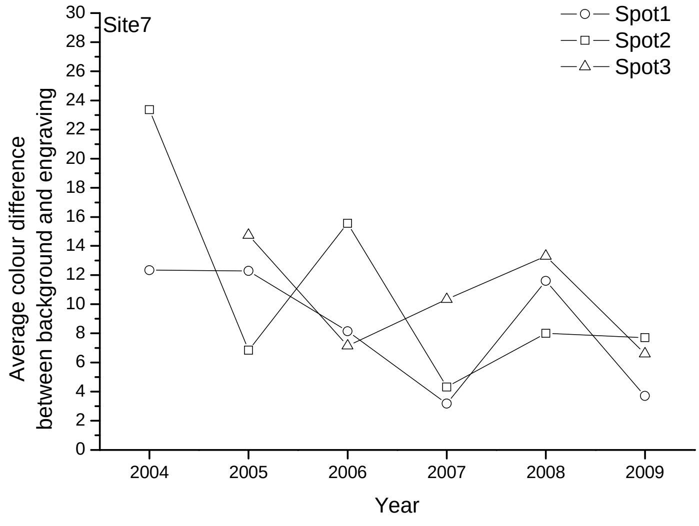
2005
2006
2007
2008
2009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Spot2
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Average colour difference between background and engraving
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2004
2005
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2009

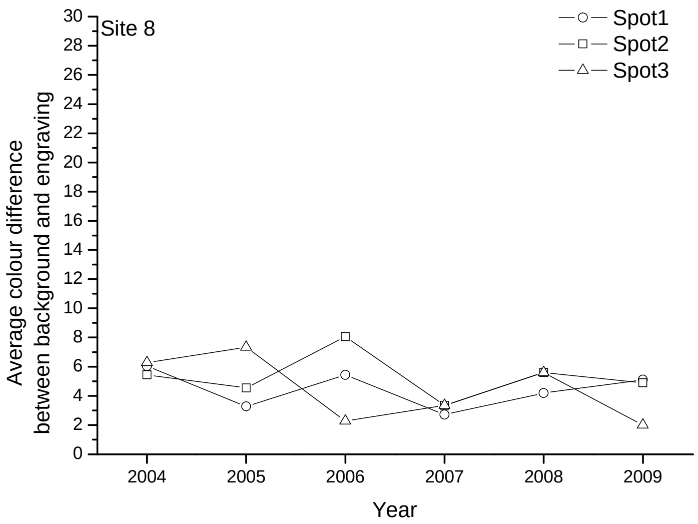

Figure 2: Site specific plots of colour differences between engraving and background for each spot examined (2004–2008). Site 5 spot 3 and Site 7 spot 2 are believed to exhibit high variance due to aberrant measurement effects.

The colour difference between the background and petroglyph for each spot is presented in Table 4 and plotted in Figure 8. The two data absences in the table are because no data was collected for site 5 spot 2 background, and site 7 spot 3 engraving. The colour difference between the background and petroglyph is an indication of the colour contrast, and to some extent, the "readability" of the petroglyph. The readability is also provided by the depth of the image engraving and texture of the image lines. Colour difference was generally lowest at Sites 6 and 8 corresponding with visual observations.

The unusually large colour difference observation for site 5, spot 3 in 2007 (also observed in the L*a*b* measurements) is believed to be due to spectrophotometer placement as discussed previously. The sample location in that region has a large patch of black patina which means that colour measurement is much more dependent on the instrument location at that spot. The patch of black patina could also account for the greater overall year to year variance observed at spot 3, compared to spot1 1 and 2 for the same petroglyph.

Over time, a consistent trend toward smaller colour differences would indicate either background fading or darkening of the petroglyph, or both. Sites 6 and 8 exhibit the least colour contrast between the petroglyph and background, with generally lower colour difference values.

Spot 2 at site 1 has increased colour change while spots 1 and 3 are following a general trend toward decreased or unchanged colour difference. Spot 1 at site 7 exhibited a trend toward less difference over 2004-07, but this was not considered an indicator of overall colour change as it was not observed in spots 2 and 3 at the same site.

Examination of the trend in 2009 provides further evidence this trend was attributable to measurement variance. Spots1 and 3 at site 1 also exhibited a consistent trend toward smaller differences between the background and petroglyph over the 3 years; this was not observed in spot 2 at the same site. The trend toward smaller colour differences overall in site 7 occurs in spots 1 and 3, but not as markedly as in spot 2. In the colour change report that includes data collected in 2010, the data will be represented against a line of best fit to indicate the overall trend.

1.4 Conclusions

The measurements made in August 2009 continue on from the collection of the first set of annual ΔE colour measurements. Together, they provide an opportunity to observe whether any consistent trends have emerged in the annual colour change measurements. Variance in the data at some sample spots continue to suggest measurements are influenced by surface roughness (which affects spectrophotometer placement), and surface colour inhomogeneity.

Site averaged colour change values at the southern sites were not consistently different to those at the northern control sites, with two slightly higher, two slightly lower and one comparable to the controls. Therefore the current indication is there was no consistent perceptible increase in colour change over the 2004–09 period.

Comparisons of the difference in colour between the engraving and the immediate background indicate the observable contrast. A consistent trend towards decreased colour contrast has not been observed in all 3 spots measured on any of the petroglyphs.

The colour measurements collected thus far may be used as a baseline measurement against which to compare future measurements in the short or long term, and are a valuable and independent evaluation of changes in rock surface colouration on the Burrup Peninsula. The continued annual colour change measurements into the future will provide further opportunity to observe whether there is any evidence of colour change.

