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Burrup Peninsula Aboriginal Petroglyphs: Colour and Spectra Change 2004–2011

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EP123469 April 2012

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Acknowledgments

This work is performed in collaboration with CESRE, CSIRO and with the technical support of Bill Carr as part of the Burrup Rock Art Monitoring Program, supported by WA Government Department of Environment and Conservation.

Abstract

The man-made Burrup Peninsula is around 30 km long and 6 km wide and is located at 1300 km from Perth (Western Australia) and was named after Mount Burrup, the highest topographic point. The peninsula is of unique cultural and archaeological significance as it contains Australia's largest and most important collection of indigenous petroglyphs. Alongside the petroglyphs, the Burrup Peninsula has several large industrial complexes including iron ore, liquefied natural gas production, salt production and fertilisers with Australia's largest tonnage port. Since some of the petroglyphs adjoin industrial areas there has been very public concern expressed that the petroglyphs could be damaged by airborne emissions from the industry. In 2002, The Western Australian government established the independent Burrup Rock Art Monitoring Management Committee (BRAMMC) to review the available expertise and oversee the studies that were conducted to establish whether industrial emissions are likely to affect the petroglyphs.

In 2003 the BRAMMC commissioned a number of studies to monitor the petroglyphs. They included air dispersion modelling studies, air quality and microclimate; colour change, dust deposition and accelerated weathering study and mineral spectroscopy. The studies were based on the monitoring of seven sites with two control sites located on the northern Burrup area and the other five located further south on the lower Burrup Peninsula, closer to the industrial areas

For the last 8 years (2004 to 2011), petroglyphs at seven specially selected sites (chosen under the guidance of indigenous elders) in the Burrup Peninsula were measured using colour and reflectance spectroscopy measurements. Three spots on each engraving and three spots on each background rock were measured in situ using a portable spectrophotometer for colour measurement and a reflectance spectrometer for visible and near infrared spectral analysis. The 2004 spectral study is the baseline dataset that has been used to monitor potential variation during the last 8 years.

The comparison of the colour and spectral data collected and processed for both the Northern (control sites) and Southern sites shows no consistent trend in an increasing or decreasing direction. For the last 8 years no observed colour contrast change was detected.

1 Introduction

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

The petroglyphs of the seven sites were measured using two types of spectrometers: a photo spectrometer and a reflectance spectrometer. On each engraving and on each background rock three spots were measured *in situ*. The colour measurements were co-located with the reflectance measurements. The colour values were crosschecked to the colour value calculated by the reflectance spectrometer.

The first year of the study (2004) is the baseline dataset that has being used to monitor potential variation that occurred in the last 8 years. The study has assessed the colour and the mineralogy, monitored and explained the changes (if any) of the seven rock art.

2 Location and sampling of the petroglyphs

The sites for monitoring (Figure 1) 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).

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 between the photo spectrometer and the reflectance spectroscopy.

Table 1. 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

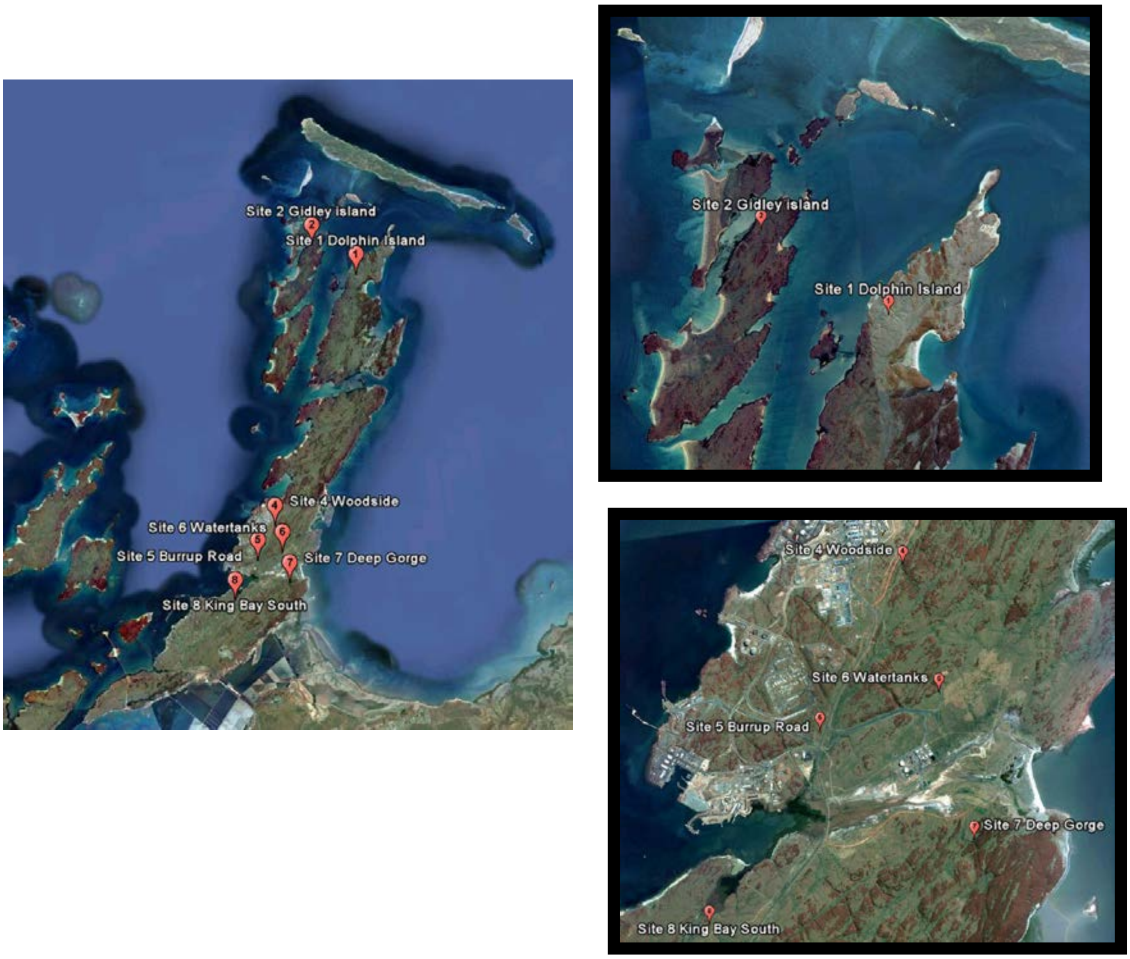


Figure 1. Google Earth® maps of the Burrup Peninsula with the petroglyphs location.

3 Colour Measurement

3.1 Introduction

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.

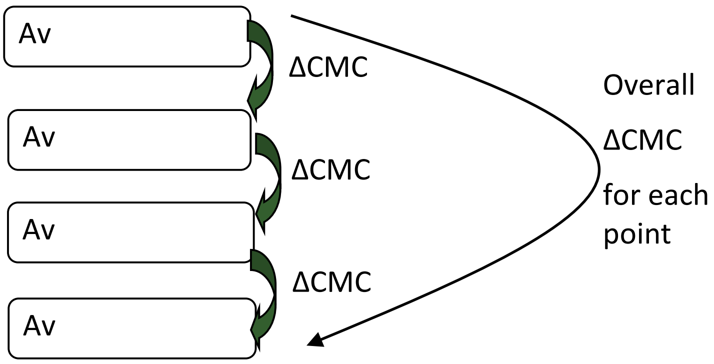
3.2 Experimental Methodology

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 2: Portable spectrophotometer used for colour measurements.

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

Repeatability	Inter-Instrument Agreement	Color System	Color Differences	Indices	Spectral Interval
0.01 ΛE, 1σ	0.02 ΛE, 1σ	CIELab/Ch; Lab(h); XYZ; Yxy; RxRyRz	ΛE; ΛE(h); ΛEFMC2; ΛE94; ΛECMC; 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)			

3.3 Results and Discussion

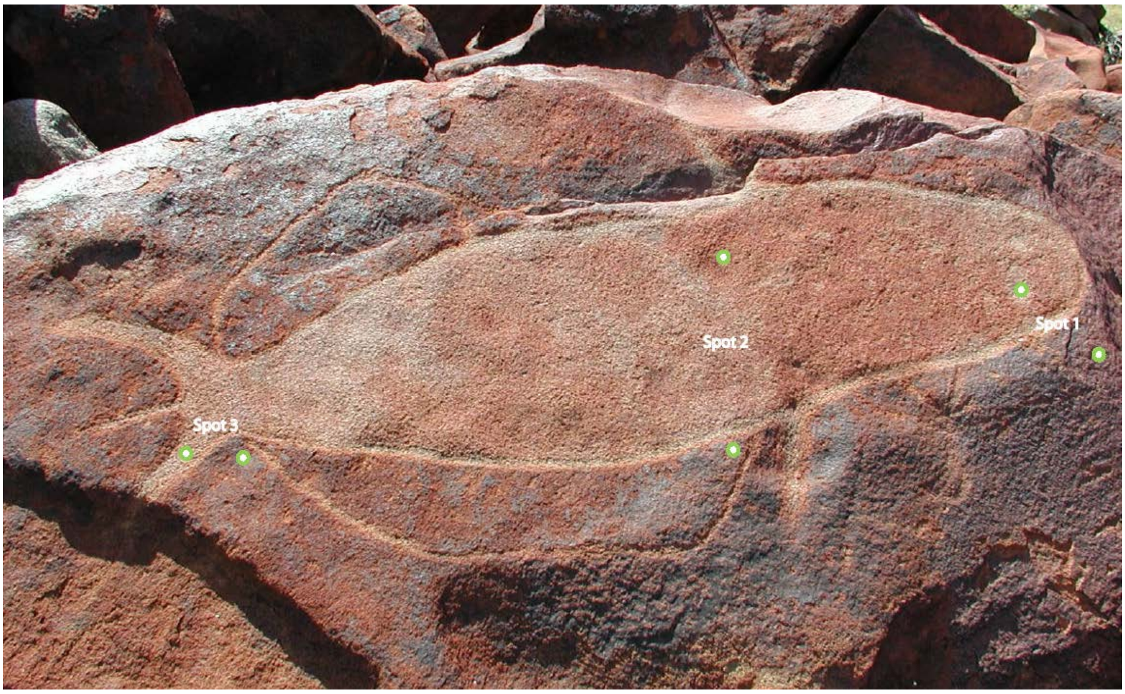
3.3.1 YEAR TO YEAR COLOUR DIFFERENCES

The following pages present photographs of the monitored petroglyphs at each site, showing the sampling points of engravings and background rock, and the average 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

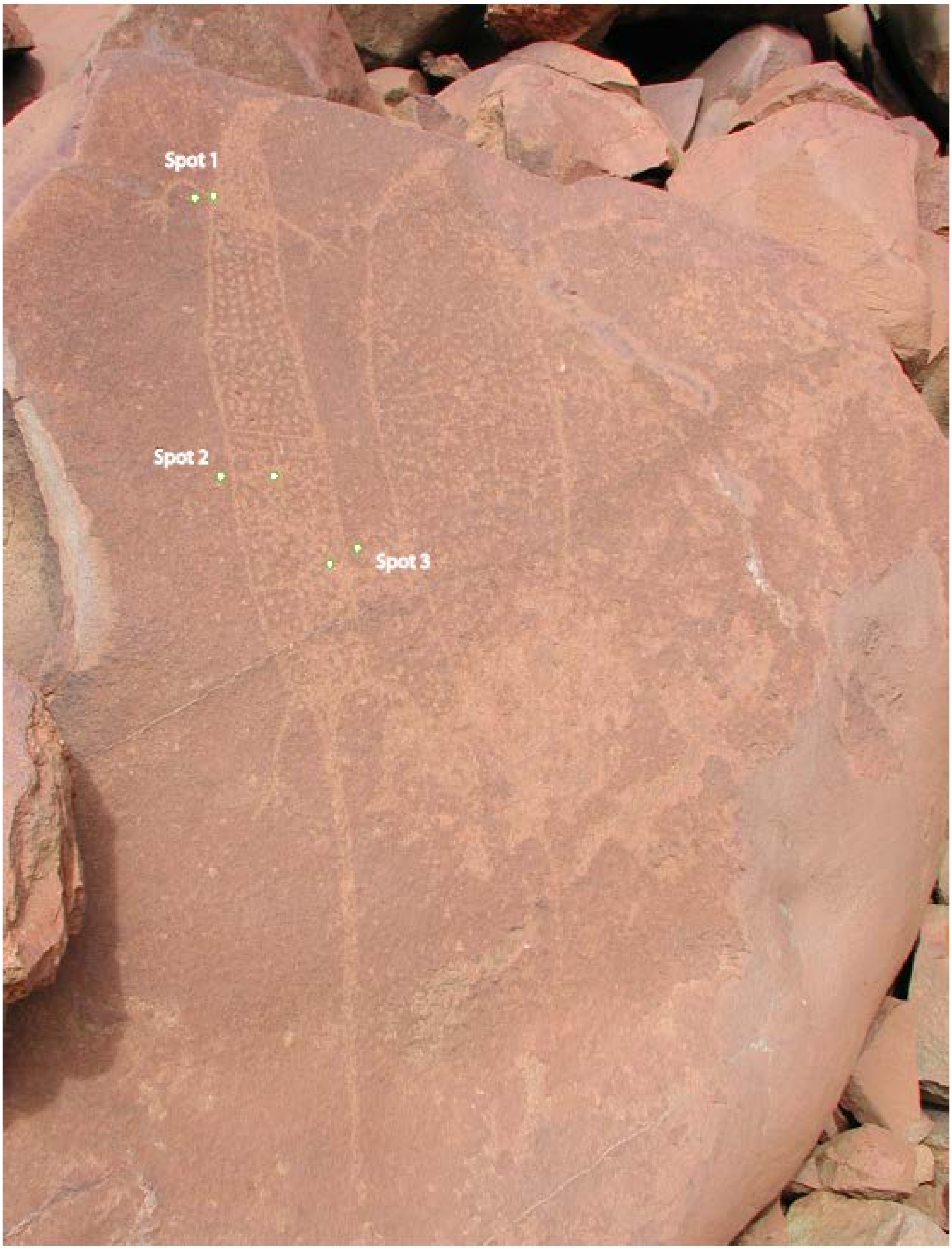


Sample	Colour scale L*	a*	b*	Colour difference* ΔE(change from previous year)
Site 1 Spot 1 Engraving				
Average 2011	37.62	8.74	15.42	13.54
Average 2010	24.33	6.48	14.19	2.78
Average 2009	23.16	8.65	15.49	6.53
Average 2008	19.10	4.54	12.45	2.34
Average 2007	17.16	5.71	13.03	2.39
Average 2006	16.79	3.83	11.59	3.04
Average 2005	14.97	6.08	12.53	2.16
Average 2004	14.32	8.08	13.00	
Site 1 Spot 1 Background				
Average 2011	33.34	11.35	10.40	4.20
Average 2010	29.57	11.05	12.23	5.15
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	28.97	10.29	10.33	1.84
Average 2005	27.66	11.26	11.20	2.24
Average 2004	29.87	11.20	10.79	
Site 1 Spot 2 Engraving				
Average 2011	29.61	15.43	16.45	21.13
Average 2010	10.44	8.39	11.00	0.67
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	8.37	8.22	9.26	1.84
Average 2005	7.91	9.84	9.99	0.69
Average 2004	8.43	9.62	9.59	
Site 1 Spot 2 Background				
Average 2011	29.51	10.18	10.79	1.50
Average 2010	29.96	10.30	12.21	4.28
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	28.82	10.21	11.06	7.88
Average 2005	20.98	9.46	11.46	6.74
Average 2004	27.66	10.35	11.87	
Site 1 Spot 3 Engraving				
Average 2011	36.38	13.72	18.05	15.75
Average 2010	21.27	9.78	15.98	8.92
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	23.22	10.68	16.27	3.16
Average 2005	25.67	12.25	17.51	3.02
Average 2004	28.67	12.12	17.18	
Site 1 Spot 3 Background				
Average 2011	27.66	12.40	12.92	15.00
Average 2010	13.36	8.43	10.76	9.62
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	13.07	7.30	9.25	2.43
Average 2005	11.45	8.75	10.33	2.44
Average 2004	13.42	7.98	9.11	

