Burrup Peninsula Aboriginal Petroglyphs: Colour Change and Spectral Mineralogy 2004–2007

D. Lau[†], E. Ramanaidou[‡], S. Furman[†], A. Hacket[‡], M. Caccetta[‡], M. Wells[‡] & B. McDonald[‡]

[†] *CSIRO Materials Science and Engineering, Clayton, Victoria*
[‡] *CSIRO Exploration and Mining, Kensington, West Australia*

September 2008

Copyright and Disclaimer

Important Disclaimer

Contents

SUMMARY

In 2004, the West Australian Burrup Rock Art Management Committee commissioned a number of independent scientific studies to evaluate the petroglyphs in the Burrup Peninsula near Karratha (Western Australia). These studies are evaluating the physico-chemical aspects of the effect of possible environmental modification on the appearance of the petroglyphs. Non-destructive testing strategies were employed in the research approach to conform to the cultural significance of the sites.

This paper reports the colour change and the spectral mineralogy monitoring at each of the sites to evaluate whether changes in colour and mineralogy are observed on rock surfaces. For the last 4 years (2004 to 2007), the petroglyphs at seven specially selected sites in the Burrup Peninsula were measured. Three spots on each engraving and three spots on each background rock were measured *in situ* using a portable BYK-Gardner spectrophotometer for the colour and an ASD spectrometer for the mineralogy. These instruments use artificial light source for reproducibility and determination of the spectra. Both methods use reflectance spectroscopy (at different wavelength range) which is a non destructive, *in situ* materials characterisation technique that provides information about the colour and mineralogy.

For each engraving and background spot, multiple spectra were acquired and averaged. The 2004 spectral study is the baseline dataset that has being used to monitor potential variation that occurred in the last 4 years.

For the colour measurements, the collection of the first set of three annual ΔE colour measurements provided an opportunity to observe whether any trends have emerged. Variance in the data at some sample spots suggests measurements are influenced by surface roughness (which affects spectrophotometer placement), and surface colour inhomogeneity. Site averaged colour change values at the southern sites (Sites 4-8) were not consistently different to those at the northern control sites (Sites 1 and 2), 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 2004–07 period. 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.

For the spectral mineralogy study, the spectra for engravings were different to those measured for background. Also for the same spot at a site, the engravings contained less moisture than the corresponding background rock. The minerals detected in both engravings and background include hematite, poorly ordered kaolinite and chlorite. Some goethite, gibbsite and manganese oxides were also recorded. For the large majority of the spots, mineralogically related absorptions were unchanged from 2004 to 2007 and only brightness varied from year to year: brightness decreases with increasing moisture. However, some small changes were noted at two locations; Site 2 Spot 1 background (control northern Site), a small increase in the amount of iron oxides was detected and on the same site for Spot 2 background (control northern Site), a modest increase in the amount of gibbsite was detected. At Site 7 Spot 3 Background (southern Site), a small decrease in the amount of iron oxides was also detected. These small changes affected only 3 points out of the 42 points from all the sites studied. It should also be noted that Site 2, where two of the changes were detected, is the furthest from industrial activities. No overall changes, for all engraving and background, at a site were observed. These small variations are local and correspond to natural mineralogical variations.

1. COLOUR MEASUREMENT

1.1 Introduction

In response to tender number 34DIR0603 issued by WA DoIR, CSIRO Materials Science and Engineering (CMSE; formerly Manufacturing and Materials Technology) measured the colour of selected petroglyphs on the Burrup Peninsula over a period of four 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.

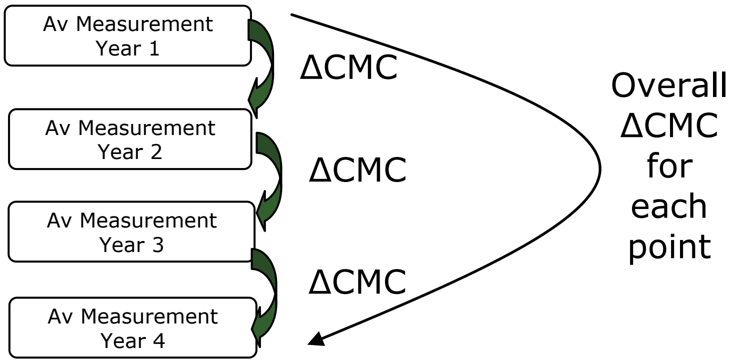
1.2 Experimental Methodology

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 the four 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 and Fig. 9) were determined by the Rock Art Management Monitoring 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 not included in this study) located in Fig. 9

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 Exploration and Mining (CEM).

1.3 Results and Discussion

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.

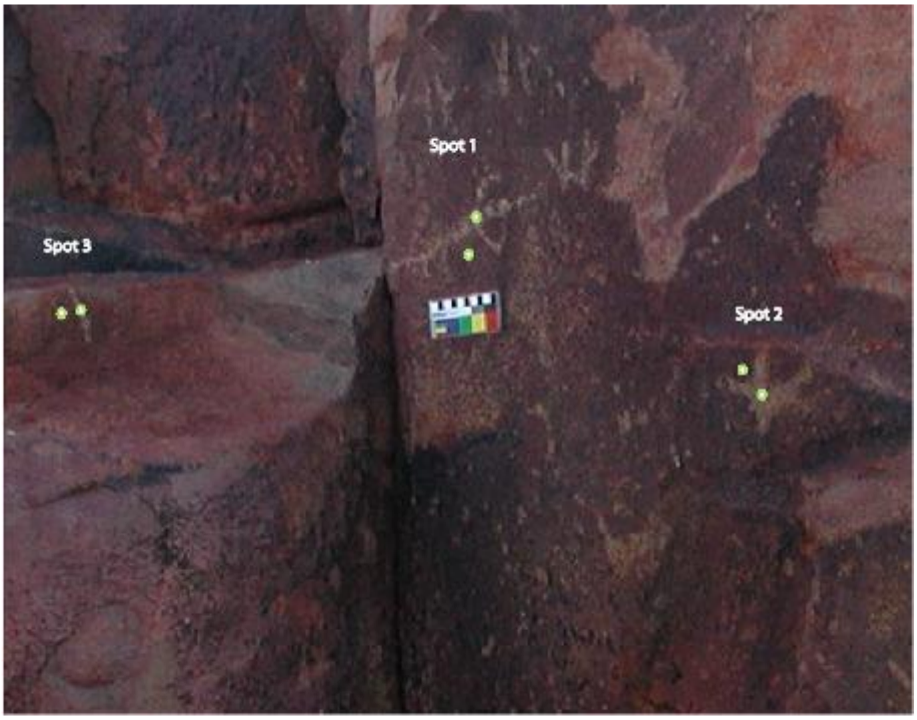
The original intention was to take an average of seven colour measurements (L*a*b*) at each sample point. However, when in the field, it became apparent that additional measurements would be useful to statistically evaluate the variability of measurements, so for many sample points there are more than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

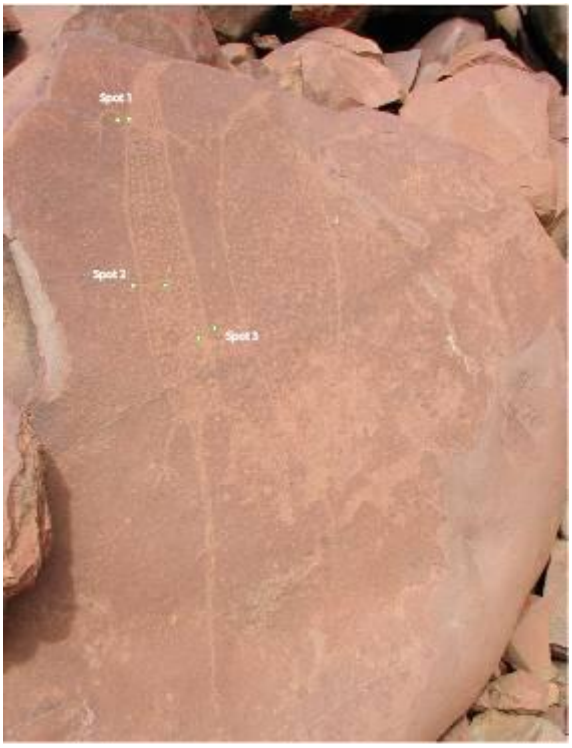
Sample	Colour scale			Colour difference* ΔE (2004–05, 2005–06, 2006–07)
	L*	a*	b*	
Site 1 Spot 1 Engraving				
Average 2007	17.16	5.71	13.03	2.40
Average 2006	16.791	3.833	11.593	3.040
Average 2005	14.970	6.081	12.525	2.155
Average 2004	14.315	8.080	12.995	
Site 1 Spot 1 Background				
Average 2007	28.24	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	
Site 1 Spot 2 Engraving				
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 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 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 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



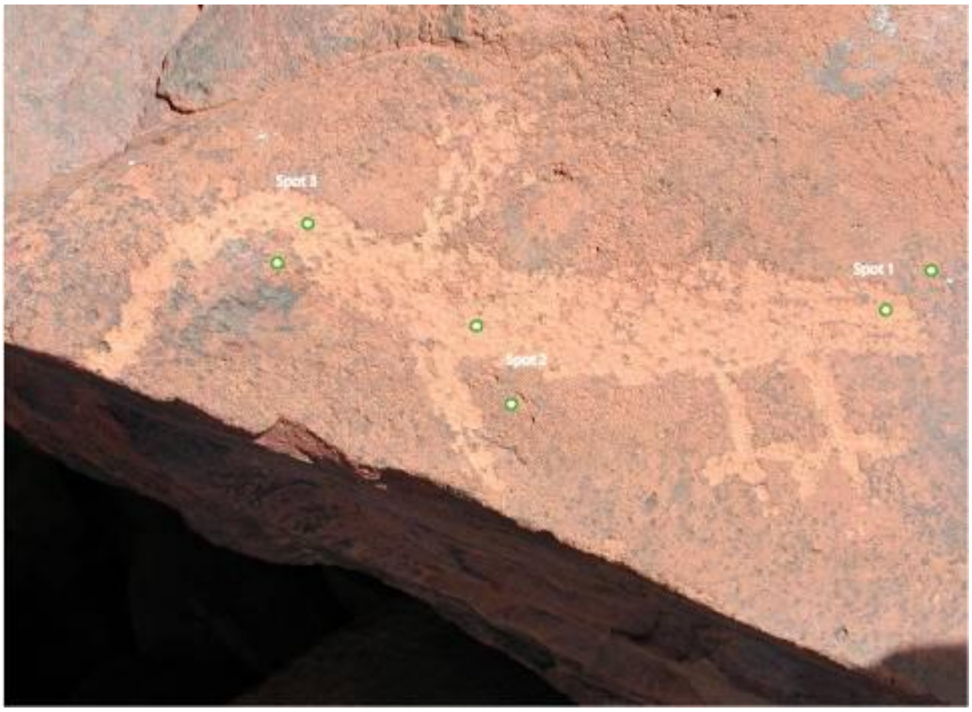
Sample	Colour scale			Colour difference*
	L*	a*	b*	ΔE
Site 2 Spot 1 Engraving				
Average 2007	31.06	7.44	14.96	3.72
Average 2006	34.104	7.790	17.069	1.620
Average 2005	33.581	9.261	17.502	2.292
Average 2004	31.900	8.957	15.975	
Site 2 Spot 1 Background				
Average 2007	25.42	7.93	10.97	1.86
Average 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 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 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 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 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*
	L*	a*	b*	ΔE
Site 4 Spot 1 Engraving				
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 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 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 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 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 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			Colour difference*
	L*	a*	b*	ΔE
Site 5 Spot 1 Engraving				
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 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 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 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 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 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	