1.5 References

[1] Mirmehdi, M.; Chalmers, A.; Barham, L; Griffiths, L., Automated analysis of environmental degradation of paint residues, *Journal of Archaeological Science*, 2001, **28**(12), 1329–1338.

[2] Mirti, P.; Davit, P., New developments in the study of ancient pottery by colour measurement, *Journal of Archaeological Science*, 2004, **31**(6), 741–751.

2. SPECTRAL MINERALOGY

2.1 Introduction

For the last 6 years (2004 to 2009 - Ramanaidou and Caccetta, 2005; Ramanaidou and Wells 2006; Ramanaidou *et al*., 2007; Ramanaidou, et al., 2009a; Ramanaidou et al., 2009b), the petroglyphs at 7 specially selected sites in the Burrup Peninsula (Western Australia) were measured using reflectance spectroscopy. Three spots on each engraving and 3 spots on each background rock were measured *in situ* using an ASD spectrometer. The forty two spectral measurements were co-located with the colour measurements acquired simultaneously by Deborah Lau. For each engraving and background spot, seven spectra were acquired and averaged. The spectral variation for each spot (both engraving and background) was also assessed. The colour values calculated by Deborah were crosschecked to the colour value calculated by the ASD spectrometer.

The 2004 spectral study (Ramanaidou and Caccetta, 2005) is the baseline dataset that has being used to monitor potential variation that occurred in the last 6 years. The six-year study (2004-2009) has assessed the mineralogy, monitored and explained the mineralogical changes (if any) of seven rock art sites in the Burrup Peninsula.

The Burrup Peninsula

A satellite Image (Landsat) of the Burrup Peninsula (Figure 1) provides an overview of the area in which the seven sites are located for this study. The exact coordinates are shown in Table 1.

Figure 3. Landsat Image of the Burrup Peninsula.

Site number	Site Name	Coordinates (GDA 94, Zone 50)	
Site 1	Dolphin	484,975	7,738,503
Site 2	Gidley	482,166	7,740,857
Site 4	Woodside	477,398	7,721,980
Site 5	Burrup road	475,959	7,719,771
Site 6	WaterTanks	477,698	7,720,137
Site 7	Deep Gorge	477,956	7,717,987
Site 8	King Bay South	474,082	7,717,229

Table 5. Coordinates of the 7 measured sites.

2.1.1 Reflectance spectroscopy

Reflectance spectroscopy is now available as a field tool for geologists through the development of portable instruments like the Analytical Spectral Device (ASD) FieldSpecPro field spectrometer. These systems measure diagnostic mineral spectral features that are particularly suitable for quantitative analysis of many geological materials. Some of the advantages of the technique include little sample preparation (if any), and rapid measurement (around 1 s) though the measurement is restricted to the sample's surface (< 50 µm).

CSIRO has been involved in the development of reflectance spectroscopy research (Ramanaidou and Cudahy, 1995; Ramanaidou and Pal, 1998; Ramanaidou et al., 2002; Ramanaidou et al., 2008) techniques for characterising iron ore, gold, bauxites, mineral sands, talc, lateritic nickel and asbestos. Using field reflectance spectrometry, the mineralogy of the samples can be characterised on the basis of key spectral features.

Reflectance spectroscopy, the analysis of reflected light, between 400 and 2500 nm is now a proven technique for mineral analysis in both the laboratory and in the field. Reflectance spectroscopy has been used intensely to characterise weathering minerals such as iron oxides and clay minerals. The most common iron oxides minerals (hematite, maghemite and goethite) have broad absorptions between 400 and 1000 nm (visible and near infrared or VNIR), whereas OH-bearing minerals such as phyllosilicates, inosilicates as well as carbonates and sulphates show narrow absorption features between 1000 to 2500 nm (short wave infrared or SWIR). The combination of these wavelength ranges provides a step forward towards quick and accurate mineral characterisation.

The Analytical Spectral Device (ASD) FieldSpec Pro covers the spectral range 400-2500 nm with a spectral resolution of 3 nm at 700 nm using 3 detectors: a 512 element Si photodiode array for the 400-1000 nm range and two separate, TE cooled, graded index InGaAs photodiodes for the 1000-2500 nm range. The input is through a1.4 m fiber optic. The average scanning time to acquire a spectrum is 1 second. There are two ways of operating the ASD, it consists of either using (1) an external source of light (sun or artificial) or (2) an internal source of light. The absolute measurements are obtained using a white reference plate that reflects 100% of the light in the 400 to 2500 nm wavelength range. For this study, the second option for lighting was used as it eliminates any external light interference.

2.2 Spectral Mineralogy for 2004-2009

For each site, the description and interpretation include:

- A digital image of the engraving with the location of the measurements (spot 1, 2 and 3 for both engraving and background).
- Comparison of the average spectra for the engravings and background for each of the three spots between 2004 and 2009.