Site 2: Gidley Island

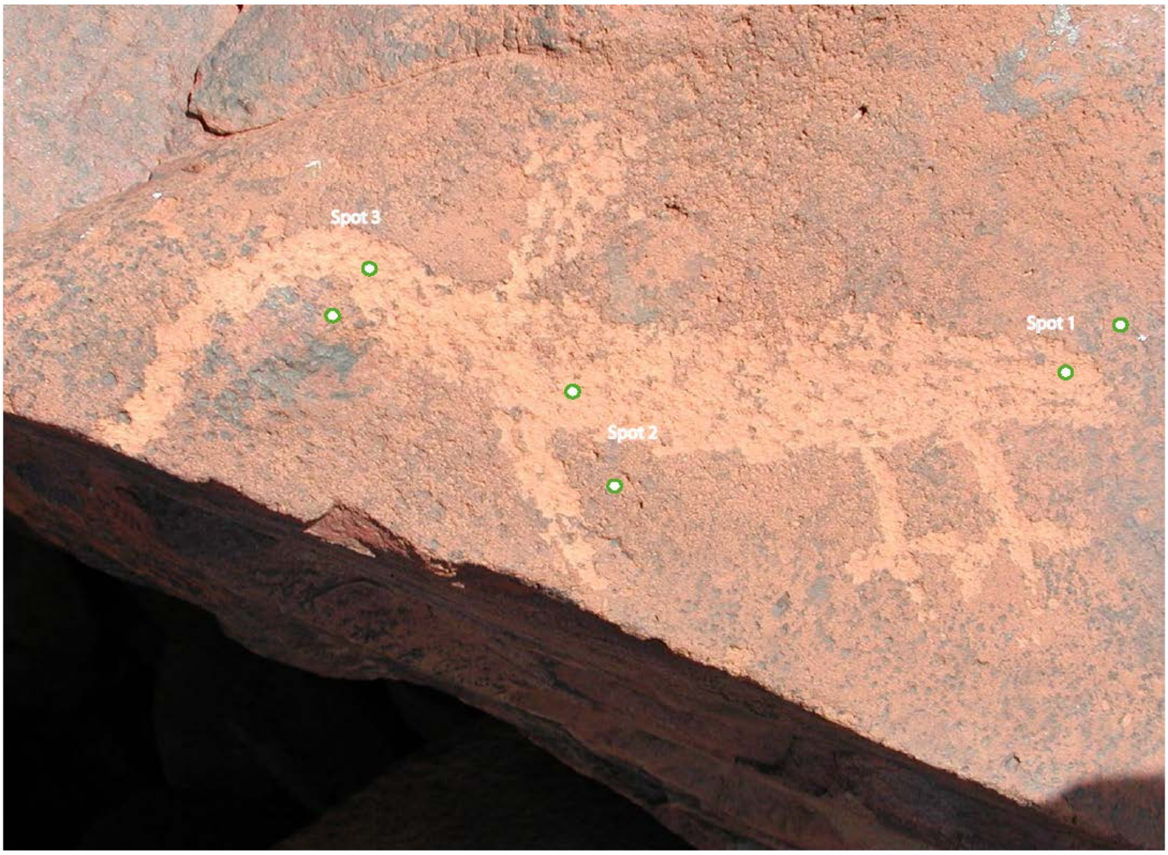
Sample	Colour scale L*	a*	b*	Colour difference* ΔE(change from previous year)
Site 2 Spot 1 Engraving				
Average 2011	39.10	9.22	16.56	2.92
Average 2010	36.37	8.21	16.78	3.85
Average 2009	32.61	9.04	16.92	2.16
Average 2008	32.99	7.11	16.02	2.23
Average 2007	31.06	7.44	14.96	3.72
Average 2006	34.10	7.79	17.07	1.62
Average 2005	33.58	9.26	17.50	2.29
Average 2004	31.90	8.96	15.98	
Site 2 Spot 1 Background				
Average 2011	31.45	10.38	12.03	5.41
Average 2010	26.44	8.70	10.87	5.68
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	26.54	9.16	11.82	2.14
Average 2005	27.01	9.88	13.77	4.63
Average 2004	22.51	9.00	13.20	
Site 2 Spot 2 Engraving				
Average 2011	42.67	10.90	20.28	8.45
Average 2010	34.37	9.62	19.35	4.50
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	34.10	9.11	19.37	1.72
Average 2005	34.02	10.67	20.11	3.30
Average 2004	31.01	10.15	18.84	
Site 2 Spot 2 Background				
Average 2011	27.95	11.19	10.11	2.16
Average 2010	26.38	10.53	11.44	4.22
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	26.99	11.49	11.49	2.09
Average 2005	26.42	12.71	13.09	2.89
Average 2004	25.80	10.77	11.04	
Site 2 Spot 3 Engraving				
Average 2011	40.27	11.26	19.59	4.90
Average 2010	35.62	9.84	19.06	6.11
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	33.04	10.82	20.02	0.82
Average 2005	33.22	10.56	19.26	5.57
Average 2004	27.68	10.56	18.70	
Site 2 Spot 3 Background				
Average 2011	29.65	13.37	16.85	9.62
Average 2010	20.19	11.70	16.24	1.17
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	15.82	10.24	14.72	6.40
Average 2005	21.40	12.57	16.82	2.68
Average 2004	18.82	12.25	16.15	

Site 4: Woodside



Sample	Colour scale L*	a*	b*	Colour difference* ΔE(change from previous year)
Site 4 Spot 1 Engraving				
Average 2011	33.06	15.98	18.78	9.33
Average 2010	24.27	13.08	17.57	8.40
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	25.36	13.07	17.96	2.44
Average 2005	23.27	14.26	18.34	1.17
Average 2004	22.72	13.84	17.40	
Site 4 Spot 1 Background				
Average 2011	28.75	13.68	14.34	10.98
Average 2010	18.35	10.39	13.02	10.59
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	20.71	11.13	13.88	2.03
Average 2005	19.22	12.50	14.02	1.12
Average 2004	20.10	12.06	13.50	
Site 4 Spot 2 Engraving				
Average 2011	32.47	15.37	18.42	18.50
Average 2010	15.26	10.35	13.88	8.94
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	1.79
Average 2006	14.47	10.11	13.72	2.25
Average 2005	14.55	11.92	15.05	1.26
Average 2004	14.56	10.86	14.38	
Site 4 Spot 2 Background				
Average 2011	31.29	14.80	15.96	2.29
Average 2010	29.13	14.21	16.44	7.06
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	3.66
Average 2006	27.78	13.47	15.52	1.65
Average 2005	26.27	13.66	16.13	0.35
Average 2004	26.52	13.90	16.11	
Site 4 Spot 3 Engraving				
Average 2011	35.14	16.41	20.23	11.71
Average 2010	24.12	13.02	18.21	6.92
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	24.31	12.43	18.13	2.61
Average 2005	23.42	14.49	19.48	1.83
Average 2004	22.41	13.68	18.19	
Site 4 Spot 3 Background				
Average 2011	31.68	14.76	15.70	4.62
Average 2010	27.38	13.11	15.25	6.29
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	28.76	13.10	14.79	4.00
Average 2005	25.30	13.83	16.65	1.99
Average 2004	26.33	13.30	15.04	

Site 5: Burrup Rd

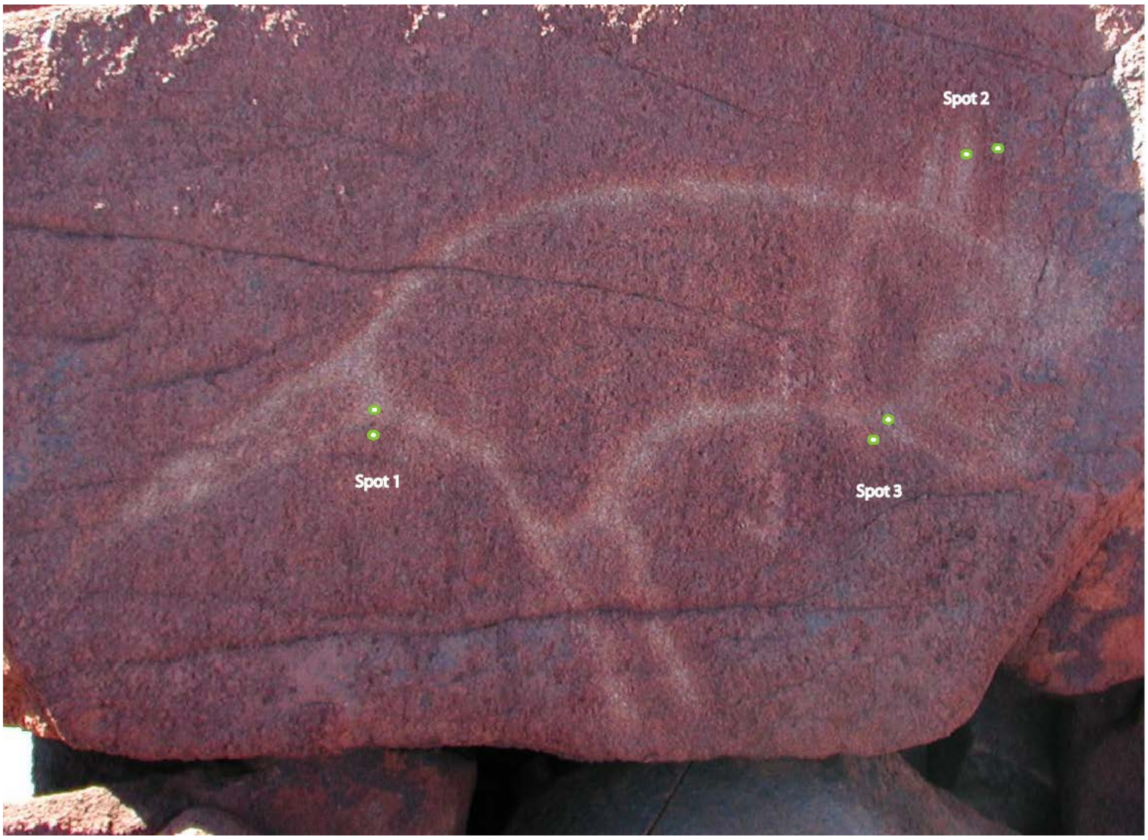


Sample	Colour scale L*	a*	b*	Colour difference* ΔE(change from previous year)
Site 5 Spot 1 Engraving				
Average 2011	36.56	18.22	21.96	10.76
Average 2010	26.43	14.97	20.31	6.78
Average 2009	30.53	14.37	14.95	5.90
Average 2008	26.73	14.82	19.44	1.84
Average 2007	27.80	15.74	20.62	6.52
Average 2006	21.82	13.58	19.19	2.33
Average 2005	22.23	15.50	20.44	4.38
Average 2004	18.90	14.24	17.88	
Site 5 Spot 1 Background				
Average 2011	33.87	13.22	13.98	4.71
Average 2010	29.73	13.53	16.21	6.46
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	3.64
Average 2006	29.53	10.88	12.22	6.28
Average 2005	27.38	14.45	16.92	5.13
Average 2004	22.94	12.89	14.88	
Site 5 Spot 2 Engraving				
Average 2011	34.56	18.43	21.75	9.68
Average 2010	25.46	15.89	19.63	1.68
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	27.52	16.20	21.24	4.86
Average 2005	22.76	16.80	22.02	1.68
Average 2004	22.99	16.78	20.35	
Site 5 Spot 2 Background				
Average 2011	31.18	13.78	14.55	2.76
Average 2010	28.54	13.65	15.36	1.73
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	2.32
Average 2006	27.19	13.76	15.23	3.61
Average 2005	29.53	15.28	17.53	
Average 2004	No 2004 measurements			
Site 5 Spot 3 Engraving				
Average 2011	37.61	19.54	23.30	8.65
Average 2010	29.66	16.28	22.33	3.20
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	35.58	17.40	23.67	7.25
Average 2005	28.45	17.51	22.35	9.24
Average 2004	36.88	20.01	25.21	
Site 5 Spot 3 Background				
Average 2011	35.69	14.51	14.71	3.34
Average 2010	32.52	14.01	15.66	1.61
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	17.28
Average 2006	32.64	13.27	14.07	6.72
Average 2005	26.14	14.02	15.60	1.00
Average 2004	25.31	13.75	15.11	