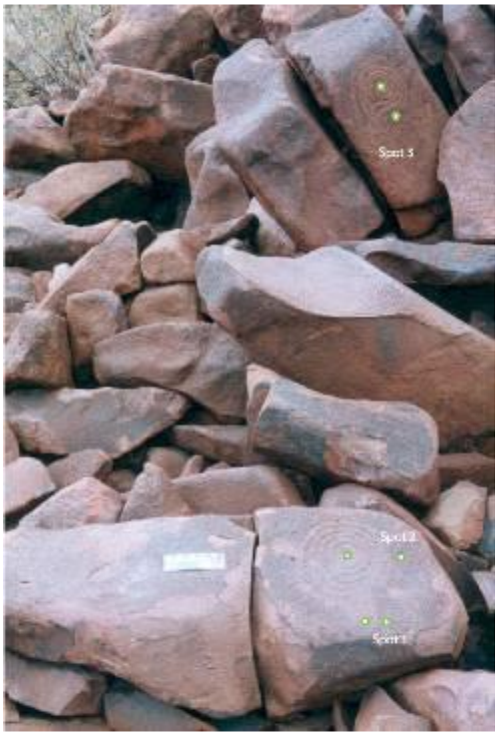
Site 6: Water Tanks

Sample	Colour scale			Colour difference*
	L*	a*	b*	ΔE
Site 6 Spot 1 Engraving				
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 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 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 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 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 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			Colour difference*
	L*	a*	b*	ΔE
Site 7 Spot 1 Engraving				
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 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 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 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 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 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	

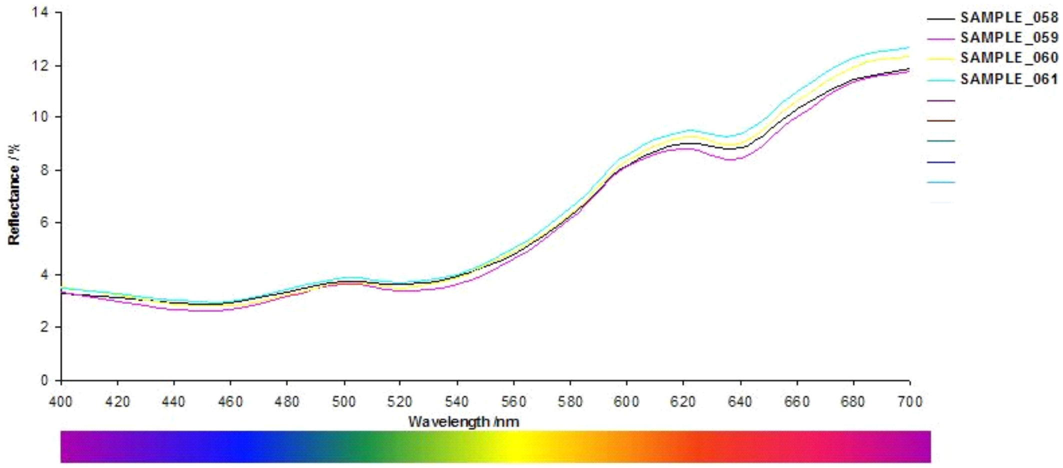
Site 8: King Bay South



Sample	Colour scale			Colour difference*
	L*	a*	b*	ΔE
Site 8 Spot 1 Engraving				
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 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 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 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 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 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	

1.4 Reflectance Spectra

The measurements collected by the portable spectrophotometer can also be displayed as spectral curves, and Figs 2–7 represent an example set for Site 8 in 2004 (top) and 2007 (bottom). The spectra for each sampling spot correspond to the average of seven L*a*b* measurements.



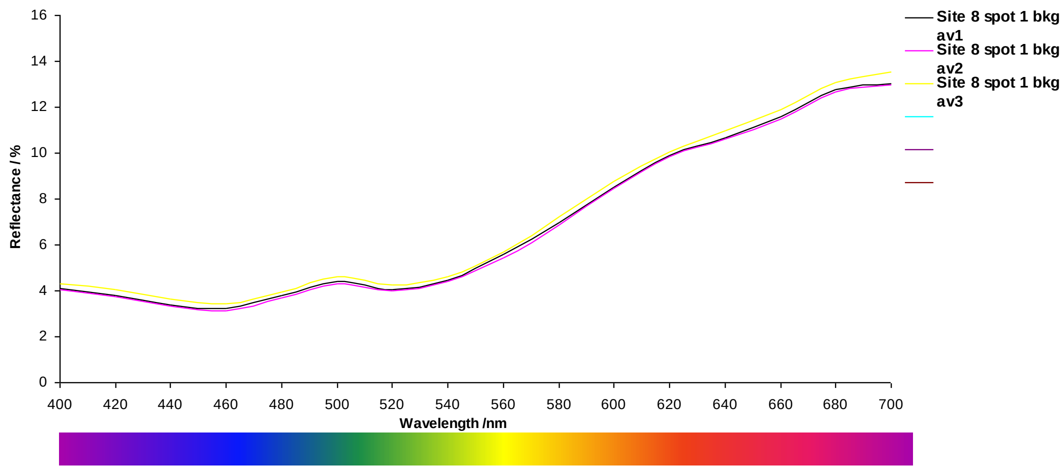
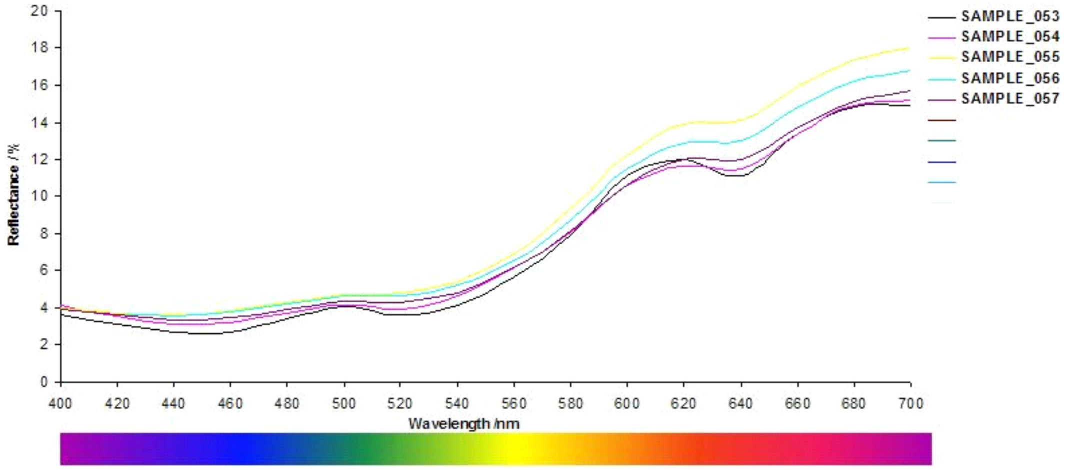


Figure 2: Site 8 spot 1 background.



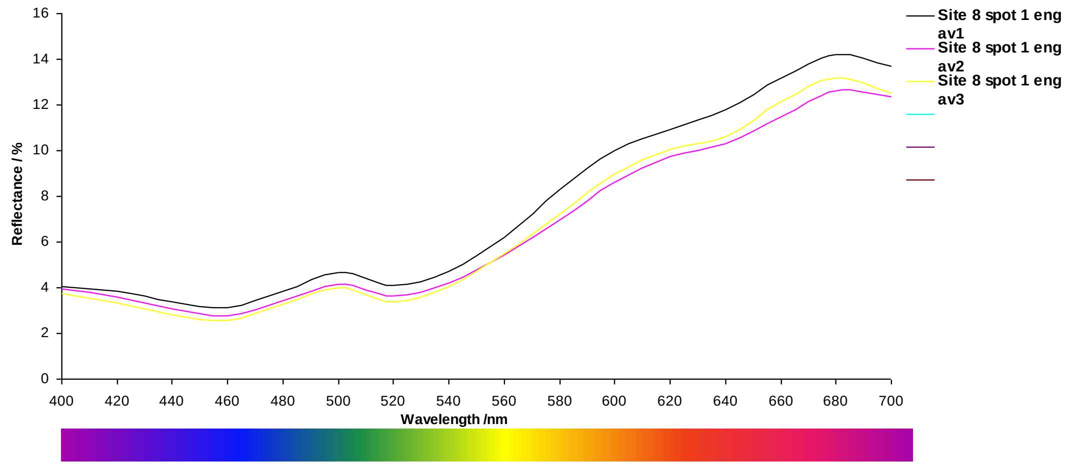


Figure 3: Site 8 spot 1 engraving.

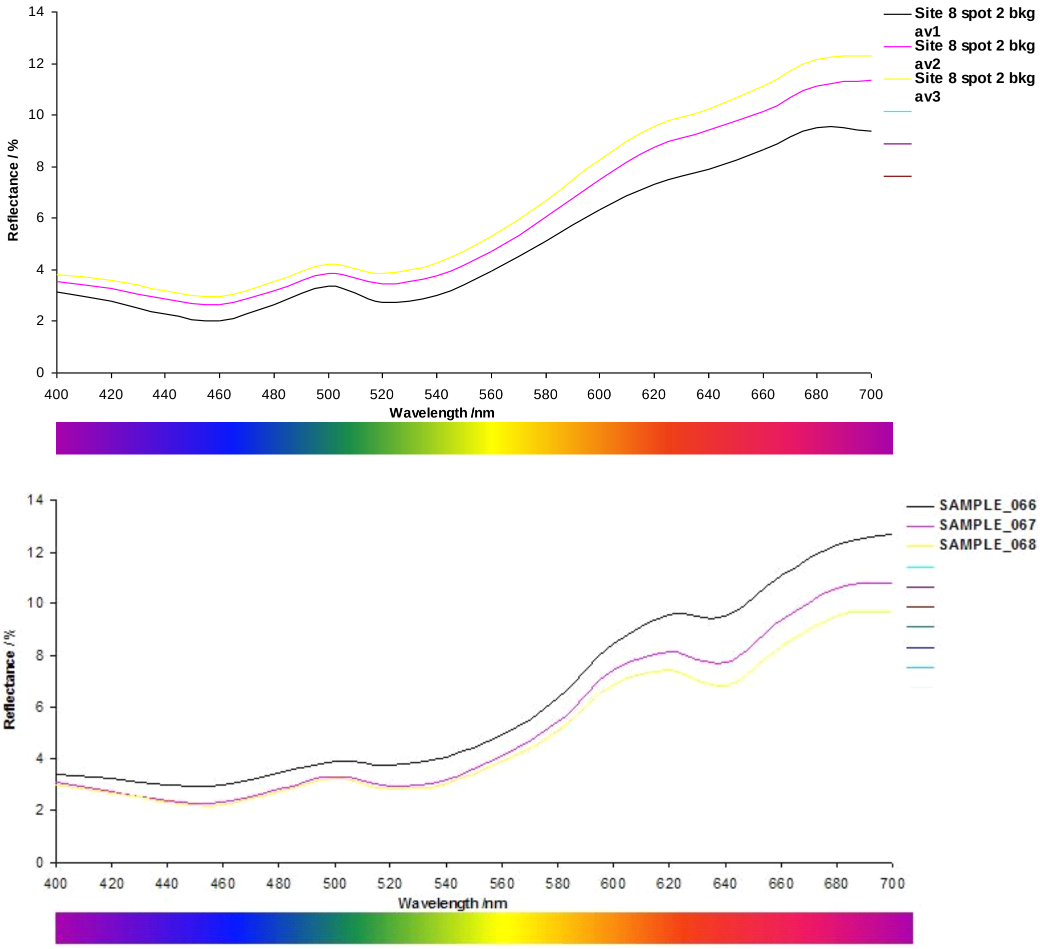


Figure 4: Site 8 spot 2 background.