Figure 4. ASD fieldSpec Pro operating on petroglyphs in the Burrup Peninsula

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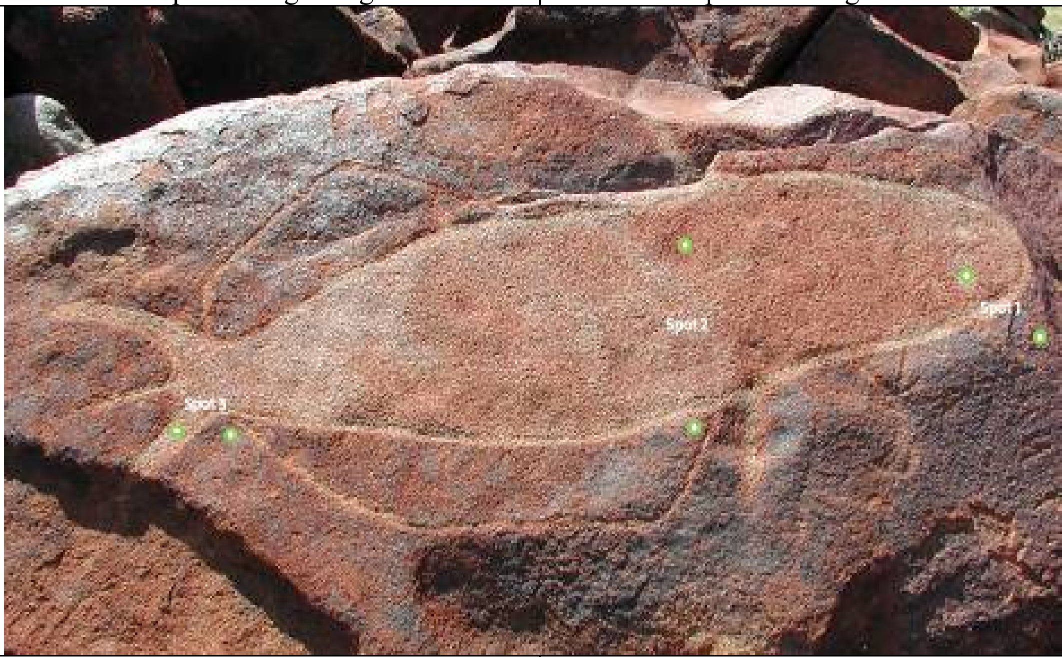
<tr><td>Site 1</td><td colspan="2">
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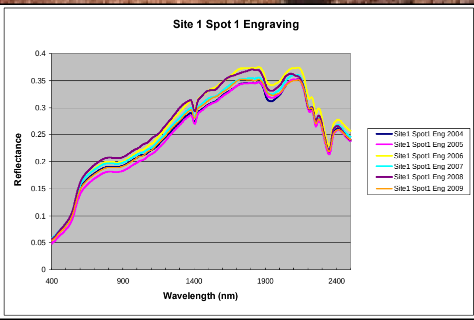
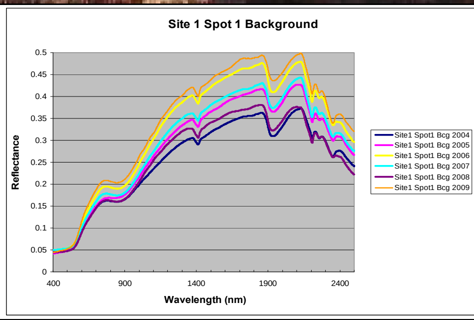
Spot 1</td><td>
</td><td>
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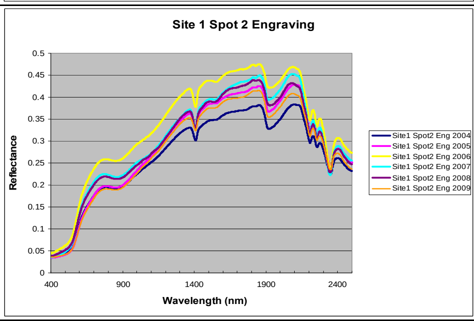
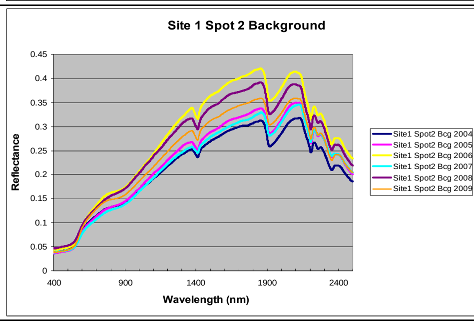
Spot 2</td><td>
</td><td>
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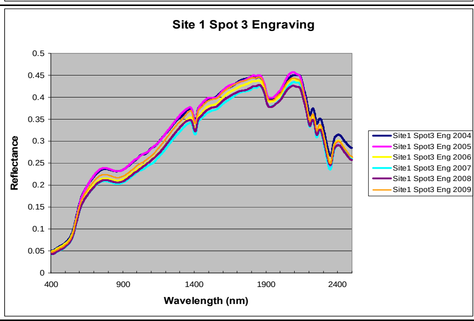
Spot 3</td><td>
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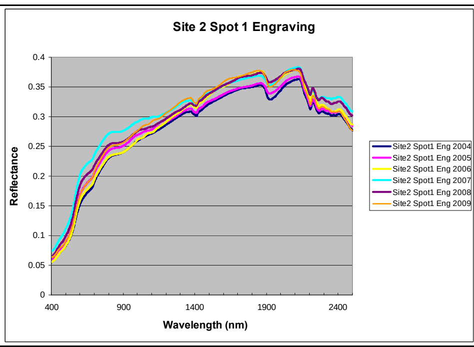
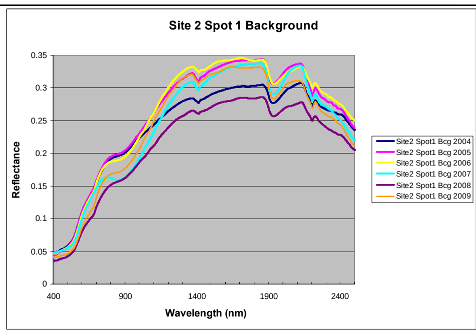
Spot 1</td><td>
</td><td>
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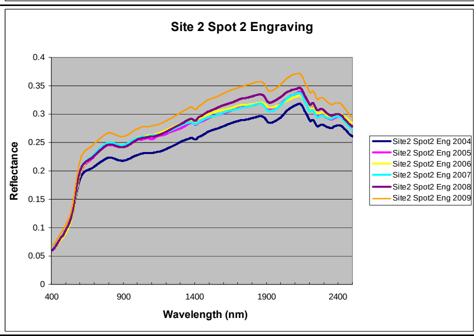