Site 6: Water Tanks

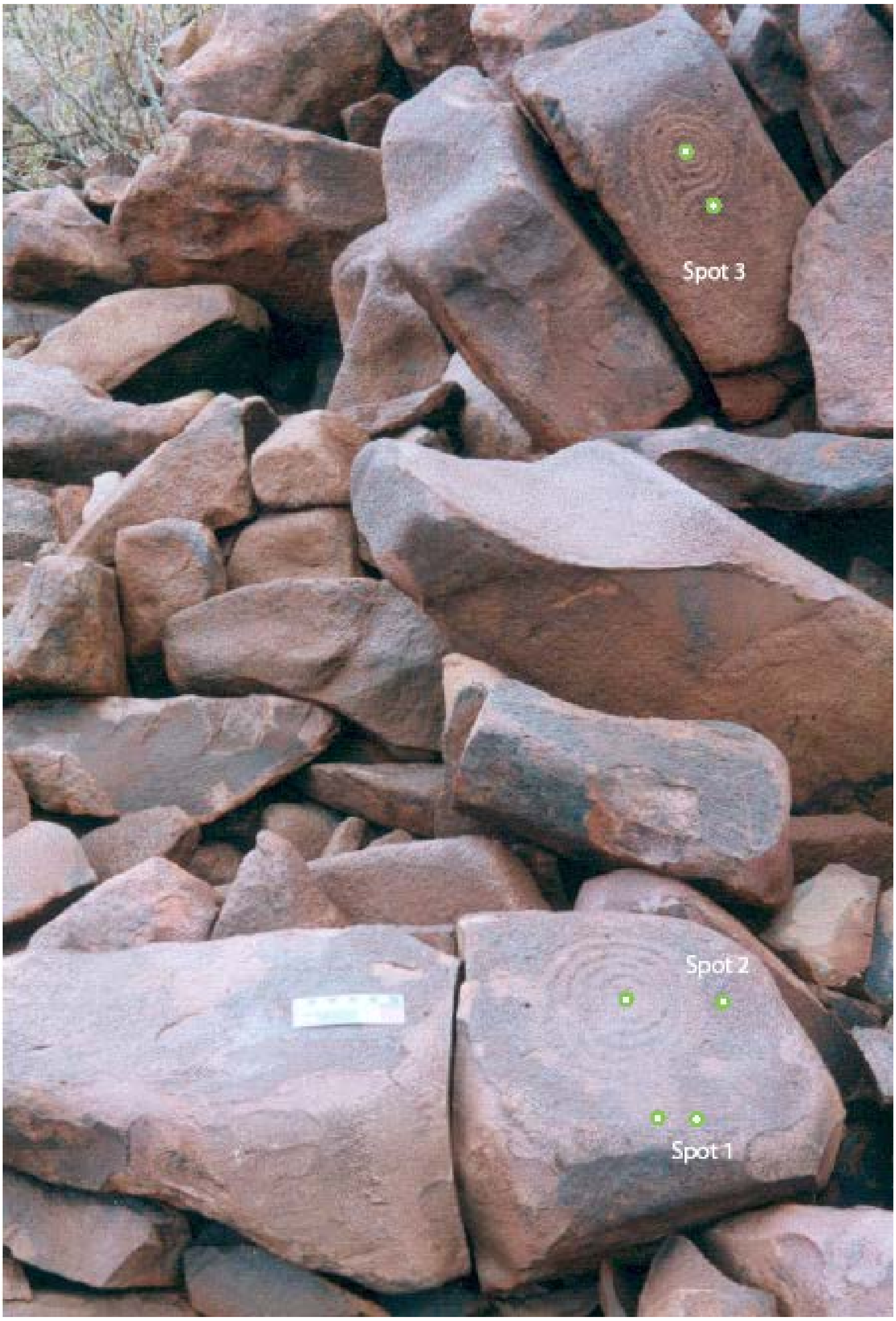
Sample	Colour scale			Colour difference* ΔE(change from previous year)
	L*	a*	b*	
Site 6 Spot 1 Engraving				
Average 2011	39.94	11.41	17.17	2.82
Average 2010	37.23	10.86	17.75	2.33
Average 2009	36.92	9.15	16.20	2.89
Average 2008	34.15	9.73	16.80	0.39
Average 2007	34.37	9.96	17.03	2.87
Average 2006	36.83	11.28	17.69	1.28
Average 2005	35.71	11.56	18.24	5.56
Average 2004	30.20	12.27	18.25	
Site 6 Spot 1 Background				
Average 2011	38.72	12.60	17.05	3.05
Average 2010	35.72	12.19	17.45	3.01
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	36.89	13.76	18.51	3.02
Average 2005	34.04	12.80	18.20	2.85
Average 2004	36.87	13.22	18.25	
Site 6 Spot 2 Engraving				
Average 2011	38.99	11.06	16.44	5.75
Average 2010	33.29	10.88	17.16	0.57
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	0.72
Average 2006	33.47	11.10	16.81	2.28
Average 2005	31.25	11.24	17.31	2.53
Average 2004	33.73	11.01	16.87	
Site 6 Spot 2 Background				
Average 2011	37.71	12.97	16.55	2.43
Average 2010	35.64	11.78	16.09	0.68
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	0.78
Average 2006	35.90	11.98	15.83	1.09
Average 2005	34.86	11.90	16.12	1.72
Average 2004	35.27	13.08	17.31	
Site 6 Spot 3 Engraving				
Average 2011	38.51	10.89	15.66	4.70
Average 2010	33.90	10.12	16.07	11.39
Average 2009 (bird droppings on spot)	42.59	4.52	11.28	
Average 2008	35.59	9.61	15.75	1.51
Average 2007	34.18	10.03	16.08	0.86
Average 2006	33.49	10.26	15.62	2.56
Average 2005	34.97	11.45	17.34	1.54
Average 2004	36.39	11.09	16.88	
Site 6 Spot 3 Background				
Average 2011	38.27	12.18	16.26	2.12
Average 2010	36.28	12.16	16.98	2.85
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	36.03	11.19	15.51	3.31
Average 2005	35.59	13.40	17.93	1.45
Average 2004	36.88	12.77	17.69	

Site 7: Deep Gorge



Sample	Colour scale			Colour difference* ΔE(change from previous year)
	L*	a*	b*	
Site 7 Spot 1 Engraving				
Average 2011	34.13	13.94	17.71	10.58
Average 2010	24.09	10.65	17.33	7.67
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	12.89	8.47	11.74	17.84
Average 2005	28.13	14.49	18.79	23.71
Average 2004	7.10	8.55	9.60	
Site 7 Spot 1 Background				
Average 2011	26.25	13.21	13.85	3.00
Average 2010	26.55	14.53	16.52	5.50
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	3.35
Average 2006	19.85	12.01	14.06	3.00
Average 2005	17.04	12.99	13.74	1.41
Average 2004	17.08	13.26	15.13	
Site 7 Spot 2 Engraving				
Average 2011	27.83	14.28	16.10	12.76
Average 2010	15.60	11.44	13.82	10.47
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	5.50	5.66	6.36	6.80
Average 2005	11.02	8.56	9.07	8.75
Average 2004	3.51	6.44	5.12	
Site 7 Spot 2 Background				
Average 2011	27.07	14.47	14.68	13.02
Average 2010	14.68	11.27	12.30	9.30
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	17.85	11.89	13.48	3.49
Average 2005	14.56	12.93	12.97	10.14
Average 2004	24.65	12.01	13.36	
Site 7 Spot 3 Engraving				
Average 2011	27.01	12.69	14.95	
Average 2010	data unreliable			N/A
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	12.77	9.35	11.52	15.86
Average 2005	2.00	2.42	2.17	N/A
Average 2004	No 2004 measurements			
Site 7 Spot 3 Background				
Average 2011	23.84	10.99	11.66	13.54
Average 2010	10.76	8.24	9.51	8.86
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	11.62
Average 2006	19.22	11.73	13.46	8.59
Average 2005	11.27	10.21	10.58	8.87
Average 2004	18.44	13.30	14.79	

Site 8: King Bay South



Sample	Colour scale			Colour difference* ΔE(change from previous year)
	L*	a*	b*	
Site 8 Spot 1 Engraving				
Average 2011	34.12	13.76	14.78	9.34
Average 2010	25.05	11.55	15.10	2.84
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	28.28	13.43	16.38	2.53
Average 2005	25.77	13.71	16.33	5.59
Average 2004	31.26	14.75	16.12	
Site 8 Spot 1 Background				
Average 2011	32.52	11.86	12.08	4.06
Average 2010	28.60	11.03	12.67	1.40
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	26.48	10.55	12.13	2.54
Average 2005	27.10	12.56	13.54	1.31
Average 2004	27.41	11.91	12.46	
Site 8 Spot 2 Engraved				
Average 2011	34.25	14.28	15.49	18.96
Average 2010	16.15	9.38	12.66	5.89
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	17.80	9.77	12.59	10.32
Average 2005	27.28	13.24	14.74	6.39
Average 2004	20.94	12.58	14.34	
Site 8 Spot 2 Background				
Average 2011	31.46	11.99	12.13	3.61
Average 2010	28.01	11.25	12.87	2.41
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	25.81	10.27	11.83	2.57
Average 2005	23.69	11.53	12.56	2.21
Average 2004	25.87	11.69	12.18	
Site 8 Spot 3 Engraved				
Average 2011	34.28	16.11	20.30	11.44
Average 2010	23.59	12.84	17.89	1.25
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	22.85	12.46	17.59	6.21
Average 2005	16.79	12.23	16.24	5.26
Average 2004	21.72	13.40	17.68	
Site 8 Spot 3 Background				
Average 2011	31.63	15.02	17.46	6.87
Average 2010	25.11	12.84	17.52	4.01
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	22.57	12.53	15.33	1.62
Average 2005	24.03	13.19	15.50	3.19
Average 2004	26.98	13.09	14.27	

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 10–11	ΔE 09–10	ΔE 08–09	ΔE 07–08	ΔE 06–07	ΔE 05–06	ΔE 04–05
4	**9.57**	8.03	7.02	2.9	2.42	1.89	1.29
5	**6.65**	3.57	6.23	3.2	6.95	4.77	4.29
6	**3.48**	3.47	2.39	1.4	1.58	2.43	2.61
7	**10.58**	8.36	8.26	3.8	7.58	6.1	10.58
8	**9.05**	2.97	2.28	2.3	2.95	4.14	3.99
Overall southern sites average	7.87						
1	**11.85**	5.24	6.46	4.1	4.5	3.12	2.97
2	**5.58**	4.25	3.86	4	2.38	3.01	3.56
Overall northern sites average	8.72						

The seven 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.

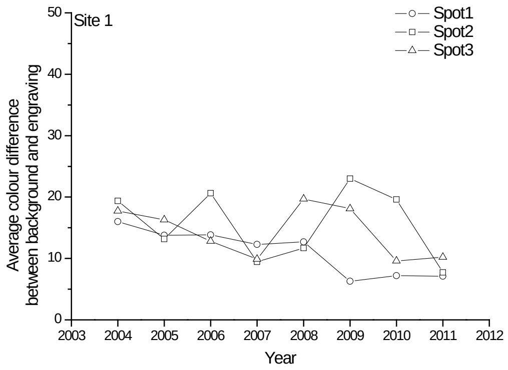
Considering the year to year ΔE values for 2004–11, which indicates the colour change over the five-year interval from 2004 to 2009, site 7 displayed the greatest year to year colour change, and this was consistent with the 2004–11 interval. For sites 4, 6 and 8 (southern), the colour change values for 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.

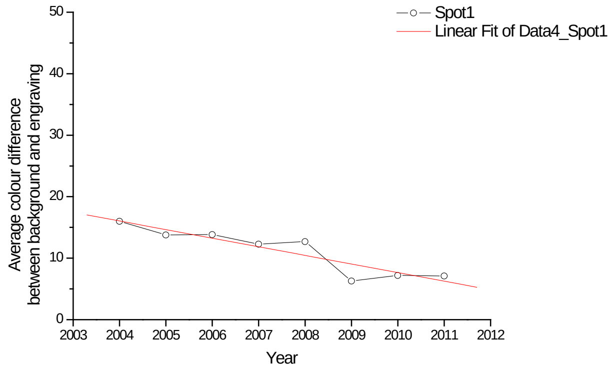
Where the colour difference appeared to have larger values overall (sites 5 and 7), this is believed to be partially due to the surface roughness of the rock, which influenced the placement of the spectrophotometer. At site 5, spot 3 there is a large patch of black patina which means that colour measurement 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 ignoring 2004 values for spots 1 & 2 engraved since the consistent values for subsequent years suggest 2004 measurements for those points were anomalous.

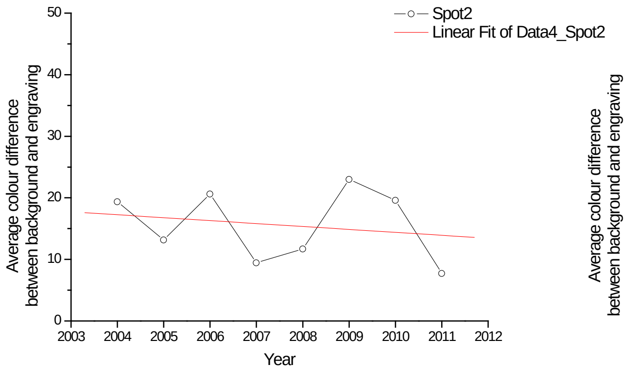
3.3.2 BACKGROUND – ENGRAVING COLOUR DIFFERENCE

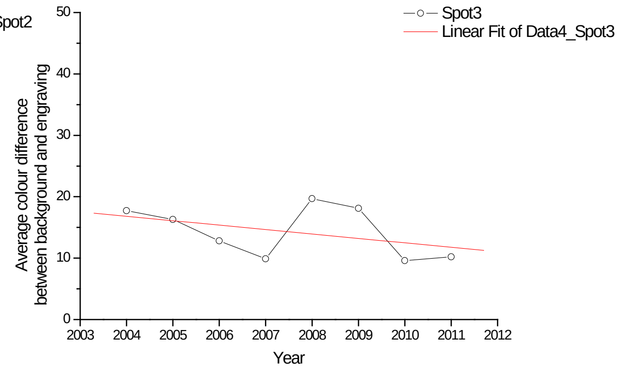
Table 4: Colour difference between background and petroglyph

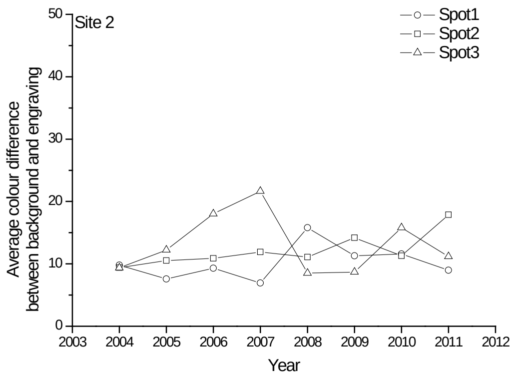
Spot 1	Site 1	Site 2	Site 4	Site 5	Site 6	Site 7	Site 8
Average 2011	**7.1**	**9.0**	**6.6**	**9.8**	**1.7**	**8.8**	**3.7**
Average 2010	7.2	11.6	7.9	5.5	2.0	4.7	4.3
Average 2009	6.3	12.9	5.4	5.6	4.7	3.7	5.1
Average 2008	12.7	5.5	6.4	3.4	2.8	11.6	4.2
Average 2007	12.3	6.9	8.4	6.3	4.5	3.2	2.7
Average 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 2011	**7.7**	**17.9**	**2.8**	**9.2**	**2.3**	**1.6**	**4.9**
Average 2010	19.6	11.3	14.6	5.7	2.7	1.8	12.0
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 2011	**10.2**	**11.2**	**5.9**	**10.1**	**1.4**	**4.9**	**4.0**
Average 2010	9.6	15.8	4.4	7.6	3.3		1.6
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