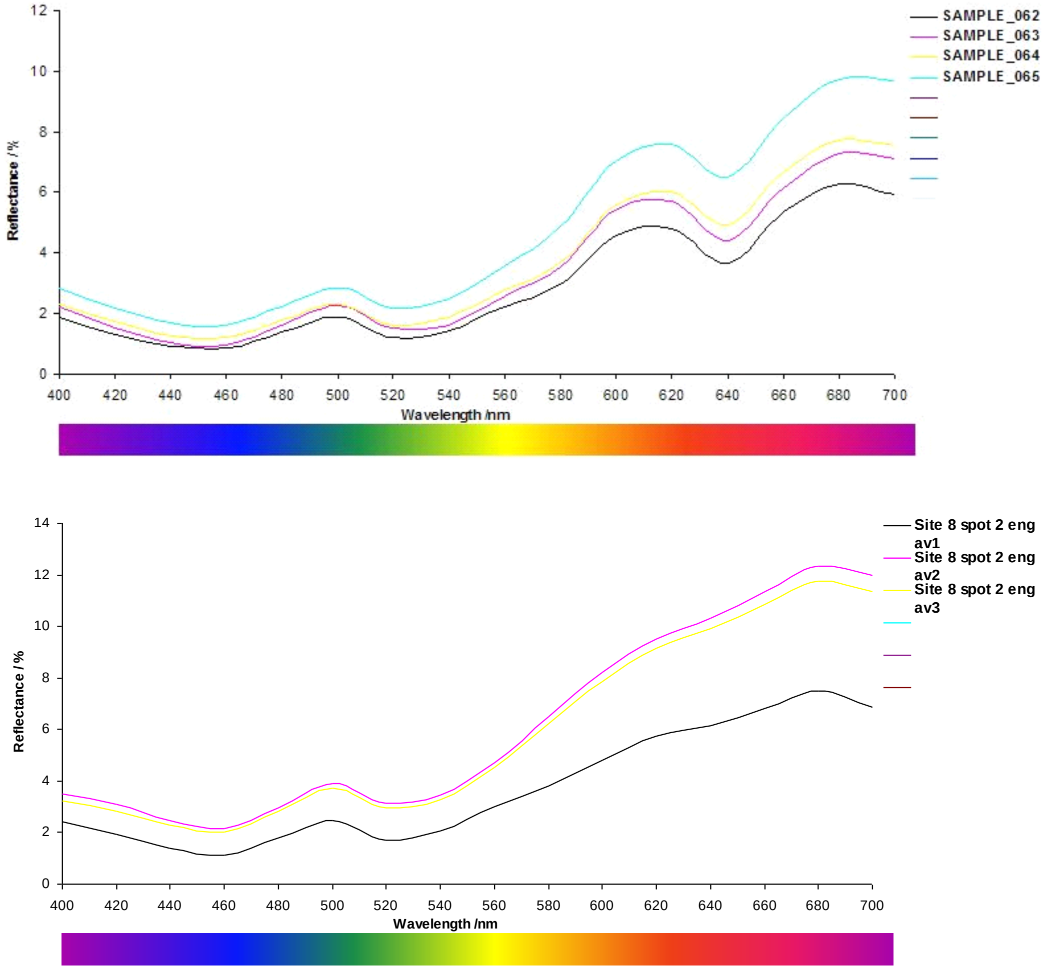


Figure 5: Site 8 spot 2 engraving.

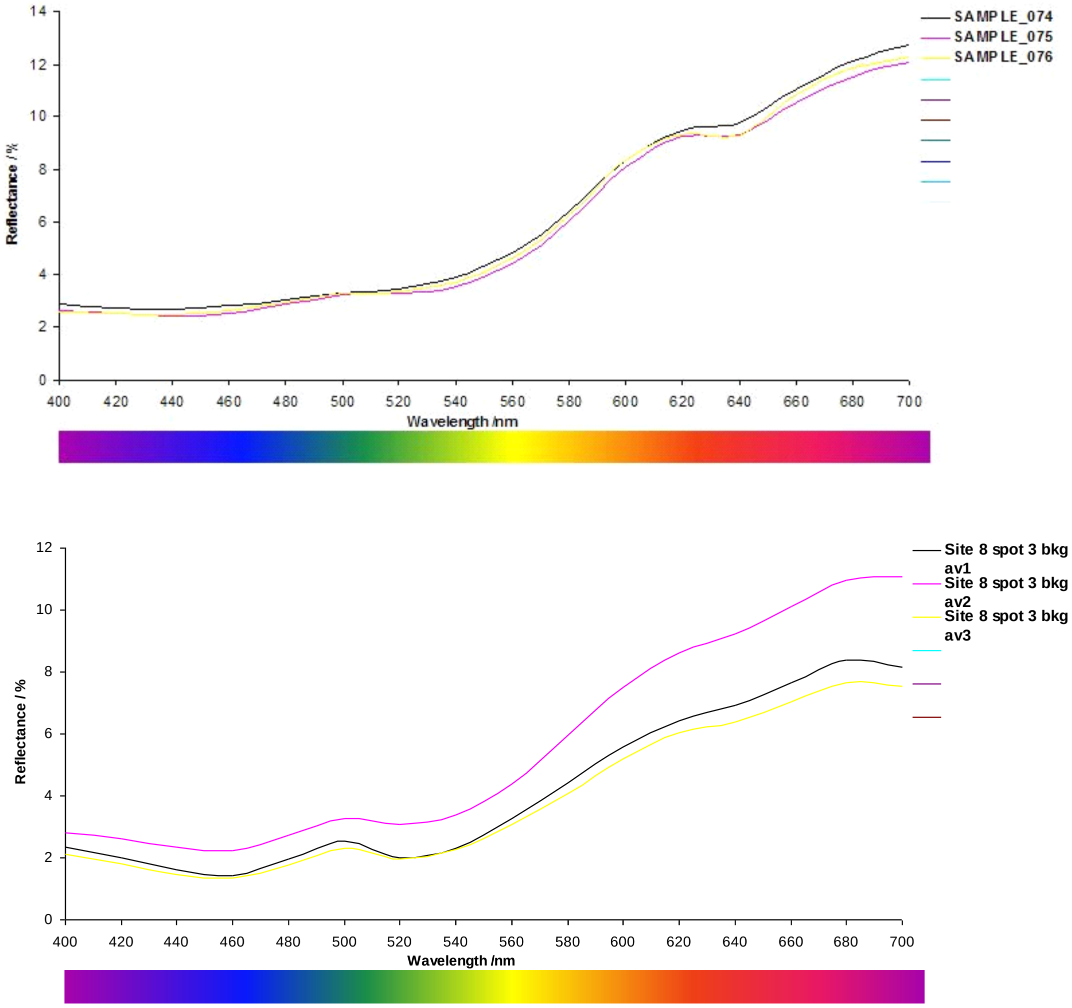
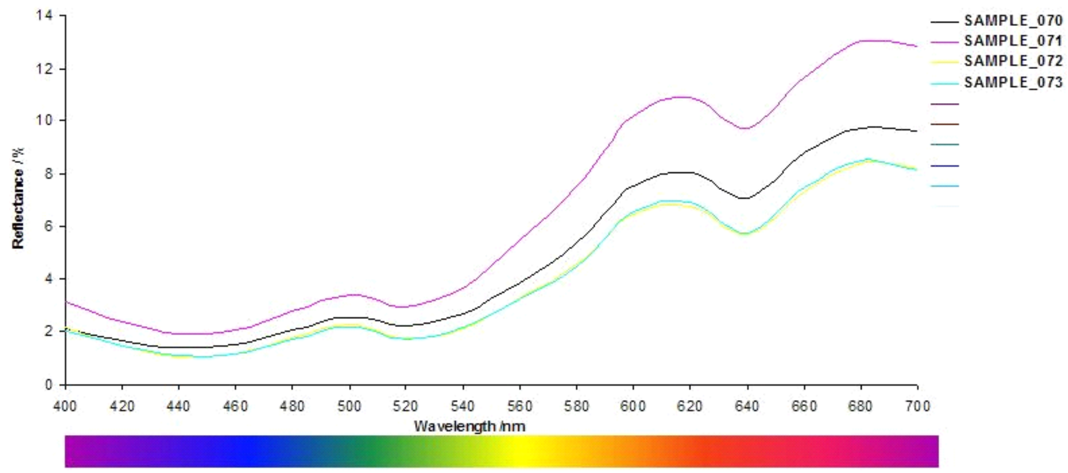


Figure 6: Site 8 spot 3 background.



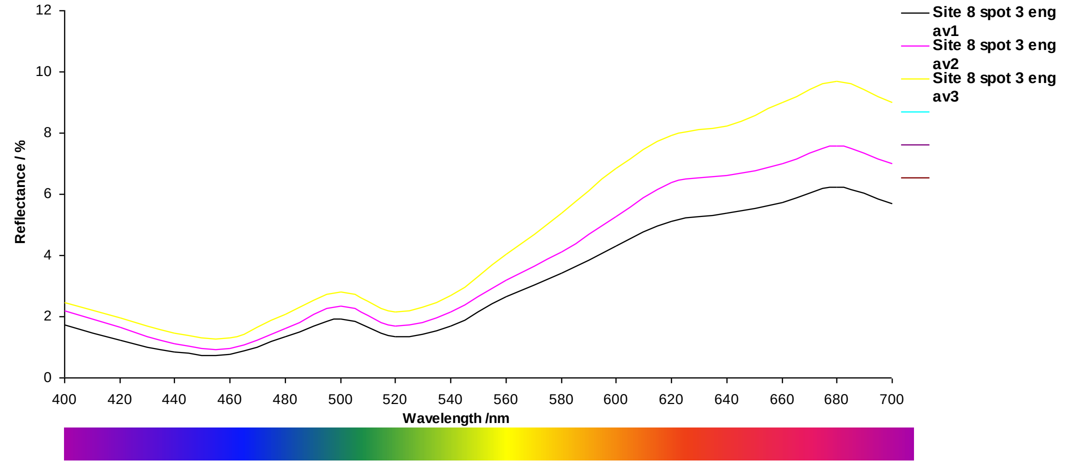


Figure 7: Site 8 spot 3 engraving.

A difference in the profile of the spectral curves was observed from years 2004 to 2007. A broad peak was observed in the 2004 spectra in the region of 600–640 nm, which is much less pronounced in the 2007 spectra. Spectra from 2005 and 2006 are much more similar to the 2007 spectra, suggesting the 2004 peak is anomalous. This does not appear to have a significant effect on the colour measurement, as the difference in reflectance is actually only in the order of 2%. It appears more substantial in the plots displayed as the reflectance scales have been stretched considerably to allow better observation of the spectral profiles.