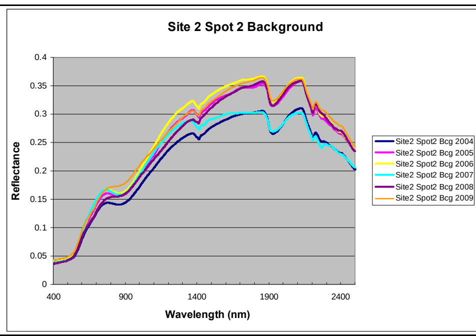
Spot 2</td><td>
</td><td>
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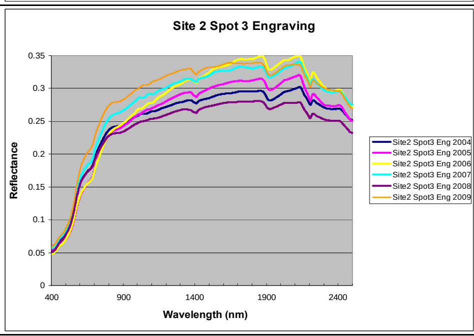
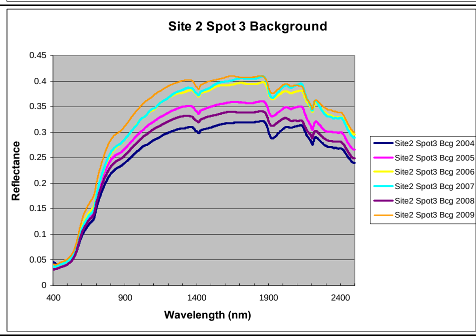
Spot 3</td><td>
</td><td>
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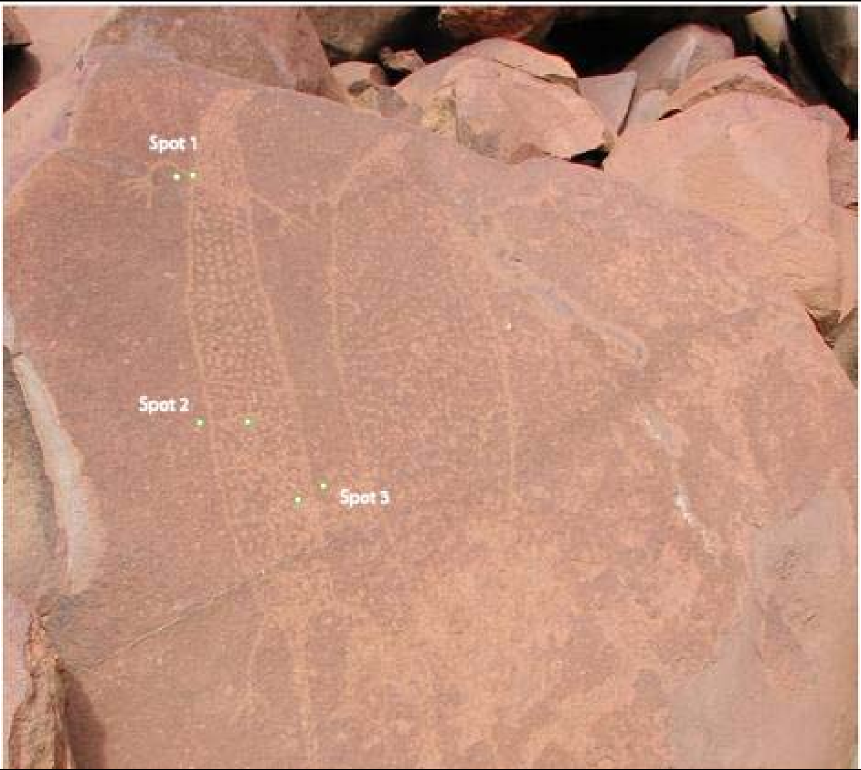
<tr><td>Site 4</td><td colspan="2">
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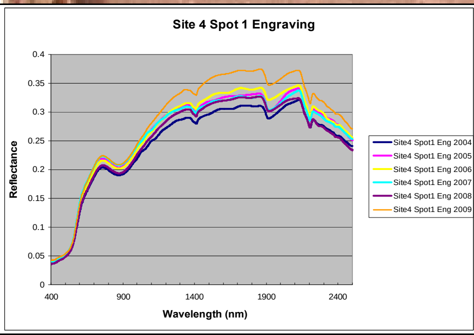
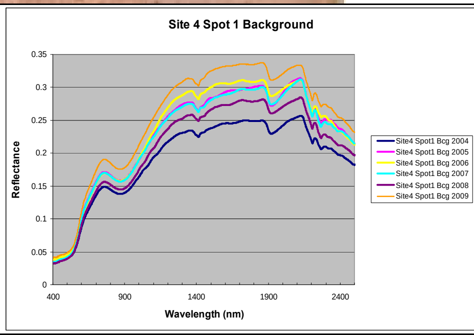
Spot 1</td><td>
</td><td>
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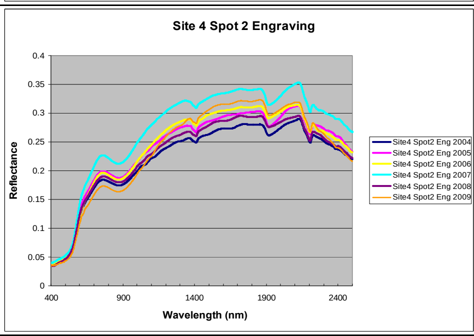
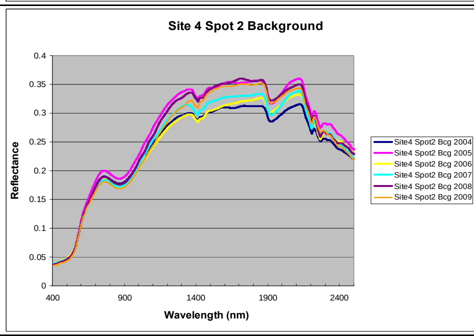
Spot 2</td><td>
</td><td>
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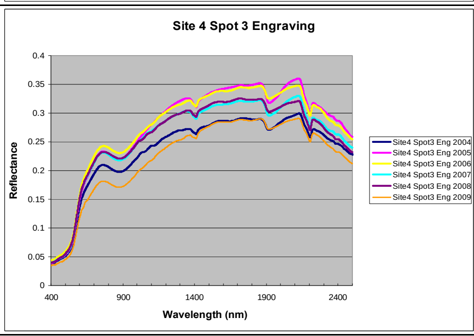
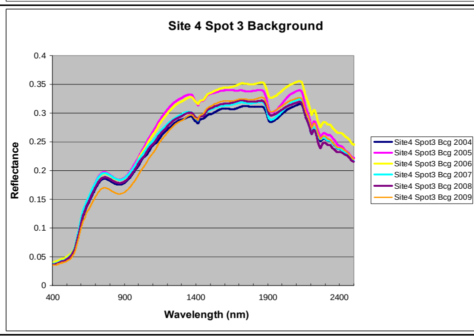
Spot 3</td><td>
</td><td>
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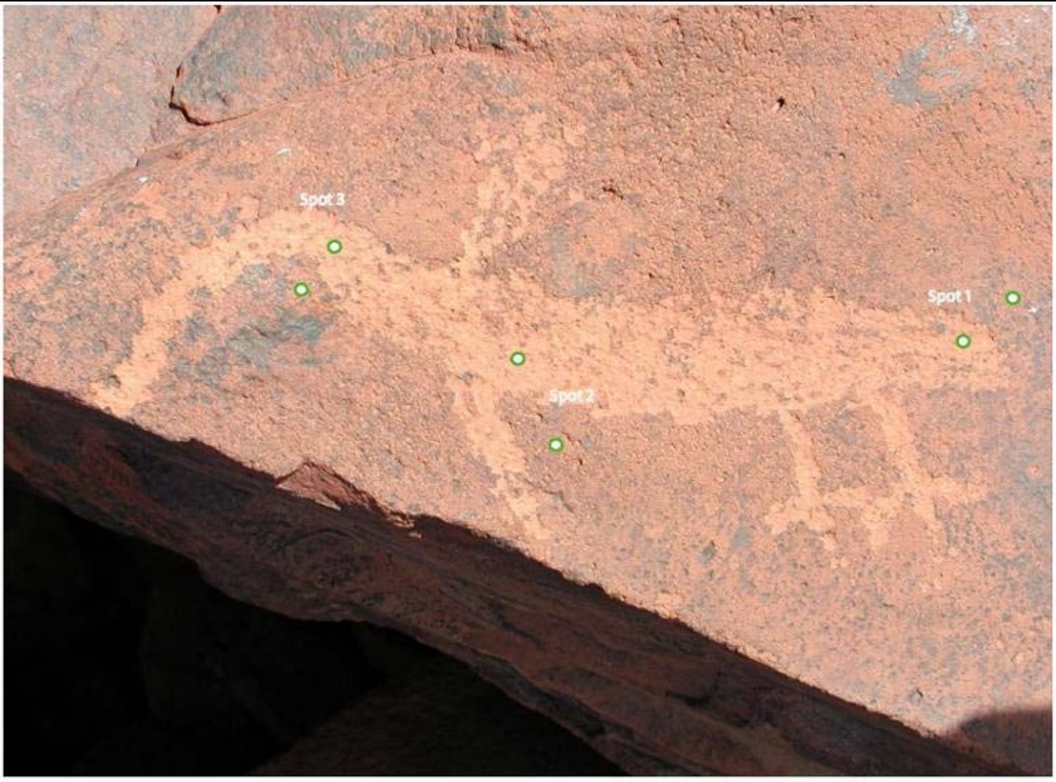