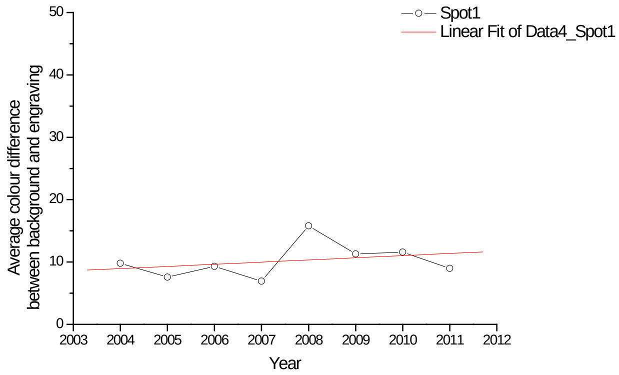

Site 1
Spot1
Spot2
Spot3
Average colour difference between background and engraving
Year

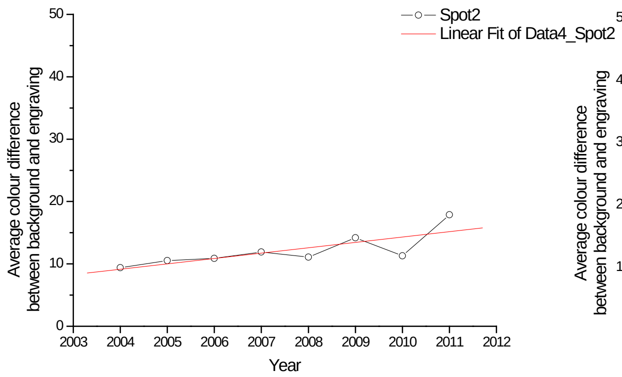

Spot1
Linear Fit of Data4_Spot1
Average colour difference between background and engraving
Year

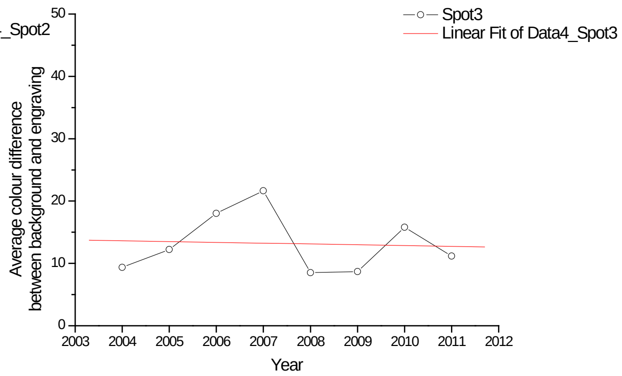

Spot2
Linear Fit of Data4_Spot2
Average colour difference between background and engraving
Year

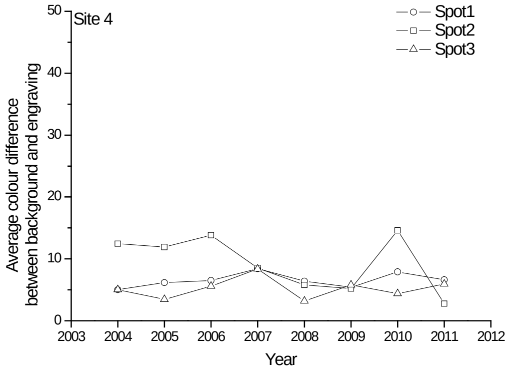

Spot3
Linear Fit of Data4_Spot3
Average colour difference between background and engraving
Year

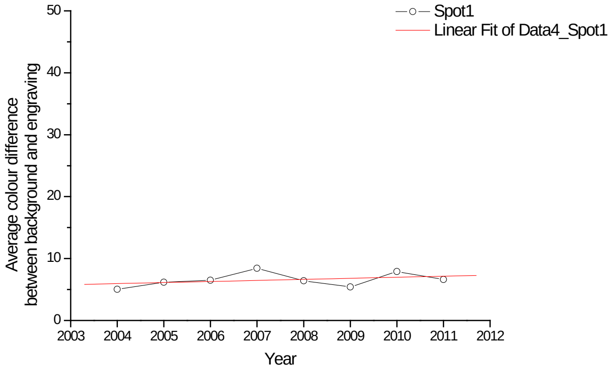

Site 2
Spot1
Spot2
Spot3
Average colour difference between background and engraving
Year

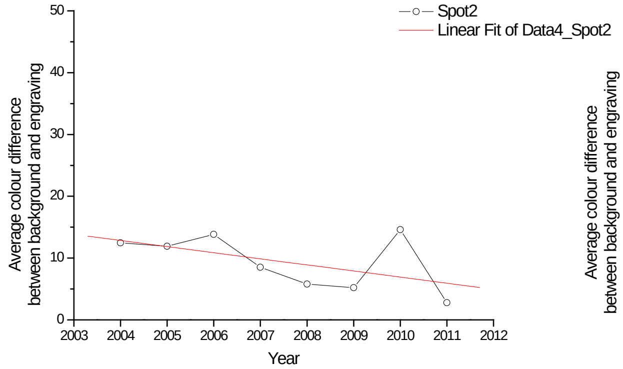

Spot1
Linear Fit of Data4_Spot1
Average colour difference between background and engraving
Year

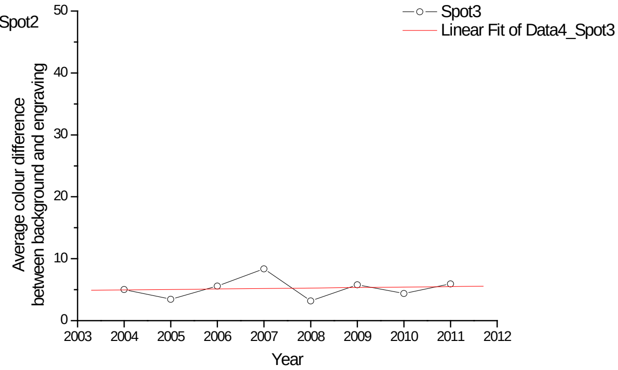

Spot2
Linear Fit of Data4_Spot2
Average colour difference between background and engraving
Year

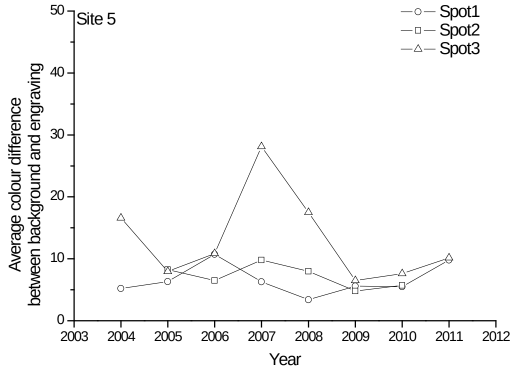

Spot3
Linear Fit of Data4_Spot3
Average colour difference between background and engraving
Year

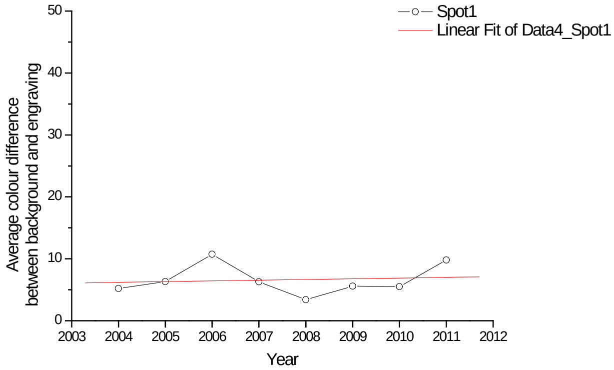

Site 4
Spot1
Spot2
Spot3
Average colour difference between background and engraving
Year

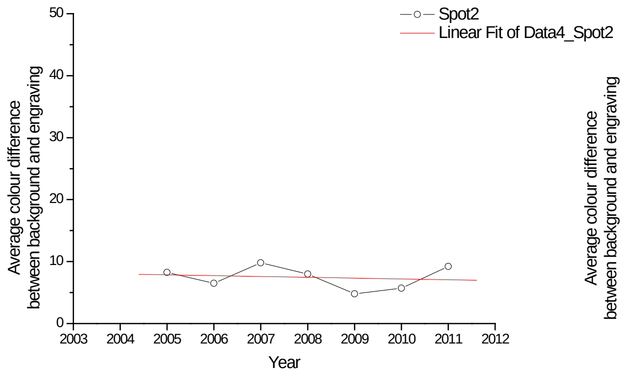

Spot1
Linear Fit of Data4_Spot1
Average colour difference between background and engraving
Year

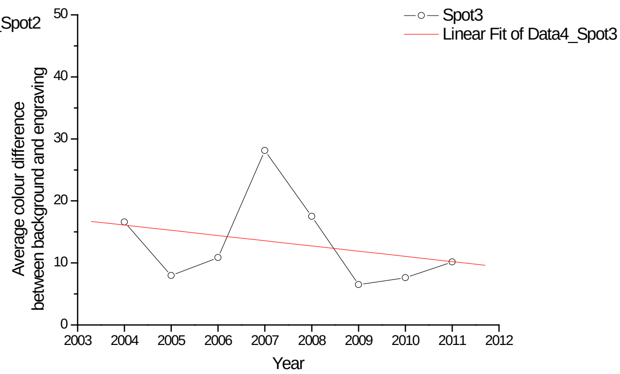

Spot2
Linear Fit of Data4_Spot2
Average colour difference between background and engraving
Year

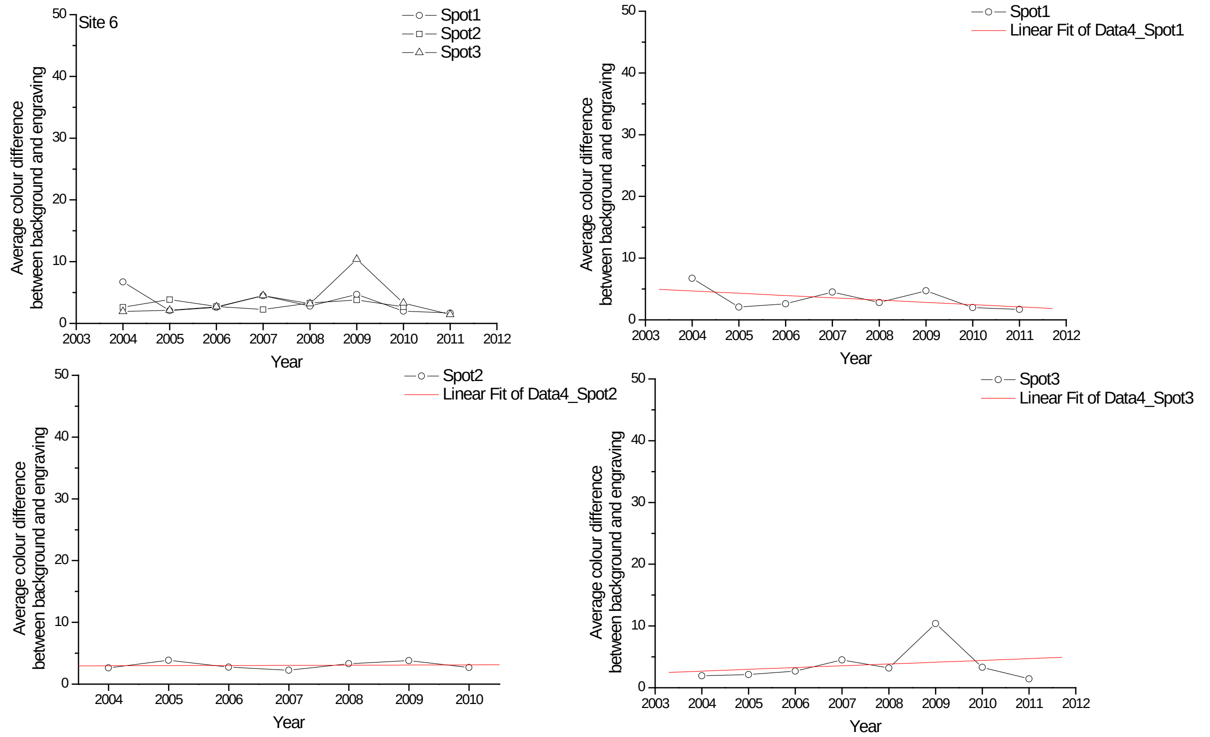

Spot3
Linear Fit of Data4_Spot3
Average colour difference between background and engraving
Year

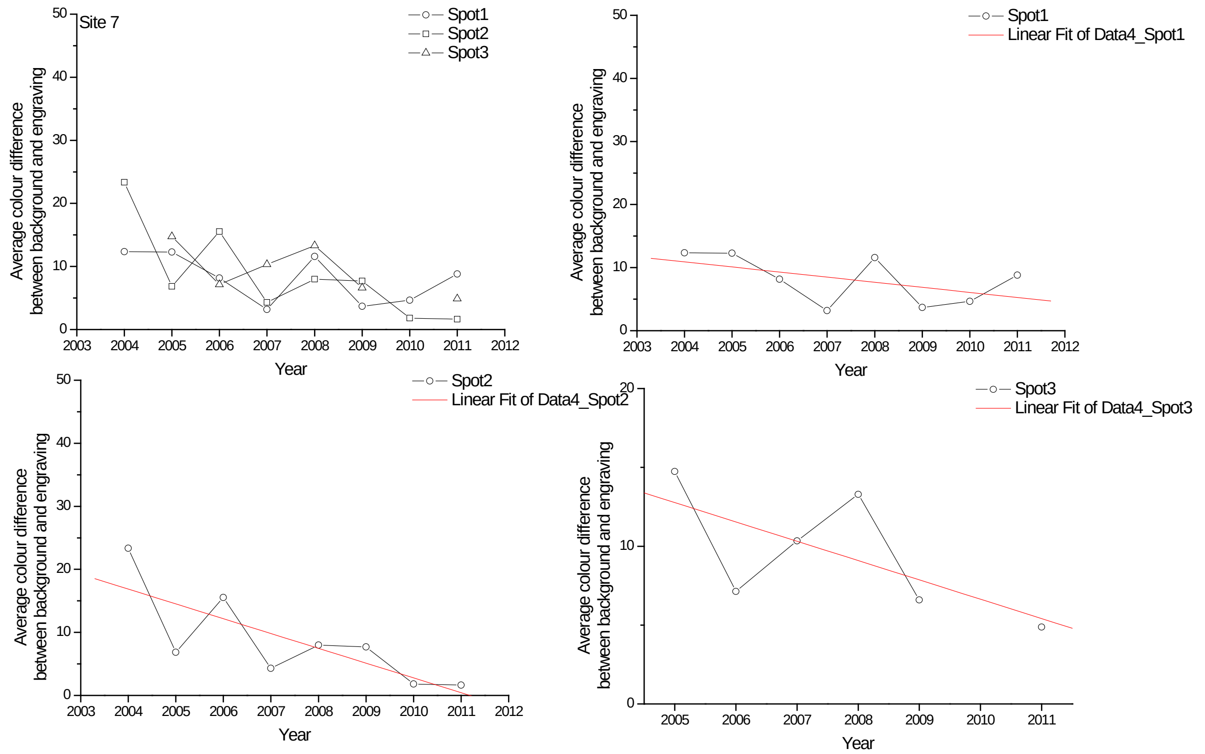

Site 5
Spot1
Spot2
Spot3
Average colour difference between background and engraving
Year