Other spectral features such as the peak at approximately 500 nm and the shoulder at 680 nm are consistent for all the sample points.

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 2006–07	ΔE 2005–06	ΔE 2004–05	ΔE 2004–07
4	2.42	1.89	1.29	**2.81**
5	6.95	4.77	4.29	**8.60**
6	1.58	2.43	2.61	**2.11**
7	7.58	6.10	10.58	**8.91**
8	2.95	4.14	3.99	**3.35**
Overall southern sites average	4.30	3.87	4.55	**5.16**
1	4.50	3.12	2.97	**5.05**
2	2.38	3.01	3.56	**3.28**
Overall northern sites average	3.44	3.07	3.26	**4.17**

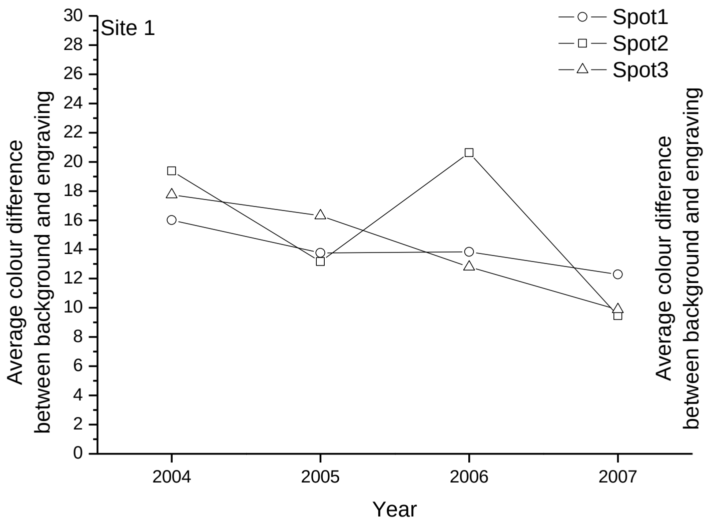
The three consecutive years of colour change measurements have allowed an examination of whether any trends are apparent at the sites, either individually or as a group, and whether the colour change measurements at the southern test sites are consistently or significantly different to those at the northern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

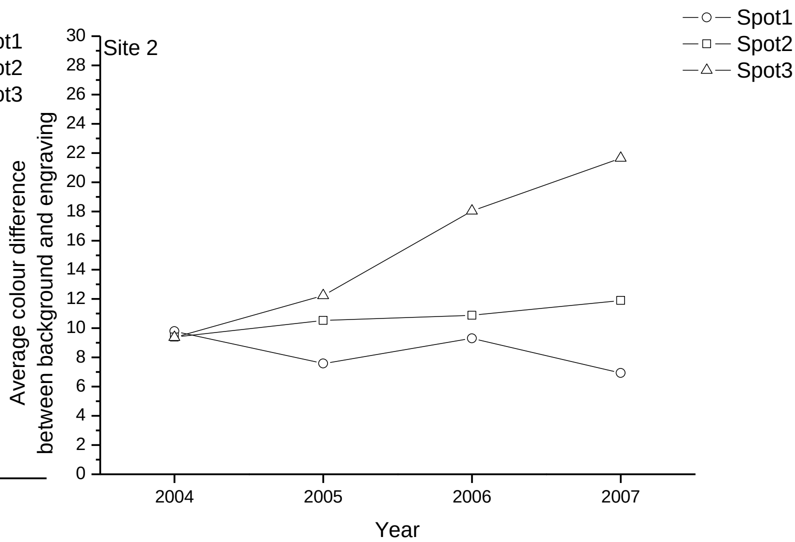
Considering the year to year ΔE values for 2004–07, which indicates the colour change over the three-year interval from 2004 to 2006, sites 5 and 7 displayed the greatest year to year colour change, and this was consistent with the 2004–06 interval. For sites 4, 6 and 8 (southern), the colour change 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, two of the test sites demonstrated greater colour change than the controls, two test sites demonstrated less colour change than the controls and one was essentially the same as the control sites.

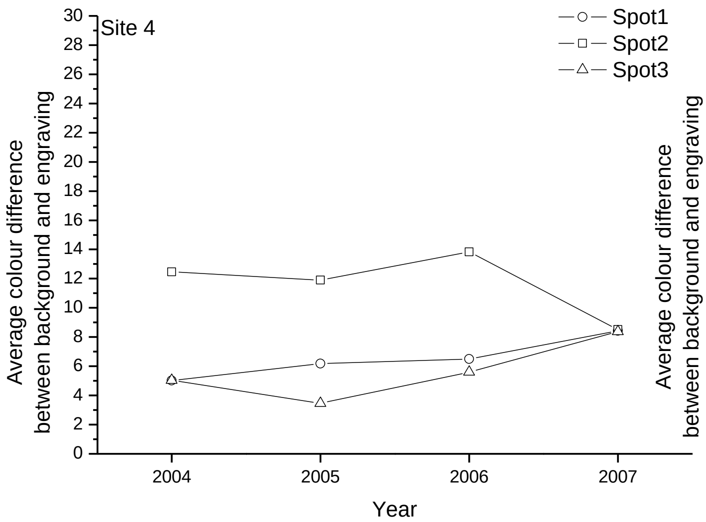
Where the colour difference appeared to have larger values overall (sites 5 and 7), this is believed to be partially due to the surface roughness of the rock, which influenced the placement of the spectrophotometer. At site 5, spot 3 there is a large patch of black patina which means that colour measurement 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.

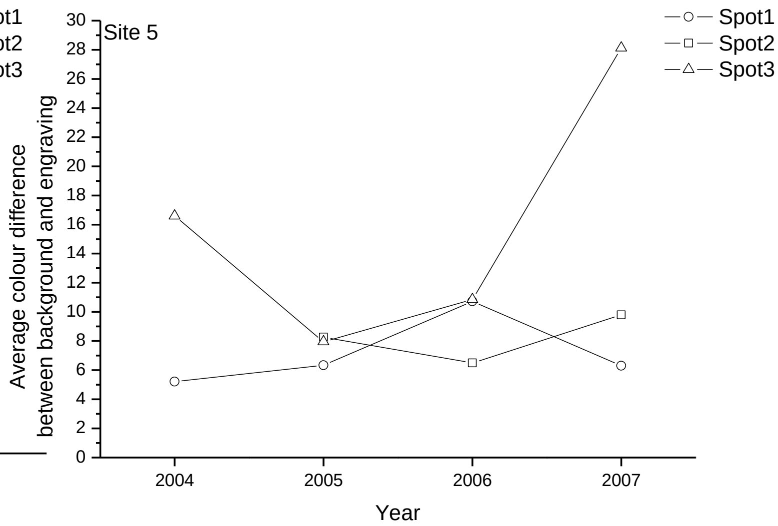
Table 4: Colour difference between background and petroglyph

Spot 1	**Site 1**	**Site 2**	**Site 4**	**Site 5**	**Site 6**	**Site 7**	**Site 8**
Average 2007	12.29	6.93	8.42	6.30	4.51	3.18	2.72
Average 2006	13.84	9.31	6.49	10.73	2.61	8.15	5.44
Average 2005	13.77	7.58	6.18	6.33	2.08	12.28	3.29
Average 2004	16.01	9.80	5.02	5.21	6.73	12.34	6.03
Spot 2							
Average 2007	9.46	11.91	8.51	9.79	2.26	4.31	3.36
Average 2006	20.62	10.88	13.84	6.49	2.76	15.55	8.06
Average 2005	13.16	10.54	11.90	8.26	3.85	6.84	4.54
Average 2004	19.38	9.40	12.47	n/a	2.62	23.36	5.45
Spot 3							
Average 2007	9.89	21.65	8.38	28.12	4.50	10.34	3.36
Average 2006	12.80	18.03	5.60	10.85	2.70	7.14	2.28
Average 2005	16.31	12.24	3.45	7.95	2.13	14.74	7.34
Average 2004	17.74	9.37	5.04	16.59	1.93	n/a	6.28
Site average (04-07)	**14.61**	**11.47**	**7.94**	**10.60**	**3.22**	**10.75**	**4.85**


Site 1
Spot1
Spot2
Spot3
Average colour difference
between background and engraving
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
2004
2005
2006
2007
Year


Site 2
Spot1
Spot2
Spot3
Average colour difference
between background and engraving
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
2004
2005
2006
2007
Year


Site 4
Spot1
Spot2
Spot3
Average colour difference
between background and engraving
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
2004
2005
2006
2007
Year


Site 5
Spot1
Spot2
Spot3
Average colour difference
between background and engraving
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
2004
2005
2006
2007
Year

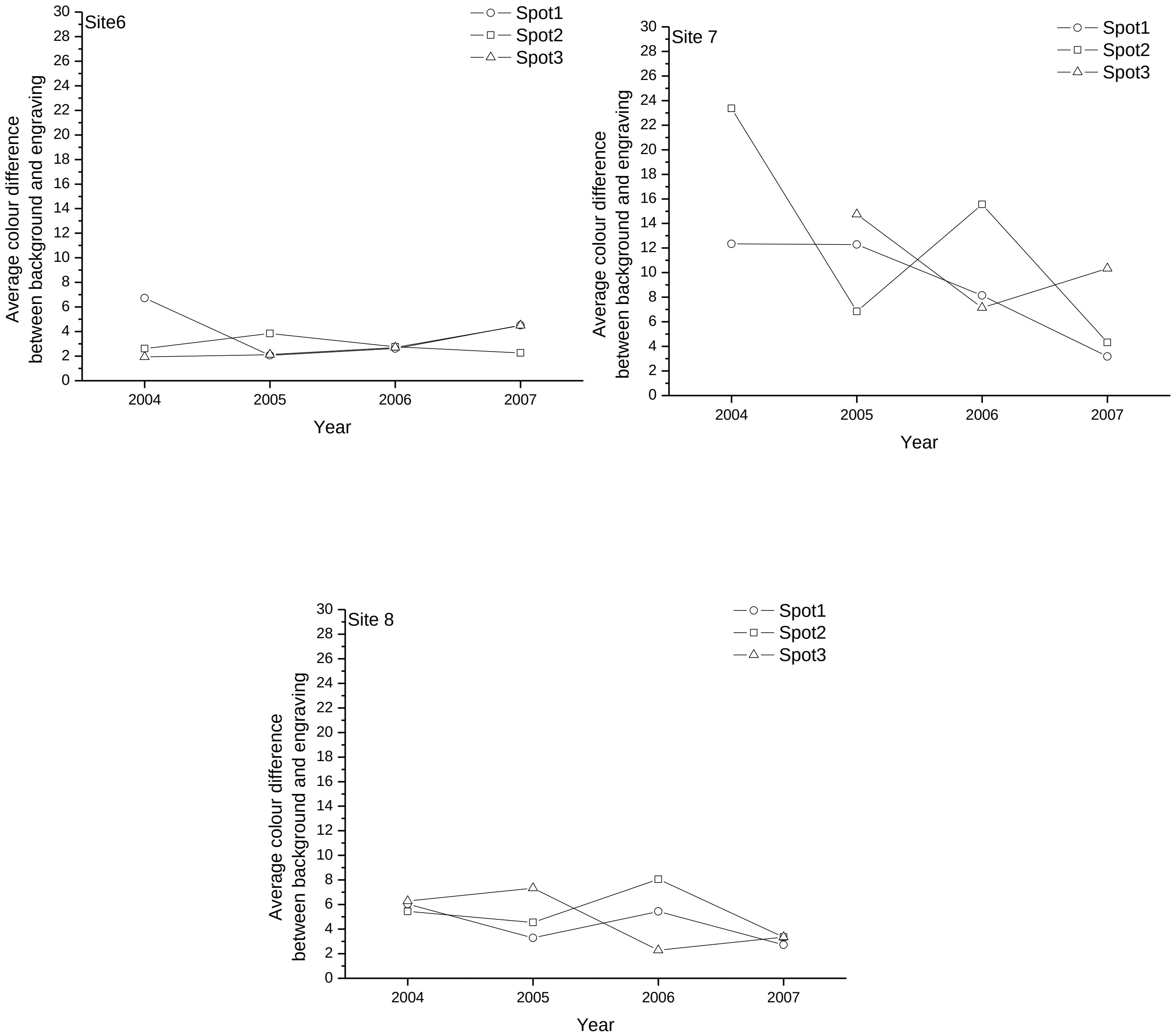


Figure 8: Site specific plots of colour differences between engraving and background for each spot examined (2004–2007). Site 5 spot 3 and Site 7 spot 2 are believed to exhibit high variance due to measurement effects.