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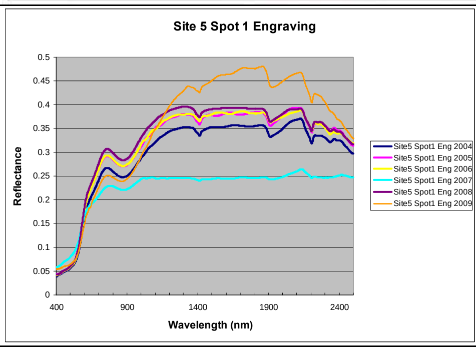

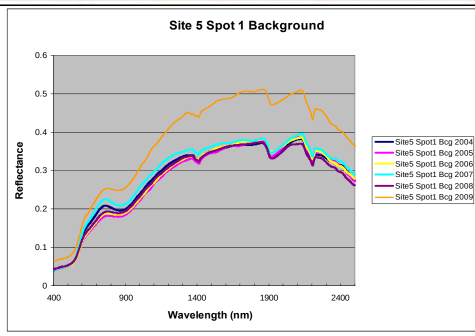

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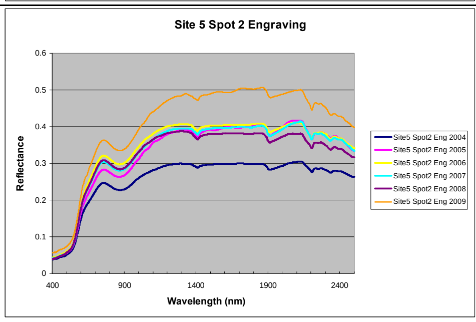