Spot1
Linear Fit of Data4_Spot1
Average colour difference between background and engraving
Year


Spot2
Linear Fit of Data4_Spot2
Average colour difference between background and engraving
Year


Spot3
Linear Fit of Data4_Spot3
Average colour difference between background and engraving
Year


Site 6
Spot1
Spot2
Spot3
Linear Fit of Data4_Spot1
Linear Fit of Data4_Spot2
Linear Fit of Data4_Spot3
Average colour difference between background and engraving
Year


Site 7
Spot1
Spot2
Spot3
Linear Fit of Data4_Spot1
Linear Fit of Data4_Spot2
Linear Fit of Data4_Spot3
Average colour difference between background and engraving
Year

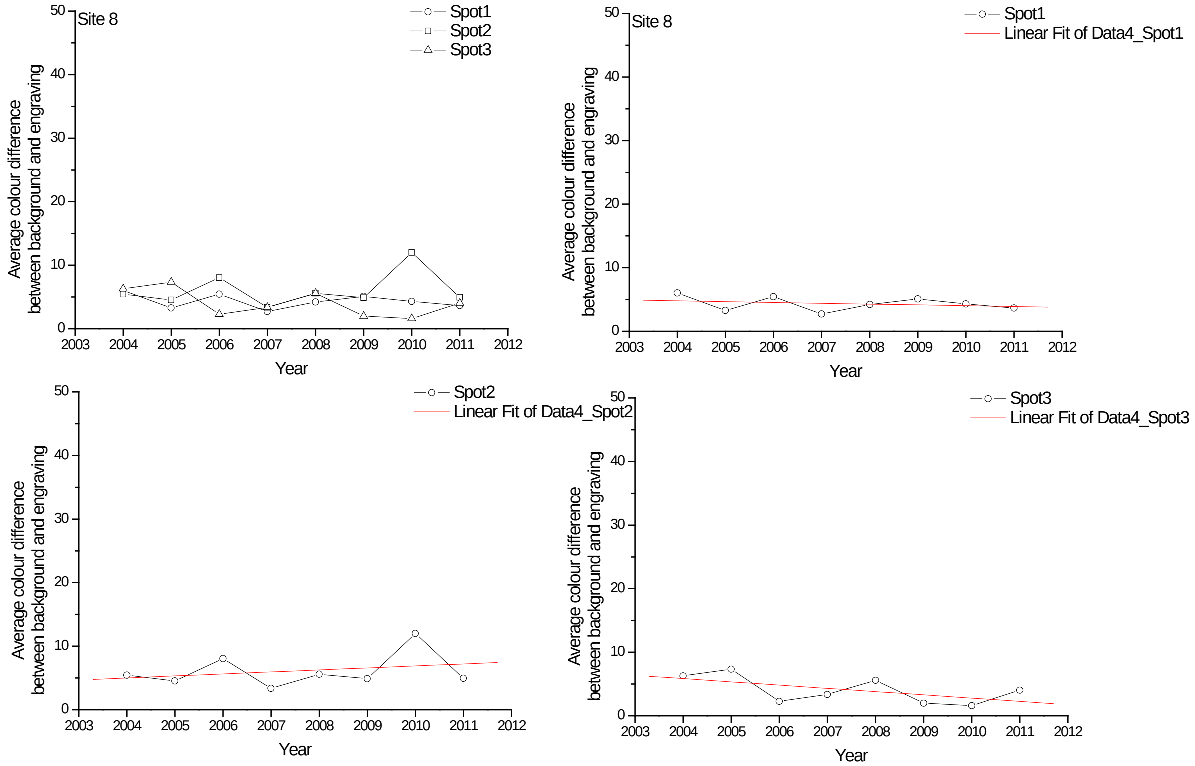


Figure 3: Site specific plots of colour differences between engraving and background for each spot examined (2004–2010). Site 5 spot 3 and Site 7 spot 2 are believed to exhibit high variance in single years due to irregular measurements.

The colour difference between the background and petroglyph for each spot is presented in Table 4 and plotted in Figure 2. The absences in the two data table in 2004 are because no data was collected for site 5 spot 2 background, and site 7 spot 3 engraving during the initial year of collection. 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 between the petroglyph and engraving 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.

In the colour change report from 2010, it was indicated the data would be represented against a line of best fit to indicate the overall trend. This is presented here for each individual engraving-background spot-pair, for each site.

Over time, a consistent trend toward smaller colour differences between background and petroglyph would indicate either background fading or darkening of the petroglyph, or both. Sites 6 and 8 already exhibit the least colour contrast between the petroglyph and background, with lower colour difference values. For site one at the Northern sites, there is an observable slight trend toward lower average colour difference. For site two, there is a slight trend to increased averaged colour difference, so there is not a consistent directional trend. For the southern sites seven the measurements are quite variable, consistent with the roughness of the surface but a linear fit indicates a decreasing colour difference trend. Sites four, five, six and eight are relatively flat. As shown in the plots presented in Figure 2, any trend towards less contrast between the background and engraved image in the southern sites has not been observed to be markedly different from that observed in the northern sites data.

4 Conclusions

The measurements made in August 2011 continue the annual collection of annual ΔE colour measurements since 2004. 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 and three slightly lower than the controls. Therefore the current indication is there was no consistent perceptible increase in colour change over the period 2004–11.

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.

5 References

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.

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

6 Spectral Mineralogy

6.1 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.