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. 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. 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.

1.5 Conclusions

The collection of the first set of three annual ΔE colour measurements provided an opportunity to observe whether any trends have emerged in the annual colour change measurements. Variance in the data at some sample spots suggests 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 2004–07 period.

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. Annual colour change measurements are planned to continue for another three years (2008–10), providing a further opportunity to observe whether evidence of colour change exists.

2. SPECTRAL MINERALOGY

2.1 Introduction

For the last four years (2004–07), petroglyphs at seven specially selected sites in the Burrup Peninsula of Western Australia (Fig. 9) were measured using reflectance spectroscopy. In situ measurements using an ASD spectrometer were taken of an area of engraving and an area of background rock at three sampling spots at each petroglyh. The 42 spectral measurements were co-located with the colour measurements acquired simultaneously by Deborah Lau of CMSE. A minimum of seven spectra were acquired and averaged for each area of engraving and background. The spectral variation of each area of engraving and background was also assessed. The colour values calculated by Deborah were cross-checked to the colour values calculated by the ASD spectrometer.

The 2004 spectral study [4,5] provided the baseline dataset used to monitor potential variation during the four-year study (2004–07) to assess the mineralogy, and monitor and explain any mineralogical changes at the seven rock art sites in the Burrup Peninsula.

Figure 9. Location of the Burrup Peninsula.

2.2 Experimental Methodology

Reflectance spectroscopy – the analysis of reflected light between 400 and 2500 nm – is now available as a field tool for geologists through the development or portable instruments like the Analytical Spectral Device (ASD) FieldSpec Pro field spectrometer. These devices 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), although the measurement is restricted to a sample's surface (<50 µm).

CSIRO has been involved in the development of reflectance spectroscopy research techniques for the characterisation of iron ores, gold, bauxites, mineral sands, talc, lateritic nickel and asbestos [3,6–8]. The mineralogy of samples can be characterised based on key spectral features.

Reflectance spectroscopy is now a proven technique for mineral analysis in both the laboratory and in the field, and it 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 and 2500 nm (shortwave infrared, or SWIR). The combination of these wavelength ranges provides a step forward towards quick and accurate mineral characterisation.

The ASD FieldSpec Pro covers the spectral range 400–2500 nm, with a spectral resolution of 3 nm at 700 nm using three 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. Input is through a 1.4 m fibre optic cable, and the average scanning time to acquire a spectrum is 1 second. There are two ways of operating the ASD: using either an external source of light (sun or artificial), or an internal source of light. For this study, the ASD internal light source was used at constant irradiance as it eliminates any external light interference. Absolute measurements were obtained using a white reference plate that reflects 100% of light in the 400–2500 nm wavelength range.

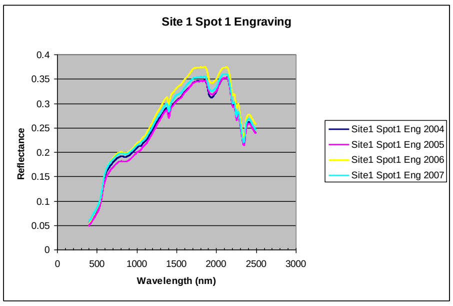
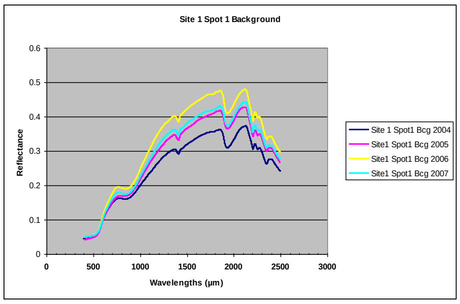
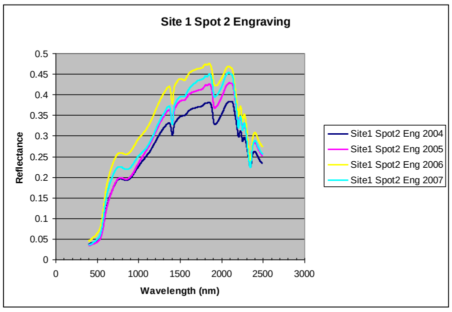
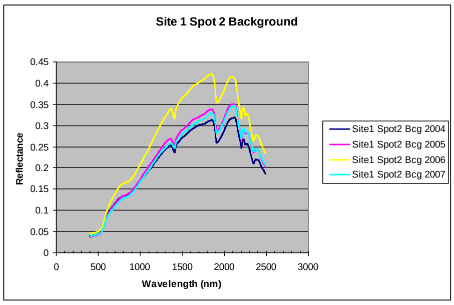
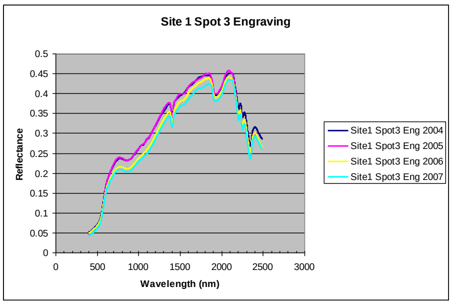
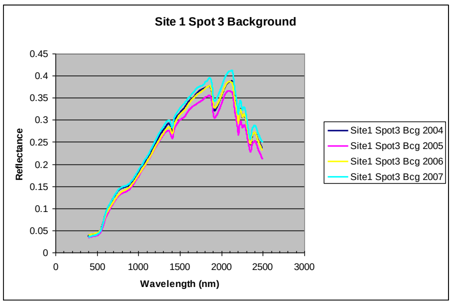
Fig. 10 shows the ASD FieldSpec Pro being used at one of the Burrup Peninsula sites.

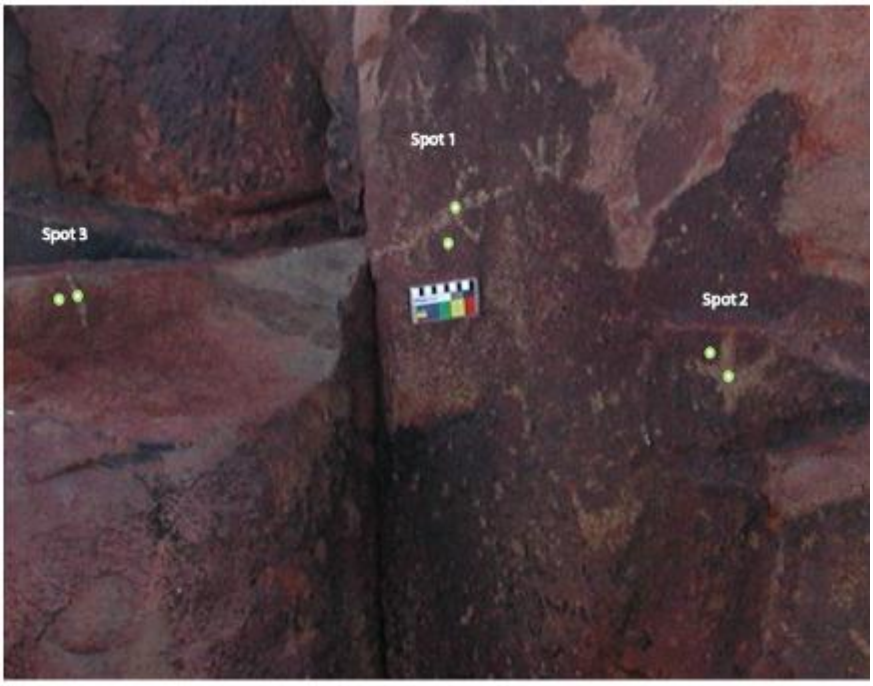
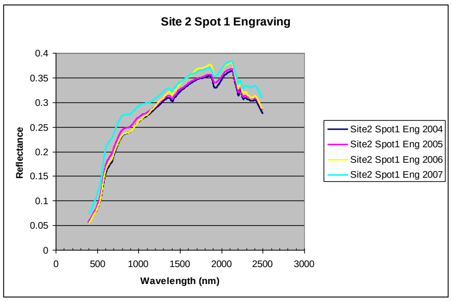
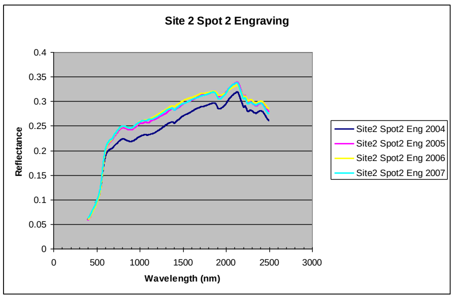
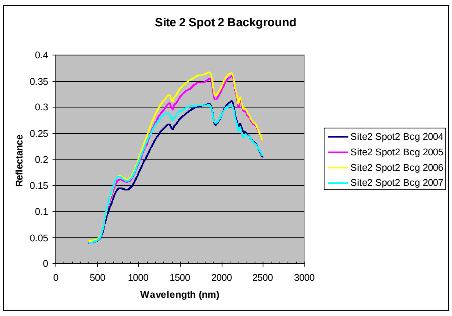
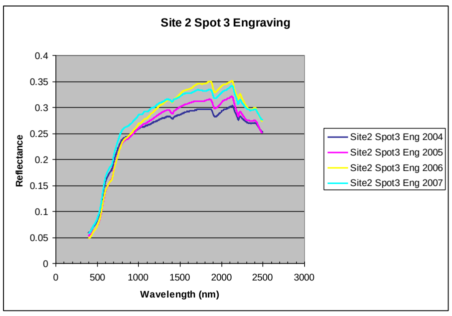
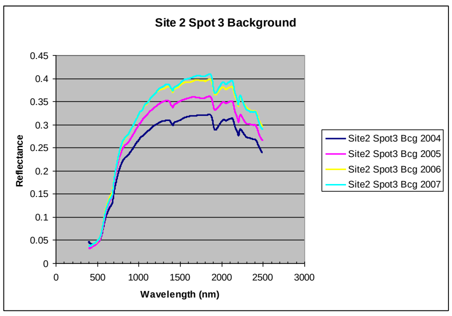
Figure 10. ASD FieldSpec Pro in operation at Burrup Peninsula.