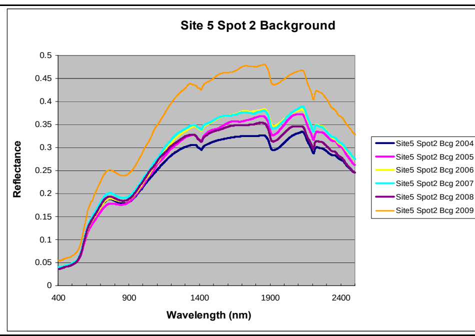

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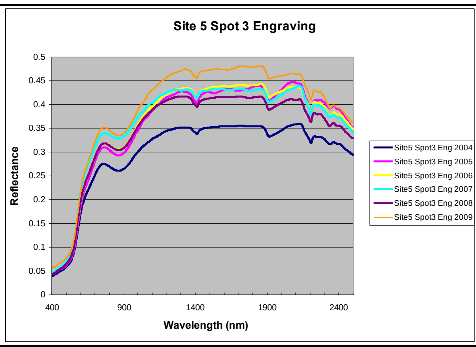

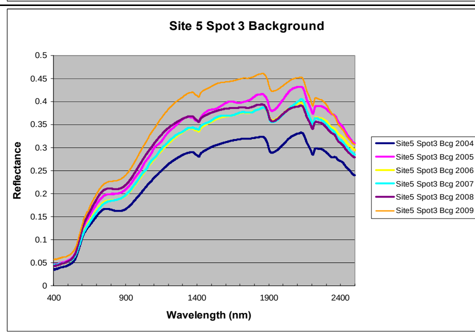

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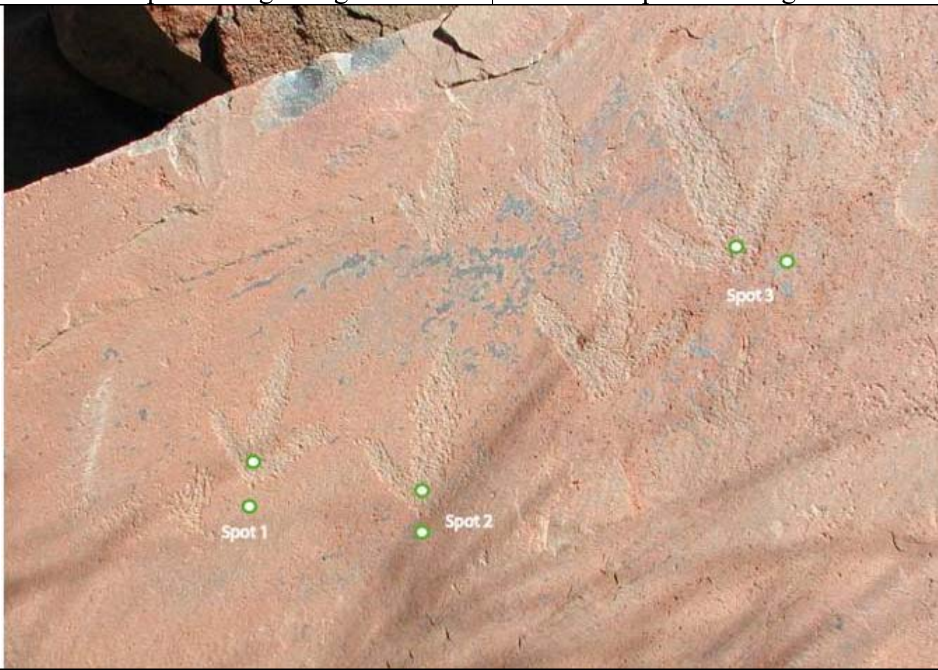
<tr><td></td><td colspan="2">
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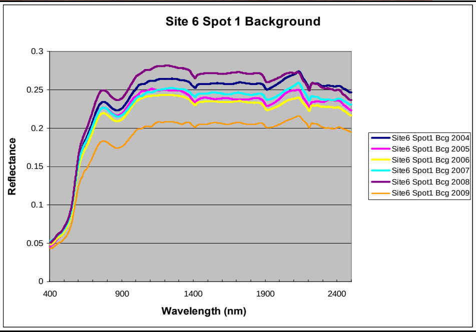
</td><td>
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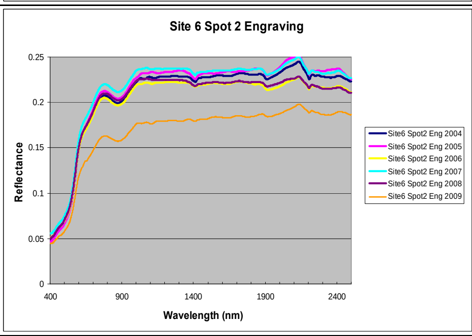
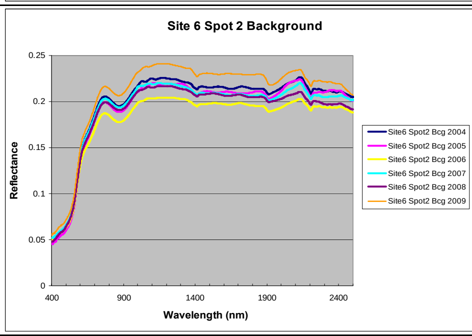
Spot 2</td><td>
</td><td>
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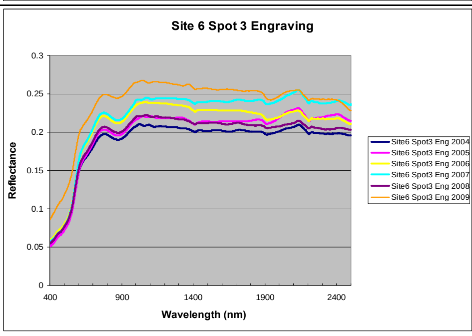
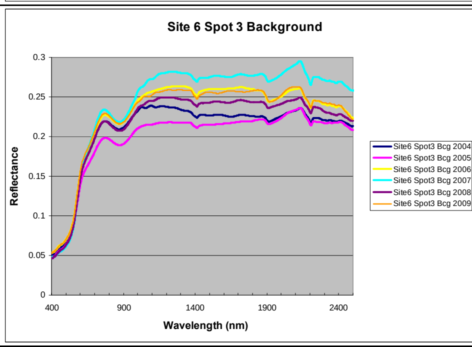
Spot 3</td><td>
</td><td>
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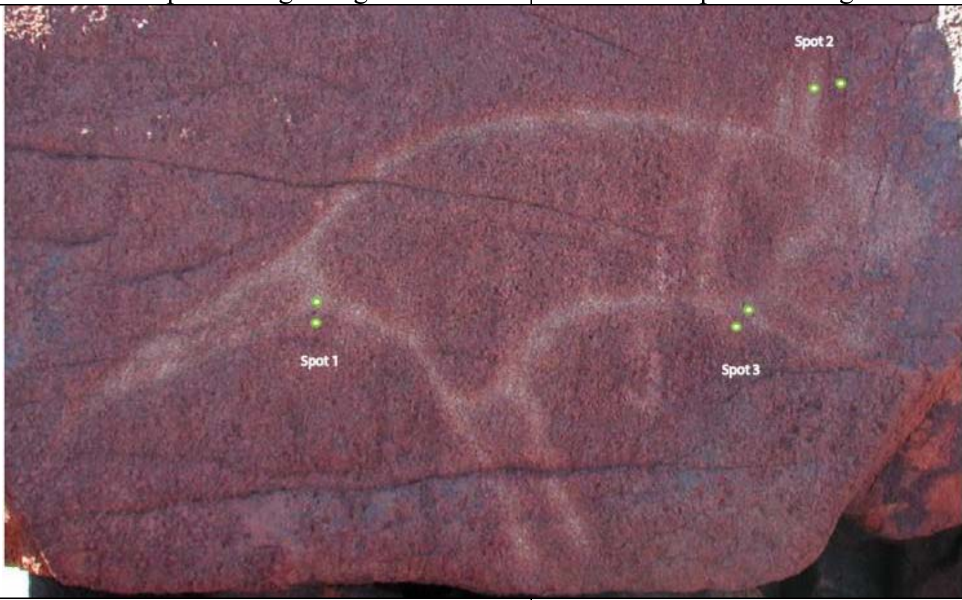
<tr><td></td><td colspan="2">