6.2 Spectral Results for 2004-2011

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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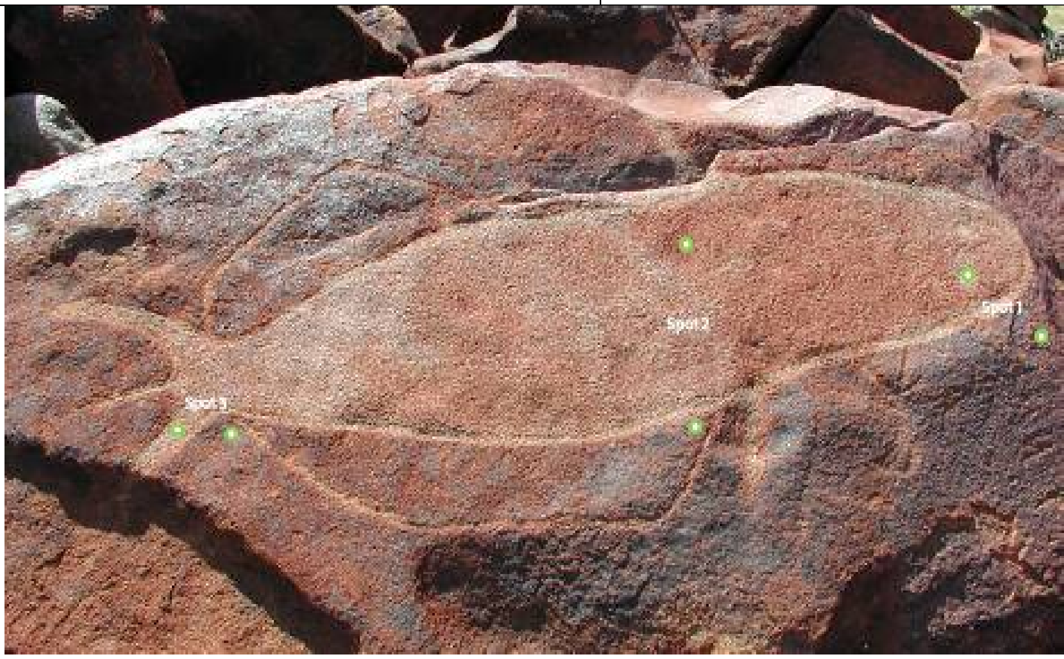
<tr><td>Location</td><td>Spectra Engraving</td><td>Spectra Background</td></tr>
<tr><td>Site 1</td><td colspan="2">
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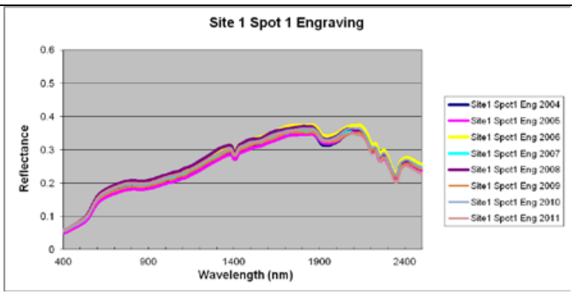
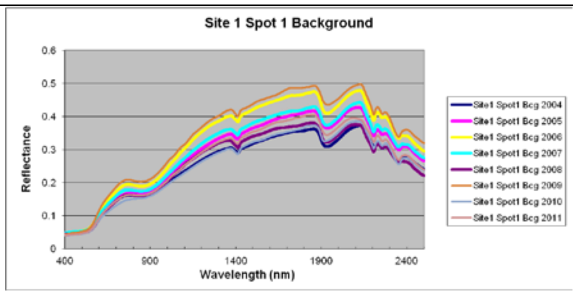
Spot 1</td><td>
</td><td>
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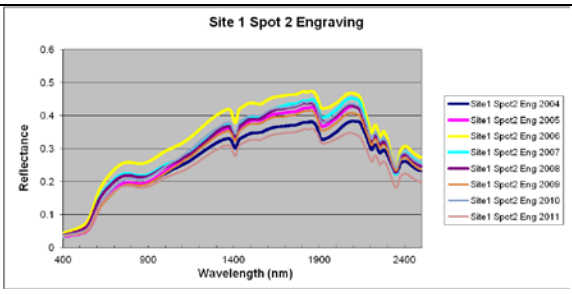
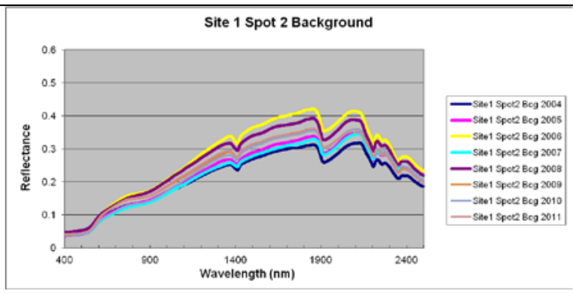
Spot 2</td><td>
</td><td>
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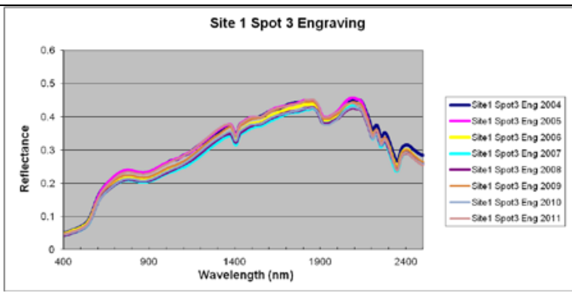
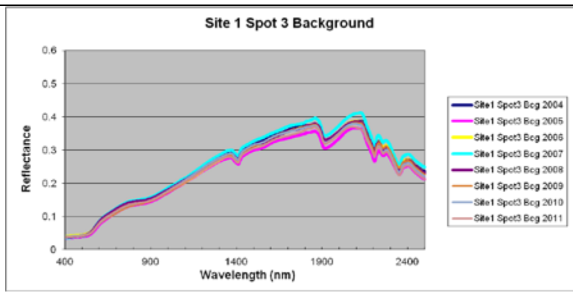
Spot 3</td><td>
</td><td>
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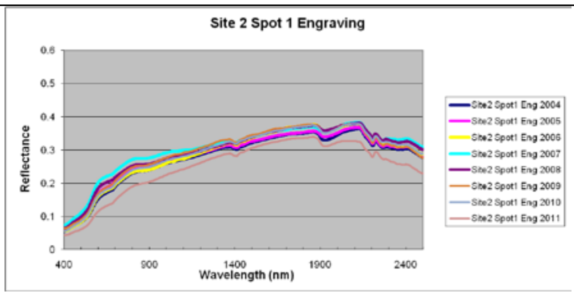
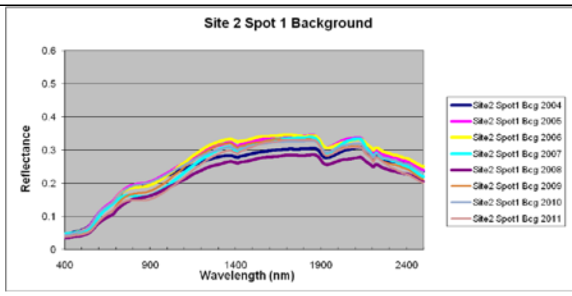
Spot 1</td><td>
</td><td>
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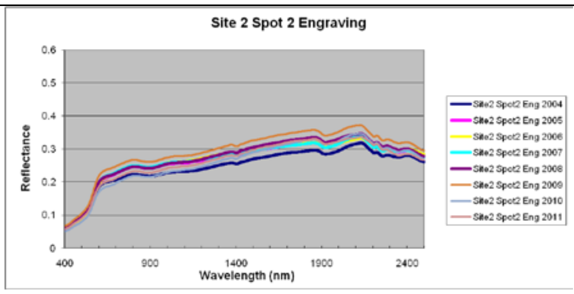
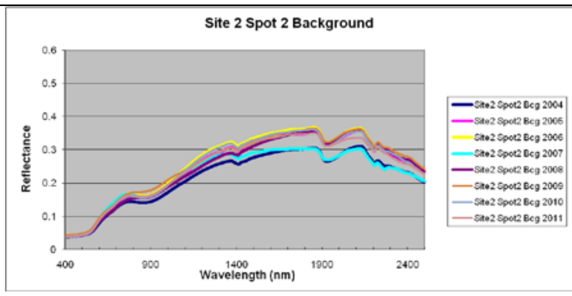
Spot 2</td><td>
</td><td>
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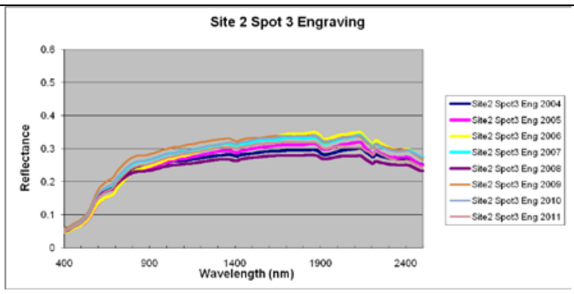
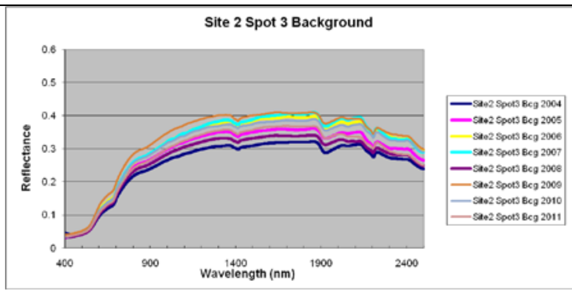
Spot 3</td><td>
</td><td>
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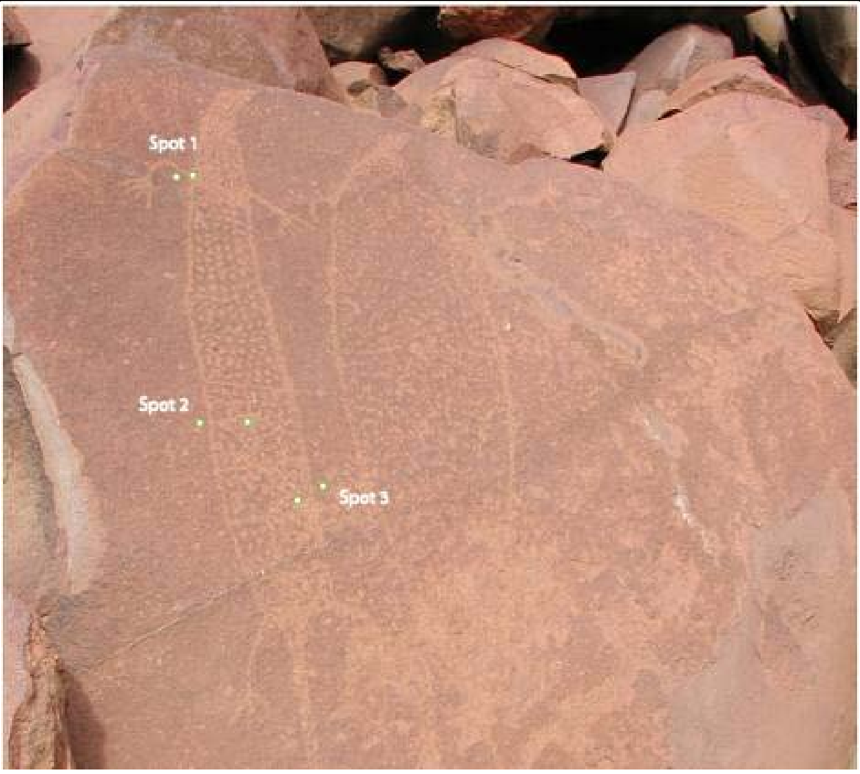
<tr><td>Site 4</td><td colspan="2">
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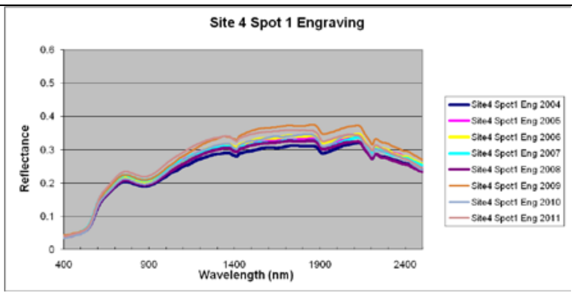
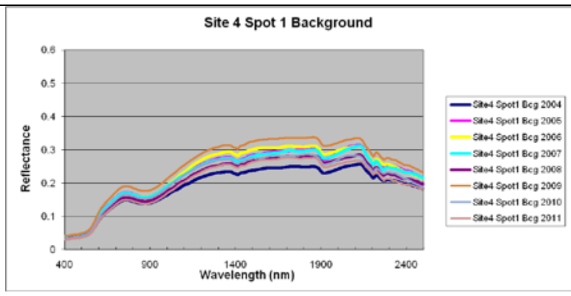
Spot 1</td><td>
</td><td>
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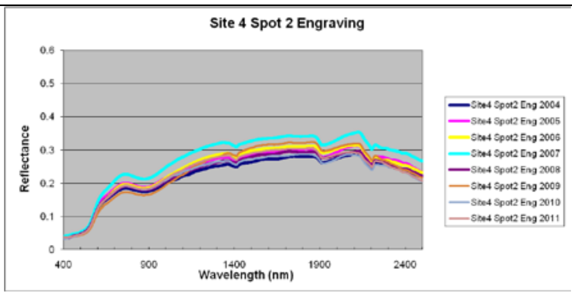
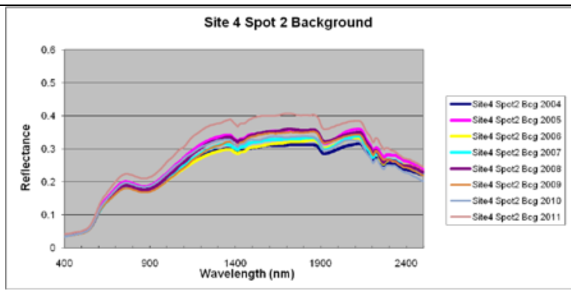
Spot 2</td><td>
</td><td>
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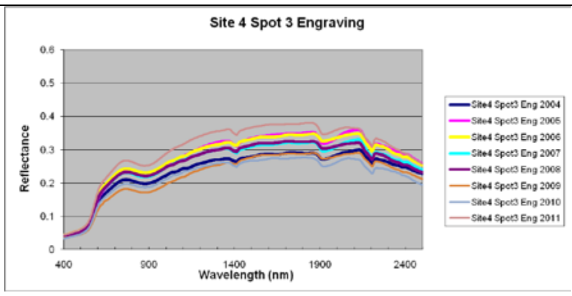
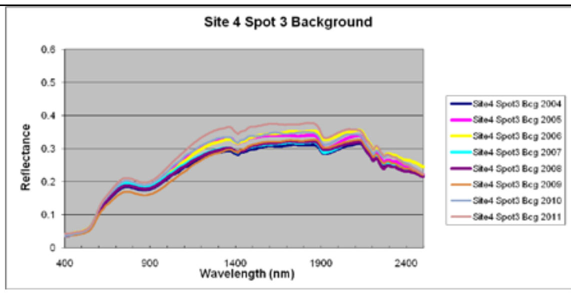
Spot 3</td><td>
</td><td>
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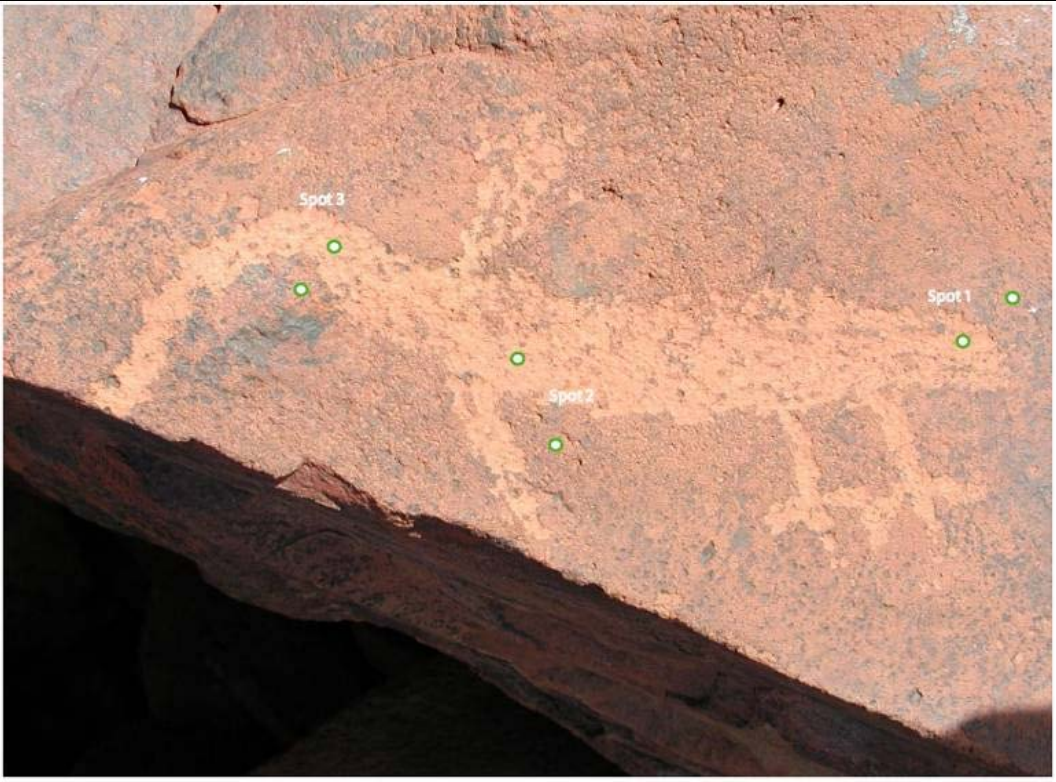

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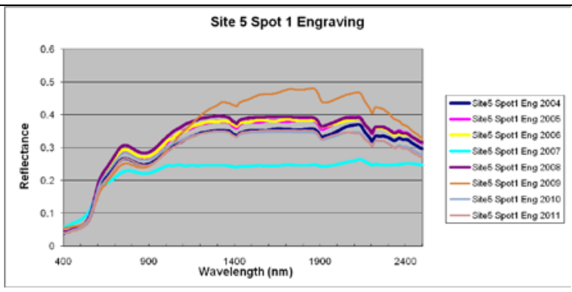

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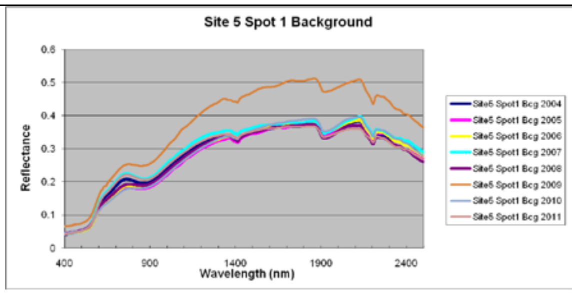

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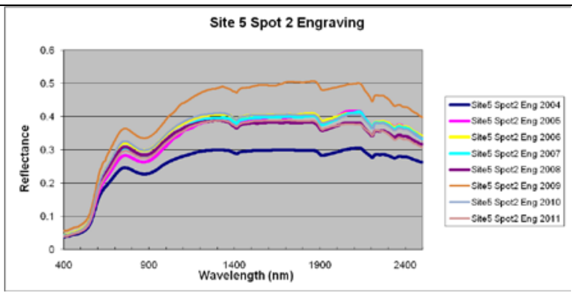

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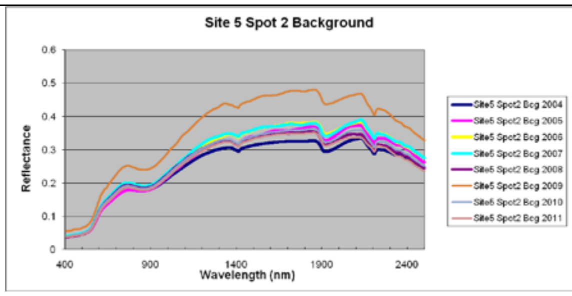

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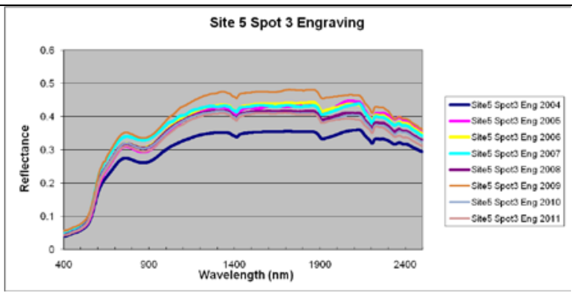

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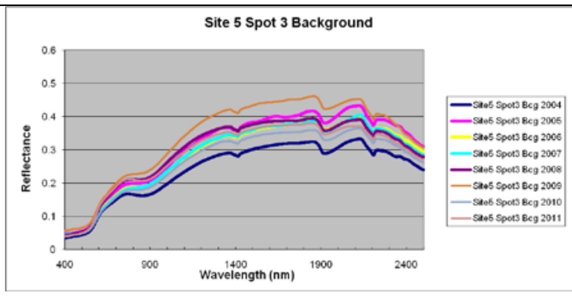