2.3 Results and Discussion

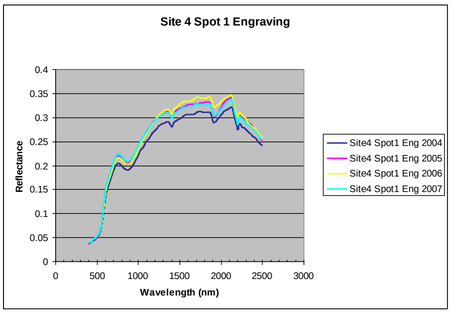
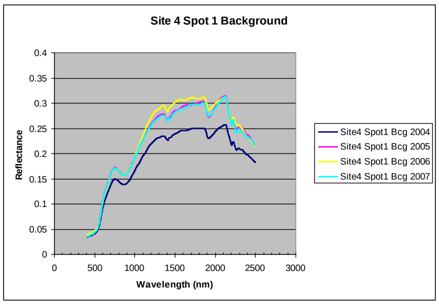
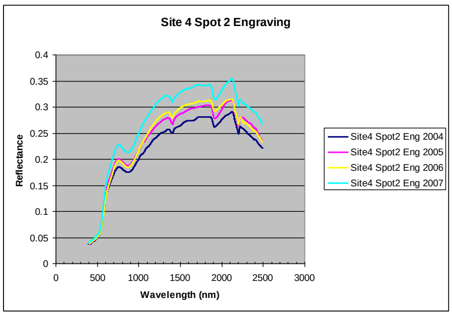
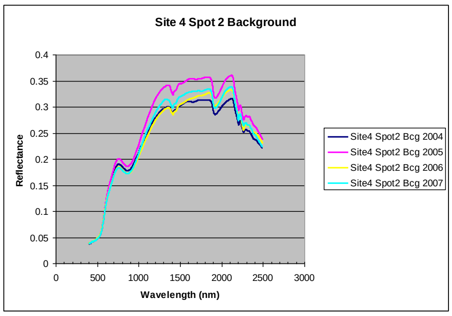
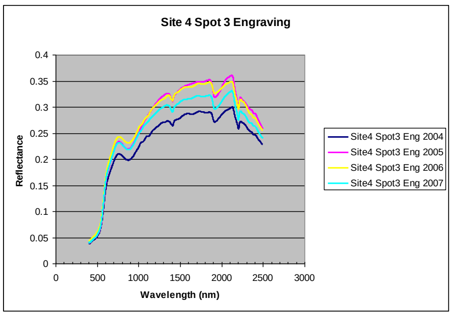
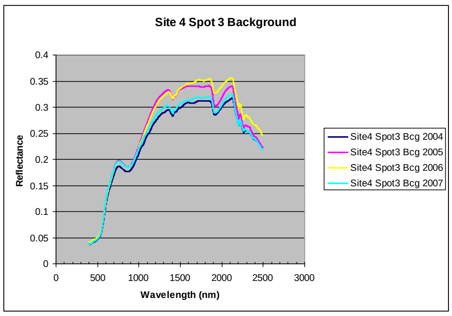
For each site, the descriptions and interpretations presented in the following pages include:

- A digital image of the petroglyph showing the locations (spots 1, 2 and 3) where measurements were taken for both engraving and background.
- Comparison of the average spectra of the engraving and background at each of the three spots between 2004 and 2007.

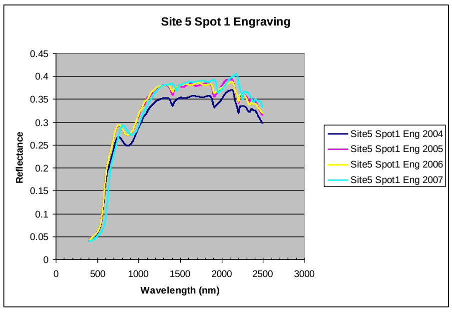
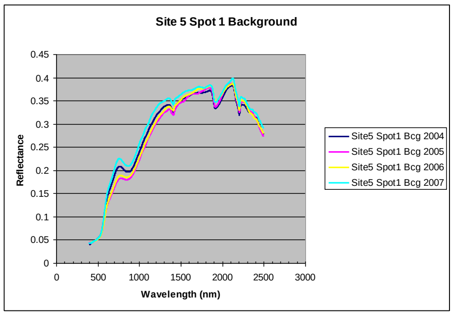
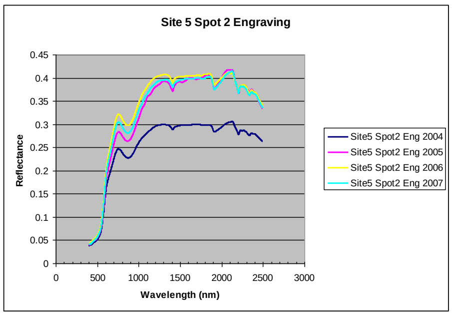
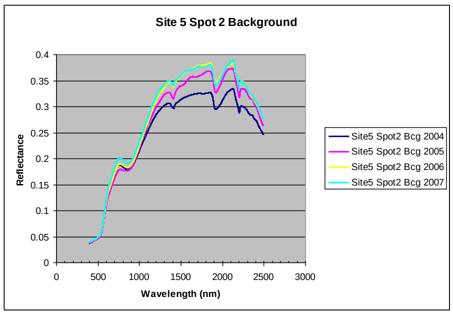
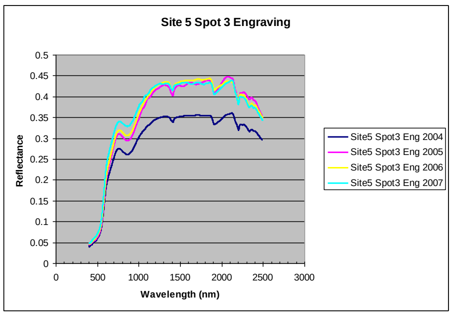
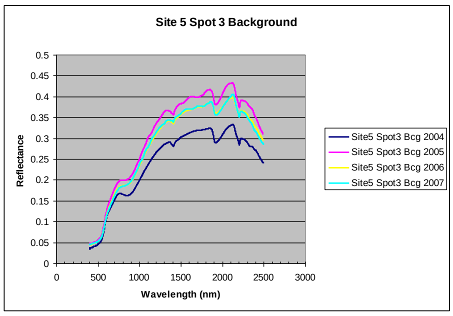
<table>
<tr><th>Location</th><th>Spectra engraving</th><th>Spectra background</th></tr>
<tr><td>Site 1</td><td colspan="2"></td></tr>
<tr><td>Spot 1</td><td>
</td><td>
</td></tr>
<tr><td>Spot 2</td><td>
</td><td>
</td></tr>
<tr><td>Spot 3</td><td>
</td><td>
</td></tr>
</table>

<table>
<tr><th>Location</th><th>Spectra engraving</th><th>Spectra background</th></tr>
<tr><td>Site 2</td><td colspan="2">
</td></tr>
<tr><td>Spot 1</td><td>
</td><td>
</td></tr>
<tr><td>Spot 2</td><td>
</td><td>
</td></tr>
<tr><td>Spot 3</td><td>
</td><td>
</td></tr>
</table>

Location	Spectra engraving	Spectra background

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

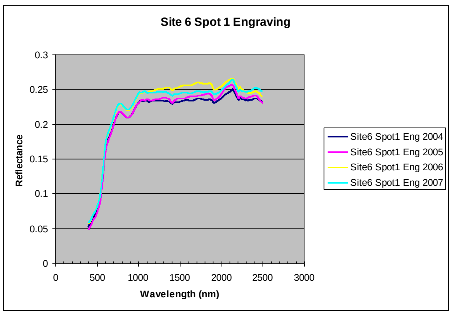
Location	Spectra engraving	Spectra background

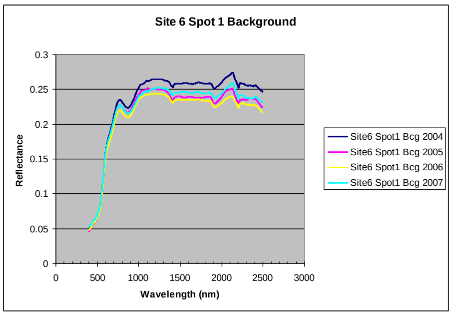
<table>
<tr><td>Site 5</td><td colspan="2">
</td></tr>
<tr><td>Spot 1</td><td>
</td><td>
</td></tr>
<tr><td>Spot 2</td><td>
</td><td>
</td></tr>
<tr><td>Spot 3</td><td>
</td><td>
</td></tr>
</table>