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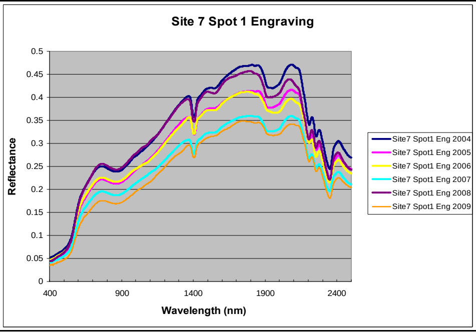
Spot 1</td><td>
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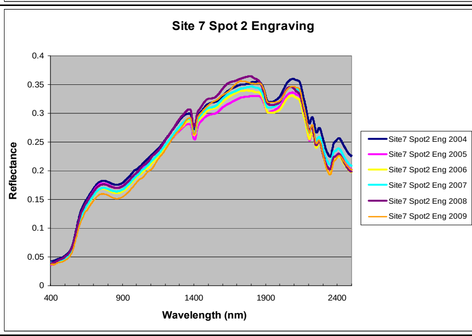
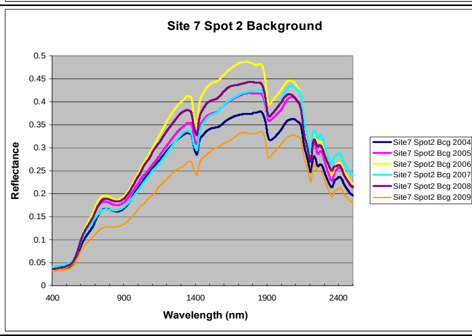
Spot 2</td><td>
</td><td>
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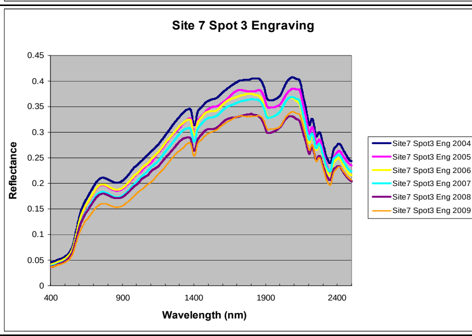
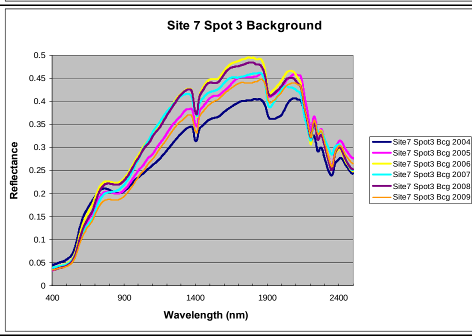
Spot 3</td><td>
</td><td>
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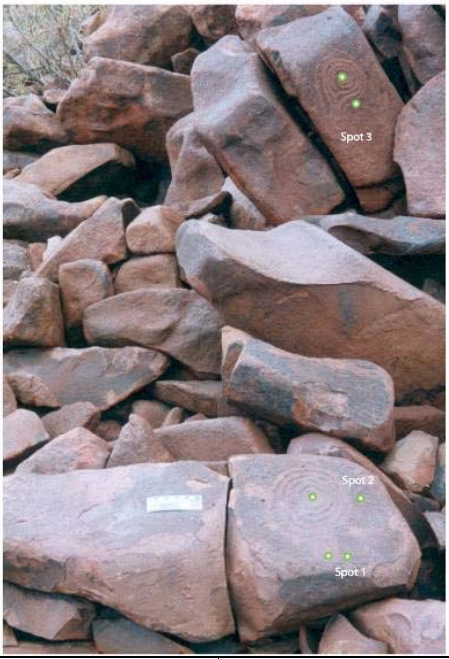
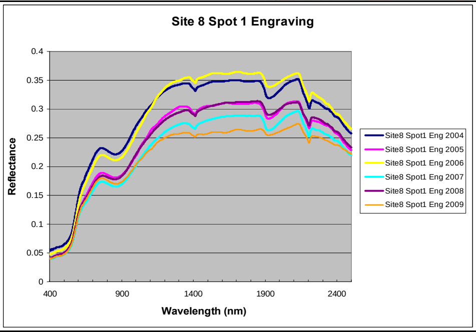
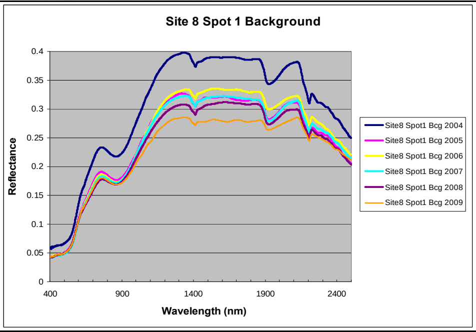
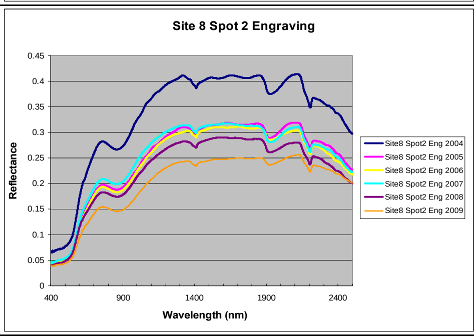
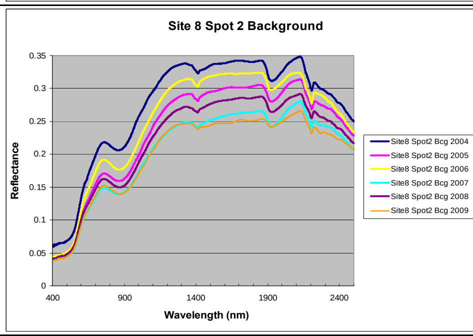
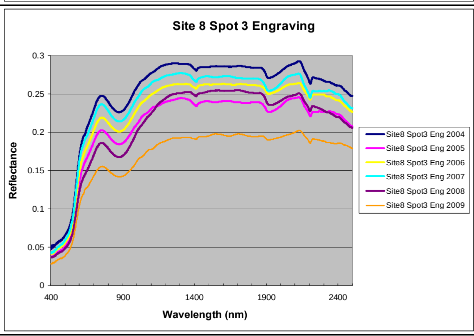
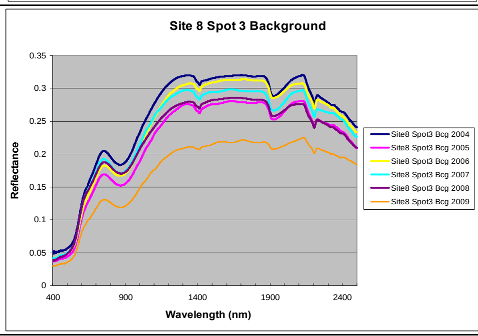
Location	Spectra Engraving	Spectra Background
Site 8		
Site 8 Spot 1		
Site 8 Spot 2		
Site 8 Spot 3		