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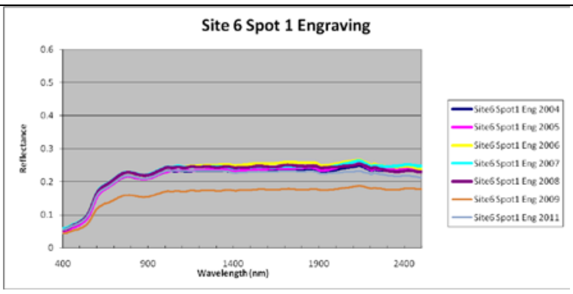
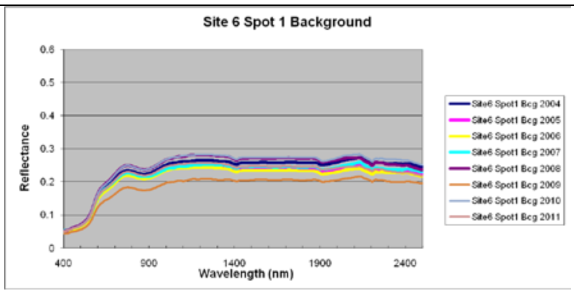
Spot 1</td><td>
</td><td>
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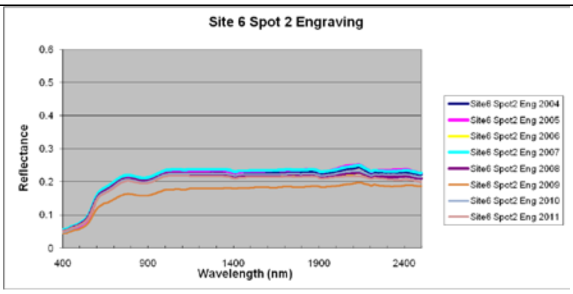
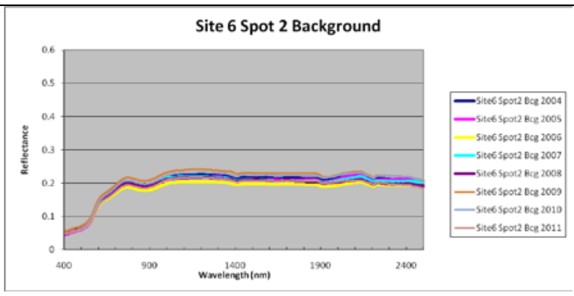
Spot 2</td><td>
</td><td>
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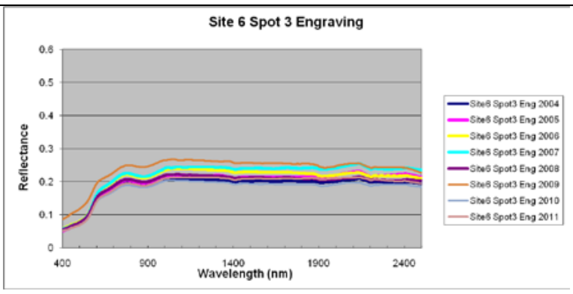
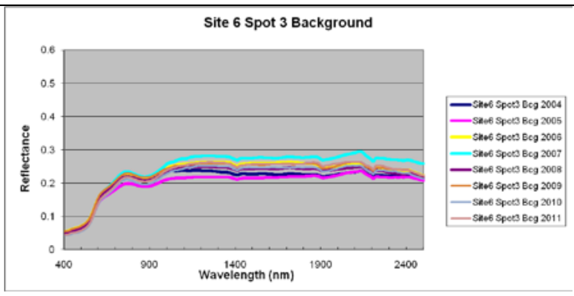
Spot 3</td><td>
</td><td>
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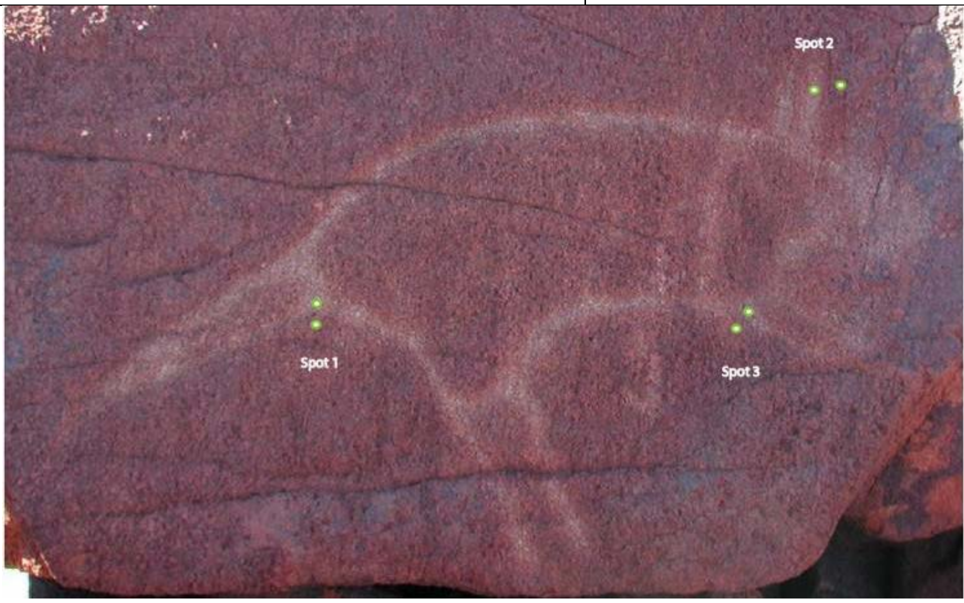

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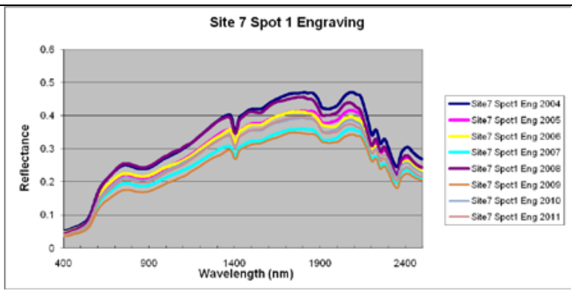

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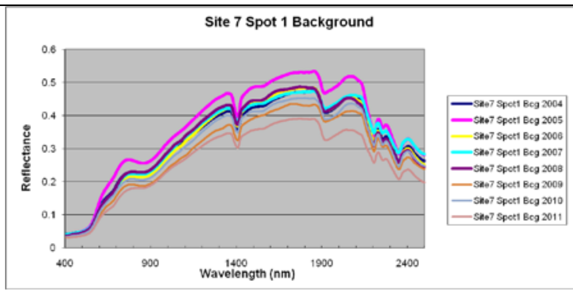

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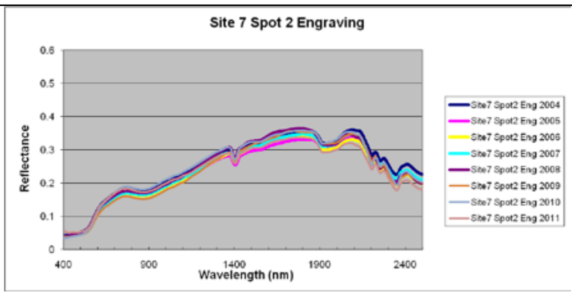

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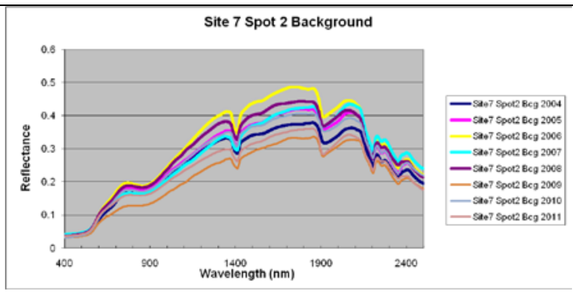

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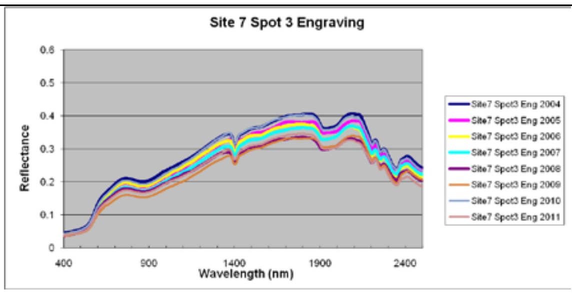

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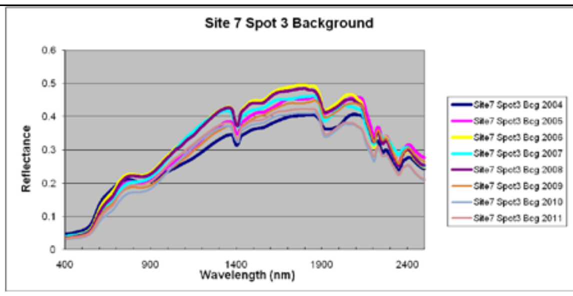

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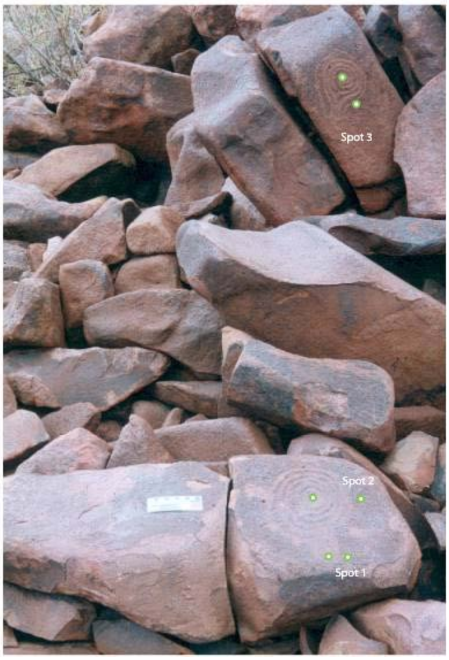
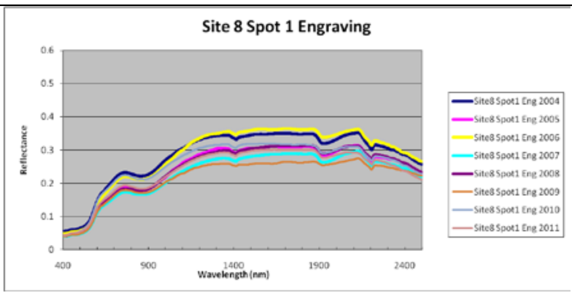
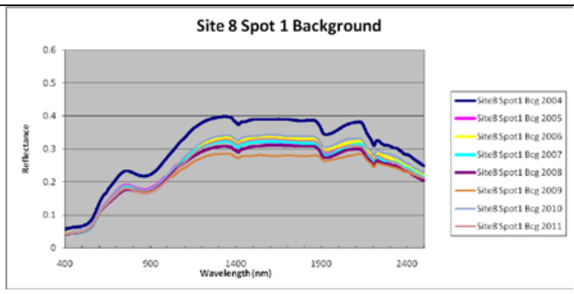
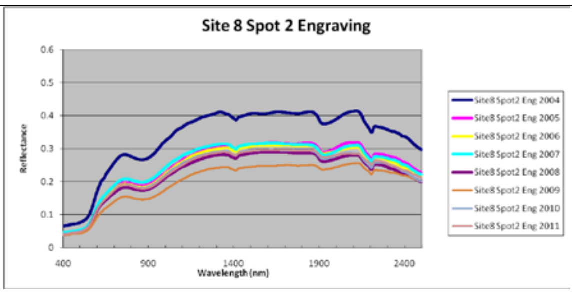
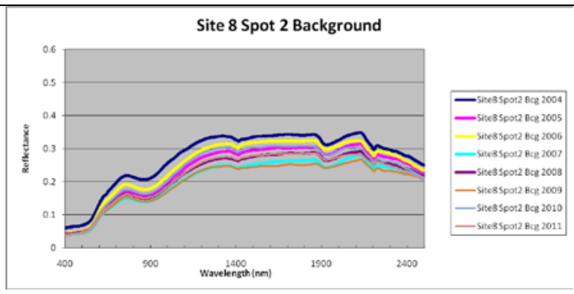
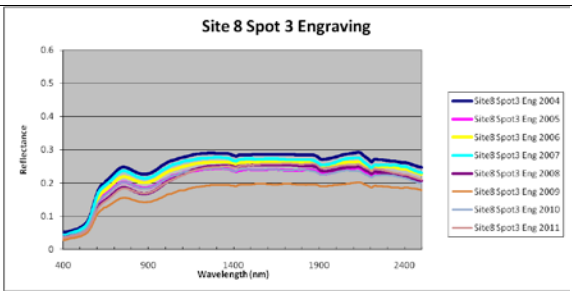
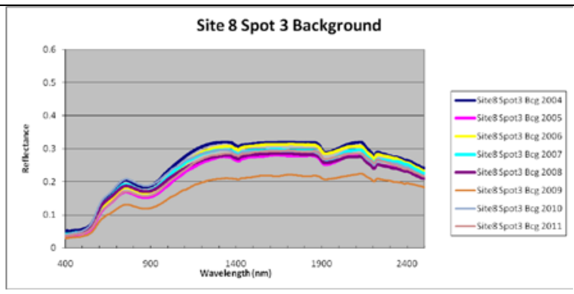
Location	Spectra Engraving	Spectra Background
Site 8		
Site 8 Spot 1		
Site 8 Spot 2		
Site 8 Spot 3		

The petroglyphs at 7 sites in the Burrup Peninsula were measured from 2004 to 2011 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 2011 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). Mineralogically related absorptions are unchanged since 2004. Only brightness (or reflectance) varies from year to year.

7 Comparison between spectrophotometer and ASD for the colour difference between the background and petroglyph

The comparison between the spectrophotometer and the ASD reflectance spectrometer for the colour difference between the background and petroglyph for each spot and for the average (and median) of all spots is presented in

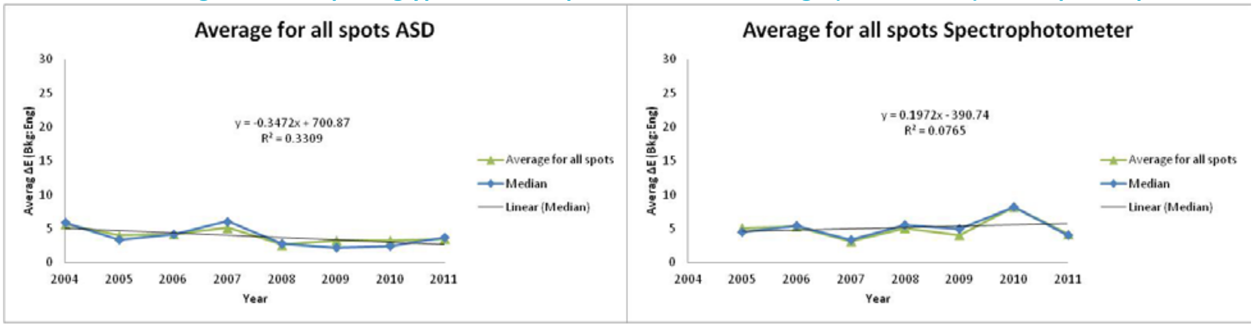
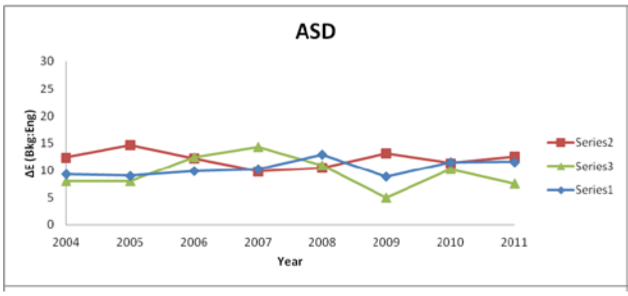
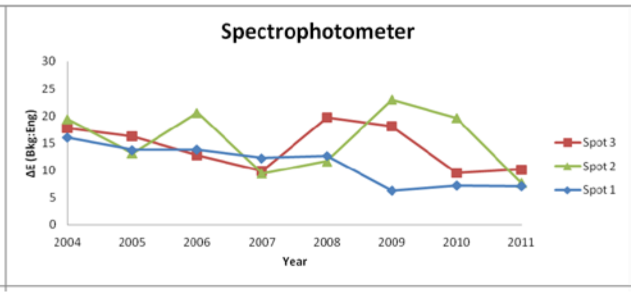


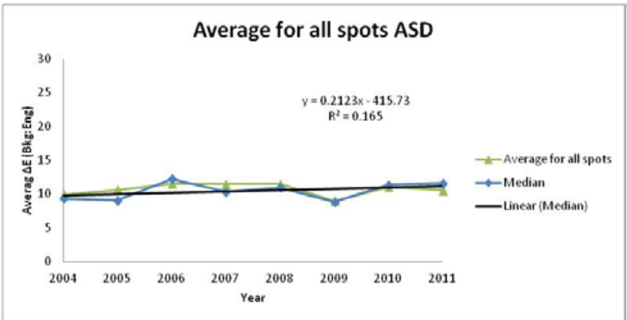
Figure 5. For both spectrometers, the colour difference between the background and petroglyphs, an indication of the colour contrast, is somehow different. This can be explained by the difference in area measured by the two spectrometers; 4 mm for the photospectrometer and 20 mm for the ASD. The results for the photospectrometer have already been discussed previously and it was stated that “*any trend towards less contrast between the background and engraved image in the southern sites has not been observed to be markedly different from that observed in the northern sites data*”.