Location	Spectra engraving	Spectra background

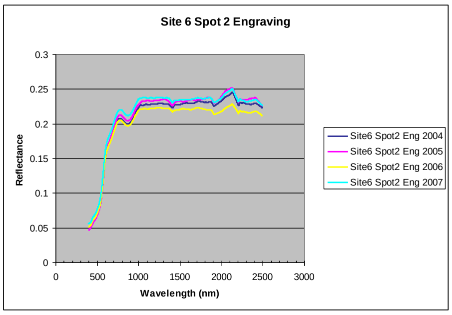
Site 6

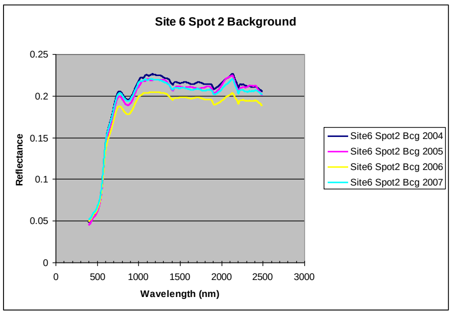
Spot 1



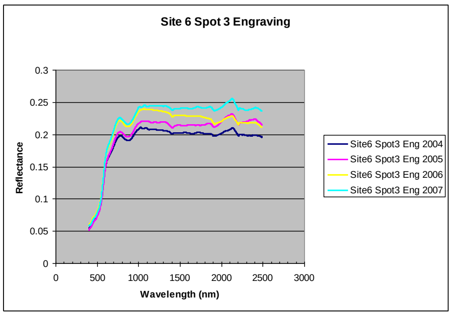


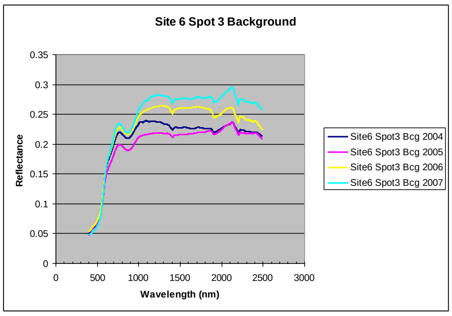
Spot 2

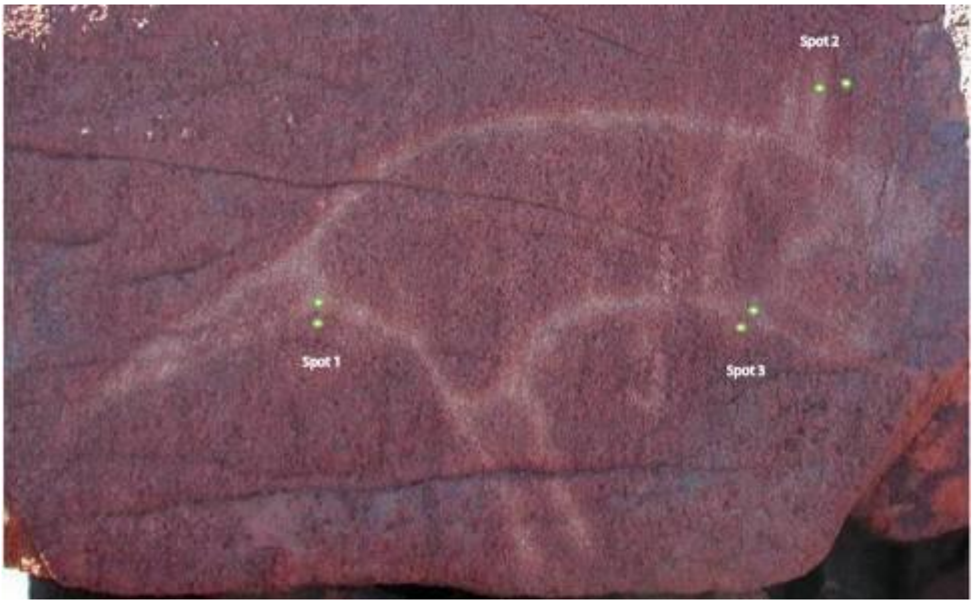
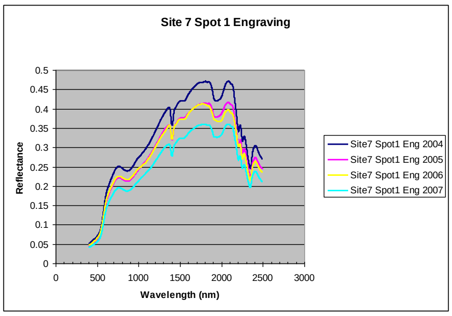
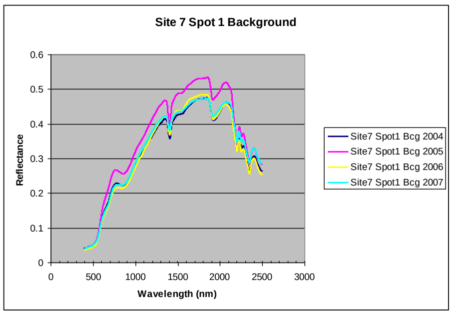
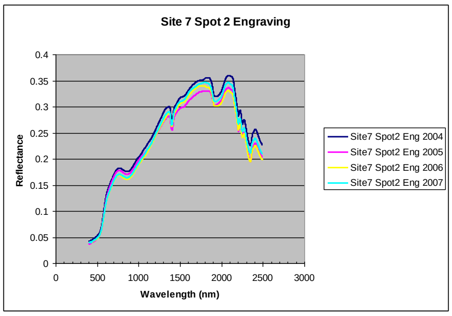
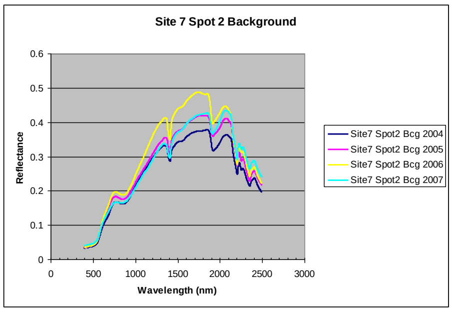
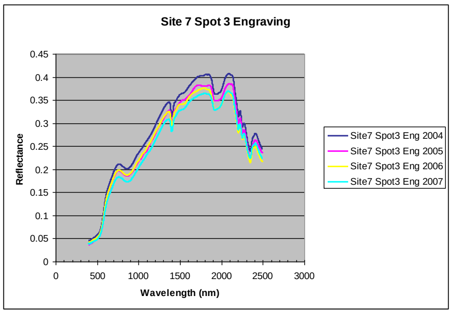
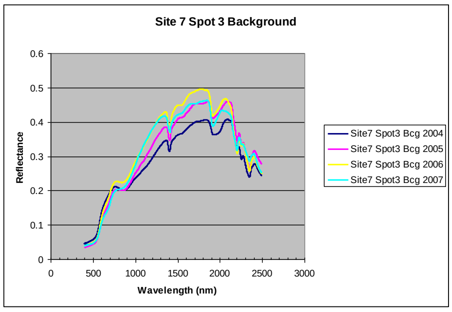


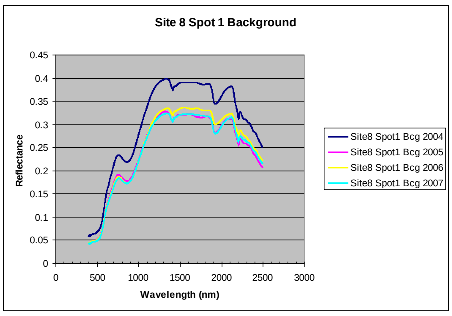
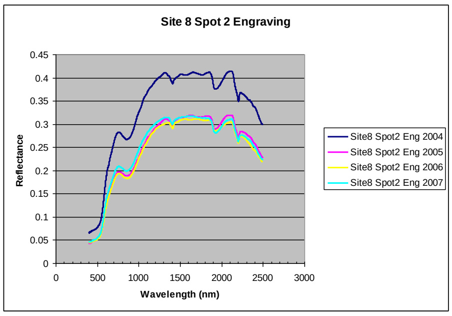
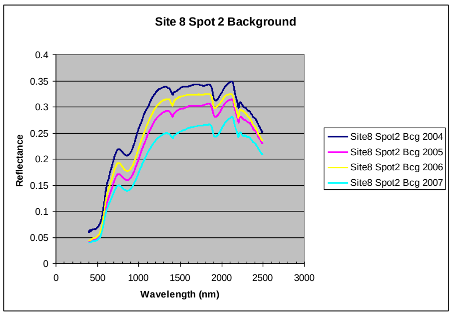
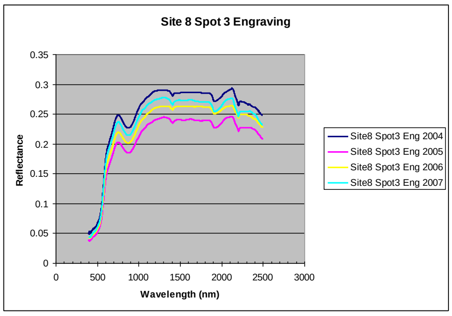
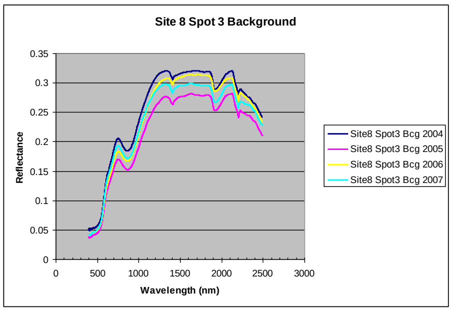


Spot 3





<table>
<tr><th>Location</th><th>Spectra engraving</th><th>Spectra background</th></tr>
<tr><td>Site 7</td><td colspan="2">
</td></tr>
<tr><td>Spot 1</td><td>
</td><td>
</td></tr>
<tr><td>Spot 2</td><td>
</td><td>
</td></tr>
<tr><td>Spot 3</td><td>
</td><td>
</td></tr>
</table>

Location	Spectra engraving	Spectra background
Site 8		
Spot 1		
Spot 2		
Spot 3		

For most of the spots, mineralogically related absorptions were unchanged since 2004, and only the brightness (or reflectance) varied from year to year. However, some small changes were noted at specific locations:

Site 2

- Spot 1 background – an increase in the amount of iron oxides was detected
- Spot 2 background – an increase in the amount of gibbsite was detected

Site 7

- Spot 3 background – a decrease in the amount of iron oxides was detected

2.4 Supplementary Experiments

Some experiments were conducted to address the variation in albedo found in the last four years (see previous reports):

> *The amount of reflected light detected has 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 could be explained by:*
>
> - *Surface variation (relative change in mineral abundance, organic growth, moisture content, mineral heterogeneity at the rock surface)*
> - *Probe not positioned at exactly the same sample locations as measured in 2004*

The effect of moisture (water) on spectral behaviour was tested through two separate experiments, i.e. a moisture–time experiment and a water experiment.

2.4.1 Moisture–time experiment

The moisture–time experiment consisted of measuring the same spot at three different times of the day, namely 6:45 am, 10:45 am and 1:45 pm. The first measurement provided the spectral behaviour for a ‘cool’ rock with a predicted higher amount of moisture, and the last one provided a spectrum of a ‘hot’ rock expected to show the lowest amount of moisture. We also compared spectra to previous years as measurements were taken at different months (e.g. end of July 2004, mid-September 2005, mid-August 2006 and early August 2007). Moisture was evaluated using the depth of the 1920 nm absorption calculated after the removal of the Hull or spectral background (Tables 5 and 6). At each measuring spot on a site, the engraving contained less moisture than the corresponding background.

For site 7 in particular, the moisture content seems to be related to the time of day, with the early morning measurement showing the highest moisture content (10/08/06 at 6:45am) (Table 5). When the spectral measurements were taken at comparable times, the moisture value was almost identical over the four years; see for example, the values for spot 2 engraving and background for 27/07/04 at 9:31 am and the 10/08/06 at 10:45 am (Table 5).

For all other sites (Table 6), it seems that in 2006 moisture for both the engravings and background was generally slightly lower than the three other years (2004, 2005 and 2007). However, the significance of this small decrease needs to be demonstrated these subsequent years.

Table 5. Relative moisture absorption for site 7 between 2004 and 2007

Date and time	Engraving			Background		
	Spot 1	Spot 2	Spot 3	Spot 1	Spot 2	Spot 3
27/07/04 9:31am	0.11	0.11	0.11	0.13	0.15	0.11
12/09/05 4:09 pm	0.09	0.09	0.09	0.12	0.14	0.11
08/08/06 4:59 pm	0.09	0.10	0.11	0.13	0.16	0.14
10/08/06 6:45 am	0.11	0.12	—	0.16	0.16	—
10/08/06 10:45 am	0.10	0.11	—	0.13	0.15	—
10/08/06 1:45 pm	0.09	0.09	—	0.11	0.14	—
03/08/07 3:23 pm	0.09	0.06	0.10	0.10	0.14	0.14

Table 6. Relative moisture absorption for the sites (excluding site 7) between 2004 and 2007

Site	Date and time	Engraving			Background		
		Spot 1	Spot 2	Spot 3	Spot 1	Spot 2	Spot 3
1	29/07/04 10:35 am	0.11	0.14	0.12	0.15	0.18	0.15
	14/09/05 9:57 am	0.09	0.14	0.12	0.13	0.16	0.15
	09/08/06 10:12 am	0.08	0.11	0.11	0.14	0.16	0.14
	02/08/07 11:36 am	0.09	0.12	0.11	0.13	0.15	0.14
2	29/07/04 3:50 pm	0.08	0.06	0.06	0.10	0.14	0.10
	14/09/05 1:09 pm	0.06	0.05	0.06	0.10	0.12	0.08
	09/08/06 12:04 pm	0.06	0.04	0.06	0.09	0.12	0.07
	02/08/07 3:44 pm	0.05	0.06	0.06	0.13	0.11	0.09
4	28/07/04 3:03 pm	0.09	0.08	0.08	0.09	0.09	0.09
	13/09/05 8:34 am	0.10	0.10	0.10	0.11	0.12	0.12
	08/08/06 2:03 pm	0.07	0.07	0.06	0.08	0.08	0.08
	03/08/07 11:57 am	0.08	0.09	0.09	0.10	0.11	0.10
5	27/07/04 3:35 pm	0.09	0.07	0.07	0.11	0.11	0.11
	13/09/05 10:50 am	0.09	0.09	0.08	0.12	0.12	0.10
	08/08/06 12:13 pm	0.06	0.06	0.06	0.09	0.09	0.08
	03/08/07 10:15 pm	0.06	0.08	0.07	0.10	0.11	0.09
6	27/07/04 2:03 pm	0.07	0.07	0.06	0.08	0.08	0.08
	13/09/05 2:16 pm	0.07	0.07	0.08	0.09	0.09	0.08
	08/08/06 4:25 pm	0.05	0.06	0.06	0.07	0.07	0.07
	03/08/07 10:52 pm	0.06	0.06	0.06	0.07	0.08	0.07
8	28/07/04 11:16 am	0.09	0.09	0.07	0.11	0.10	0.10
	13/09/05 3:43 pm	0.09	0.10	0.08	0.11	0.09	0.10
	08/08/06 3:09 pm	0.07	0.07	0.05	0.09	0.08	0.08
	03/08/07 9:23 am	0.10	0.10	0.08	0.12	0.11	0.10

2.4.2 Water experiment

We chose a rock surface at site 7 that was free of engravings but spectrally similar to the measured background rocks. The image plot and the superimposed spectra in Fig. 11 show the progress of the water absorption at 1920 nm.