Mineralogically related absorptions are unchanged since 2004. Only brightness (or reflectance) varies from year to year.

2.3 Conclusion of 2004-2009 spectral reflectance study

The petroglyphs at 7 sites in the Burrup Peninsula were measured from 2004 to 2009 using reflectance spectroscopy covering the visible to shortwave infrared wavelength range (400 – 2500 nm). The same engravings and background rocks were measured *in situ*. Forty two spectral measurements were acquired for each site with the ASD spectrometer (own light source) at the same sampling locations for both the engravings and the surrounding undisturbed background rocks. The seven spectra acquired for each spot were averaged to derive a single spectrum in each case.

The spectra of engravings were different from those of background and the mineralogy detected included hematite, poorly ordered kaolinite and chlorite. Some goethite and manganese oxides were also recorded.

The mineralogy of the rock for the last six years has not changed, the absorption features are similar to those first found in 2004. These minerals include:

- Hematite
- Poorly ordered kaolinite
- Chlorite
- Minor goethite
- Minor manganese oxides

For the 2004 to 2009 period, it was noticed that the brightness (or amount of reflected light) of the rocks have changed; sometimes brighter, sometimes darker. This behaviour was observed in the visible (380 to 750 nm) and in the near infrared (>750 nm). These changes are explained by a variation in moisture content (Ramanaidou et al., 2009b).

2.4 References

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