The water experiment consisted of the following steps:

1. The surface of the rock was measured using the optic fibre probe.
2. Water was applied and the wet rock was measured using the optic fibre probe. At first, the depth of the absorption increased rapidly, and the spectrum of the fully water-saturated surface (100% moisture) had a maximum depth of 0.82 (7). As the water percolated through the rock, the absorption decreased.
3. The probe was removed after 1 minute.
4. The probe was reapplied, and the water absorption again increased as evaporation began.
5. The probe was again removed after 1 minute.
6. The probe was reapplied, and water absorption decreased as water was no longer available.
7. The probe was again removed after 1 minute.
8. The rock was again measured, after the 10-minute experiment, and the moisture of the rock was found to have reverted to its original value.

This experiment demonstrated that moisture has an impact on spectral behaviour, and that a cycle of infiltration and evaporation occurred in less than 10 minutes before the moisture reverted to its original value (refer to Table 7).

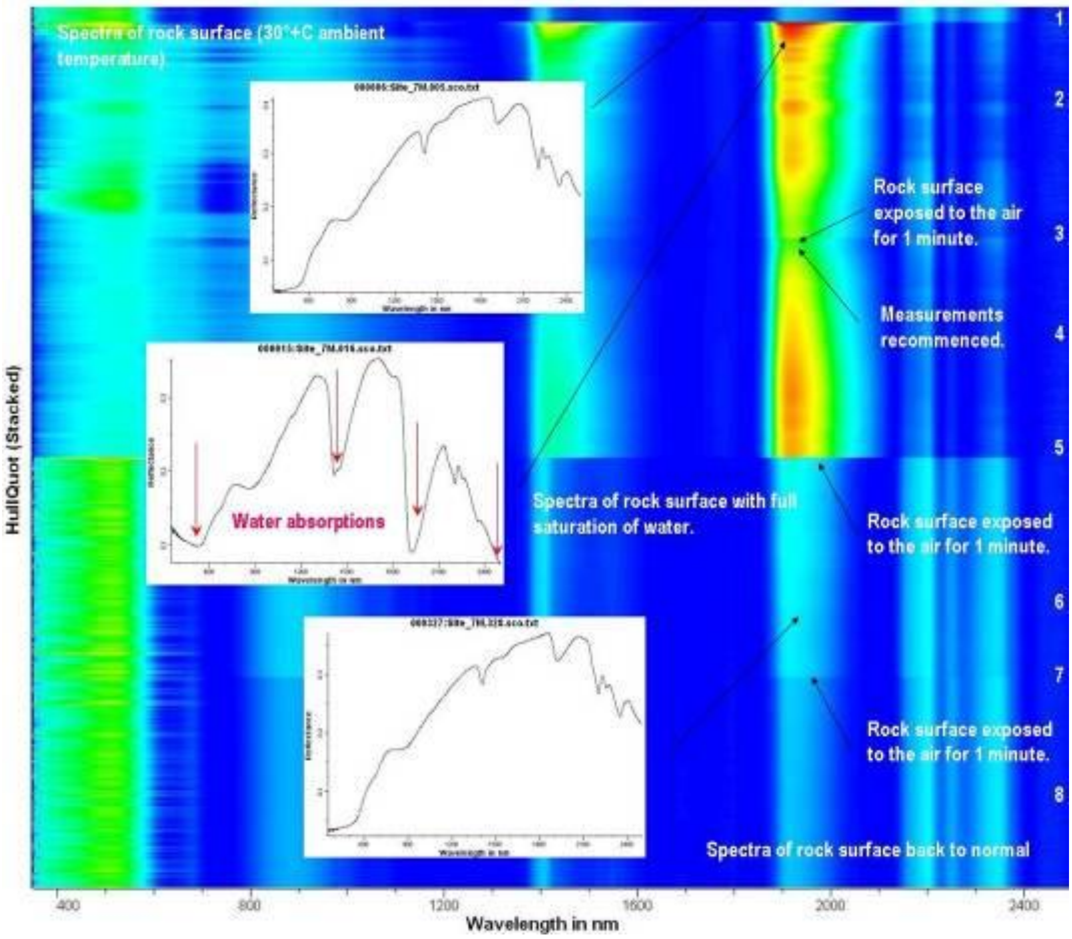


Figure 11. Image plot and spectra for the water experiment.

Table 7. Relative moisture absorption values for site 7 background points measured during the water experiment on 10/08/06 at 2:00 pm

Location on Fig. 11	Relative moisture absorption
1	0.12
Start of 2	0.82
Finish of 2	0.48
Start of 4	0.40
Finish of 4	0.66
Start of 6	0.27
Finish of 6	0.17
Start of 8	0.13
Finish of 8	0.12

Fig. 12 demonstrates that brightness (calculated as the mean reflectance between 450 and 2500 nm) decreases when moisture rises.

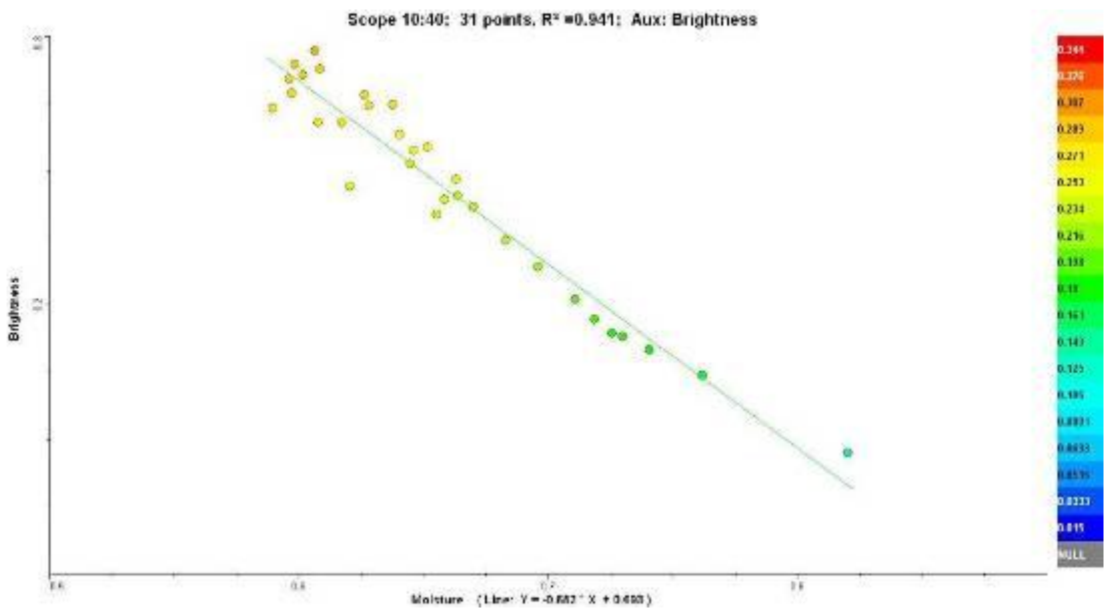


Figure 12. Scatterplot of brightness versus moisture (depth at 1900 nm).

2.5 Conclusions

Petroglyphs at seven sites in the Burrup Peninsula were measured from 2004 to 2007 using reflectance spectroscopy covering the visible to shortwave infrared wavelength range (400–2500 nm). Forty-two spectral measurements were acquired at each site with the ASD spectrometer (internal light source) at the same sampling locations on both the engravings and the surrounding undisturbed background rock. The seven spectra acquired at each spot were averaged to obtain a single spectrum.

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

For most of the spots, mineralogically related absorptions were unchanged from 2004 to 2007, and only brightness (or reflectance) varied from year to year. However, some small changes were noted at two locations; Site 2 Spot 1 background, a small increase in the amount of iron oxides was detected and on the same site for Spot 2 background, a modest increase in the amount of gibbsite was detected. At Site 7 Spot 3 Background, a small decrease in the amount of iron oxides was also detected. These small changes affected only 3 points out of the 42 points from all the sites studied. It should also be noted that Site 2, where two of the changes were detected, is the furthest from industrial activities. No overall changes, for all engraving and background, at a site were observed. These small variations are local and correspond to natural mineralogical variations.

Finally, for the same spot at a site, the engravings contained less moisture than the corresponding background rock. Moisture content is the lowest in mid afternoon. Moisture has an impact on spectral behaviour, brightness decreases with increasing moisture.

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.

[3] Ramanaidou, E.R.; Cudahy, T.J., Determination of the hematite/goethite ratio by field VNIR spectroscopy, Proc. 1st Australian Conference on Vibrational Spectroscopy, University of Sydney, 1995, p. 92.

[4] Ramanaidou, E.R., Burrup Peninsula Aboriginal Petroglyphs: Spectral Mineralogy for 2004, CEM Report, 2005.

[5] Lau, D., Ramanaidou, E., Furman, S., Cole, I. and Hughes, T. (2005). Field studies of rock art appearance, interim report 1, CMIT(C)-2005-228, 68pp.

[6] Ramanaidou, E. R.; Pal, P., Detection of asbestos minerals using a field portable spectrometer, Proc. 3rd Australian Conference on Vibrational Spectroscopy, University of Melbourne, 29 September to 2 October 1998, pp. 184–185.

[7] Ramanaidou E. R.; Hacket, A.; Wells, M.A., *Burrup Peninsula Aboriginal Petroglyphs: Spectral Mineralogy for 2006*, CEM Report, 2006.

[8] Ramanaidou, E. R.; Wells, M. A.; Belton, D.; Verrall, M.; Ryan, C., *Mineralogical and Microchemical Methods for the Characterization of High-Grade BIF Derived Iron Ore*, Society of Economic Geologists Special Publication (in press).

Contact Us

Phone: 1300 363 400
+61 3 9545 2176
Email: enquiries@csiro.au
Web: www.csiro.au

Your CSIRO

Australia is founding its future on science and innovation. Its national science agency, CSIRO, is a powerhouse of ideas, technologies and skills for building prosperity, growth, health and sustainability. It serves governments, industries, business and communities across the nation.