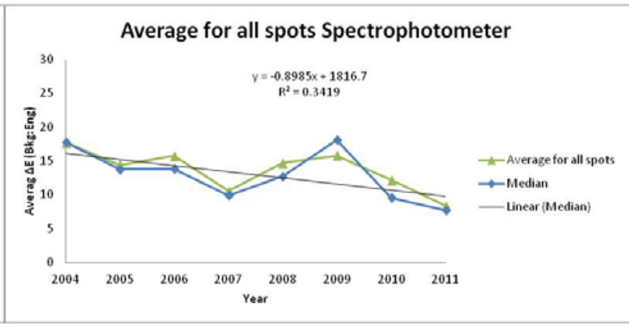
The colour difference between the background and petroglyph measured using the ASD generally shows less variation from year to year that can again be explained by the larger measured area. The variation observed in the Northern sites (1 and 2) as well as those from the Southern sites (4, 5, 6, 7 and 8) show no specific trends. For each site, the median of the colour difference for the 3 spots was fitted with a linear regression that shows minimum slope variation (the a value in y = ax +b) that be either positive or negative. In sites 1 and 2 (the background sites), this slope is positive for site 1 but negative for site 2. For all sites, the ΔE values vary from year to year on both side of the linear regression.

Site 1 Dolphin Island

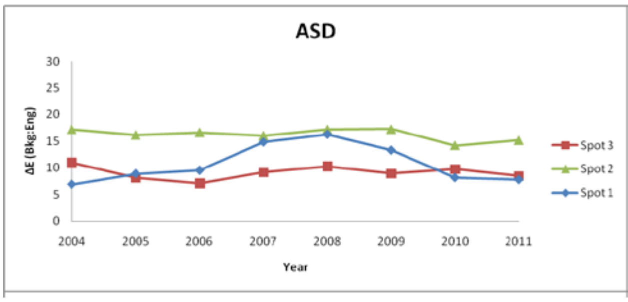


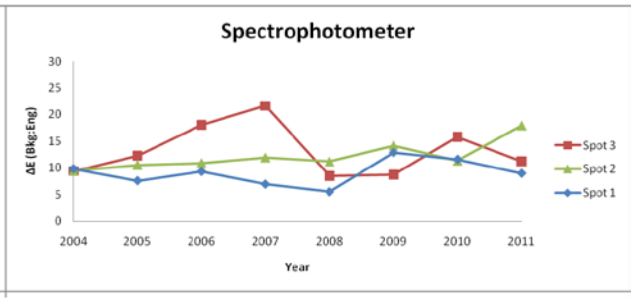


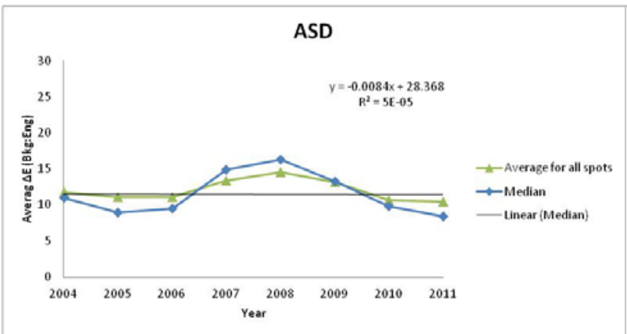


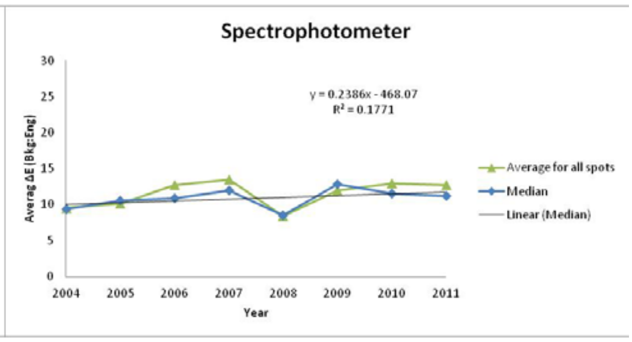


Site 2 Gidley Island









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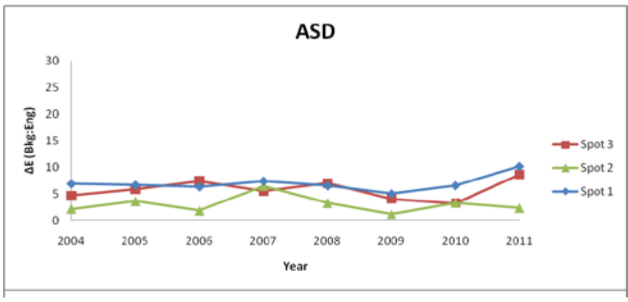
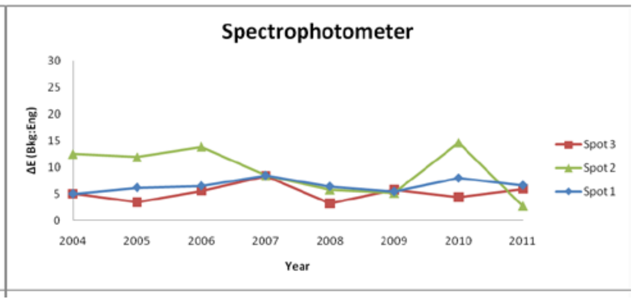
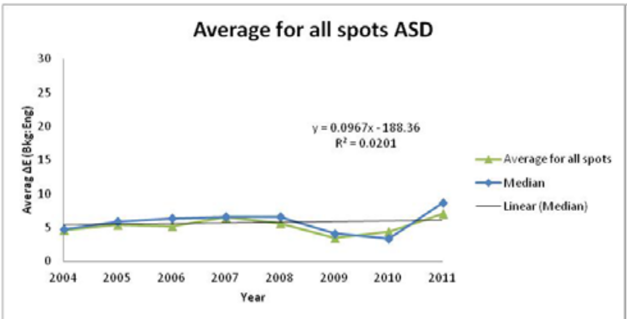
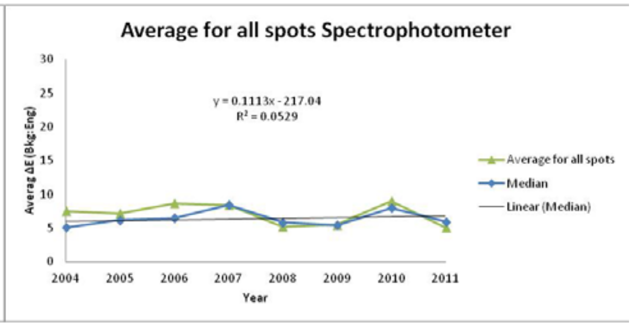
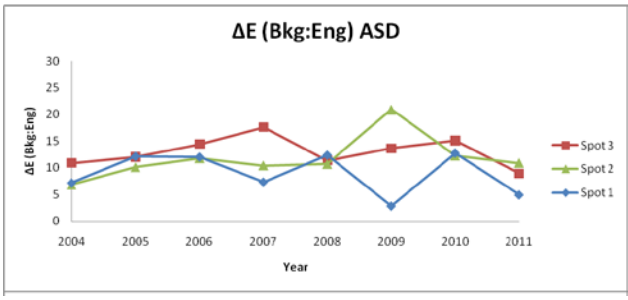


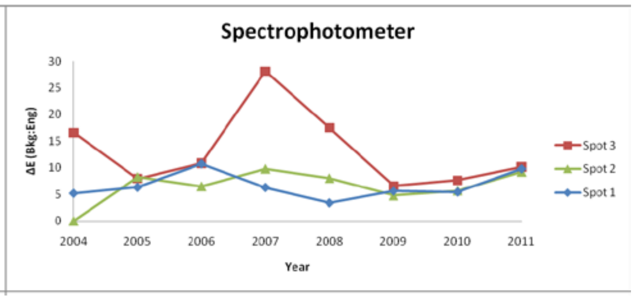


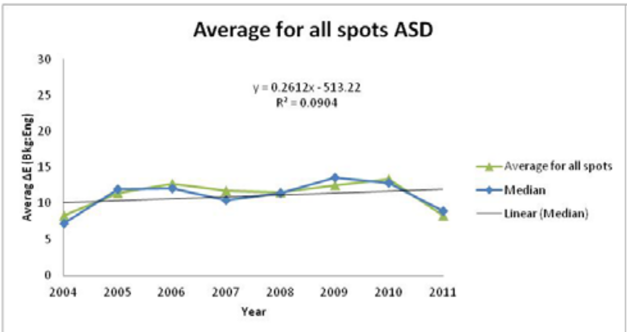


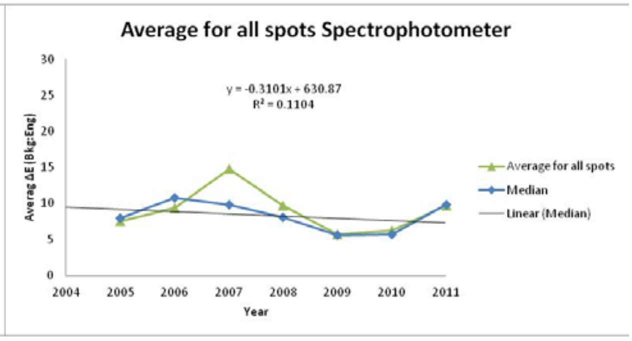


Site 5 Burrup Road

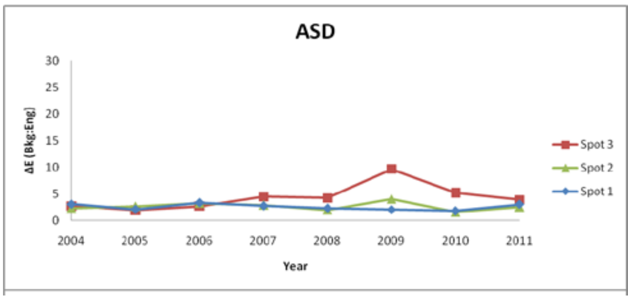


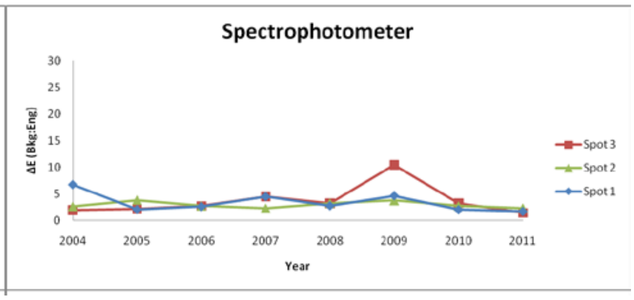


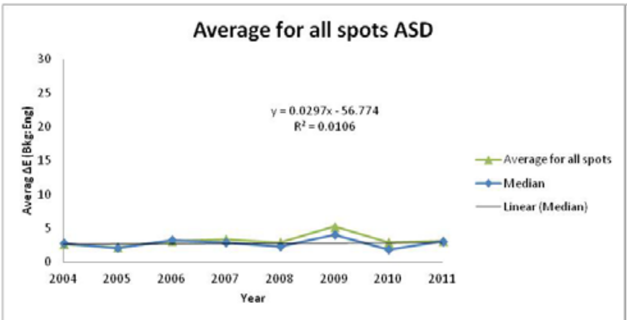


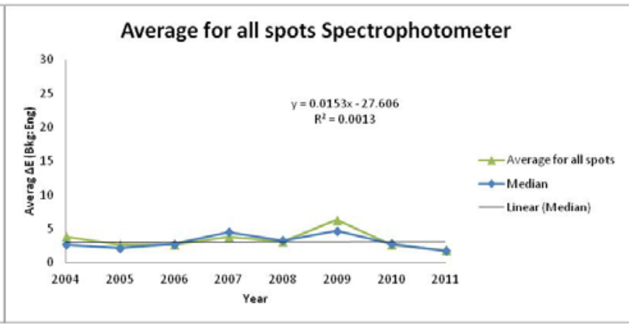


Site 6 Water Tanks

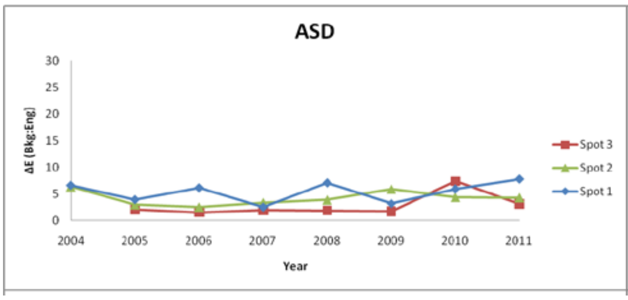


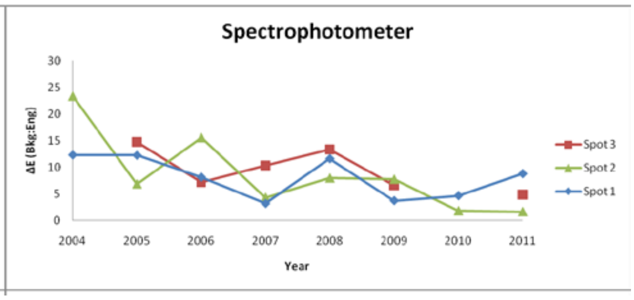


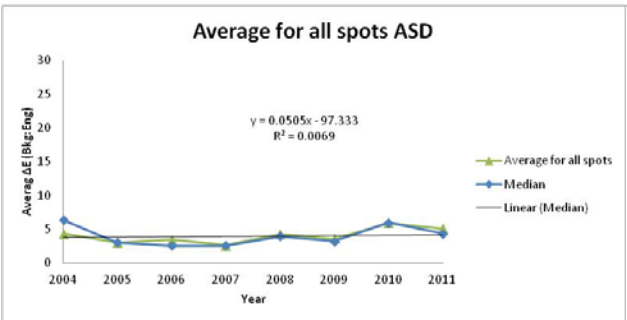


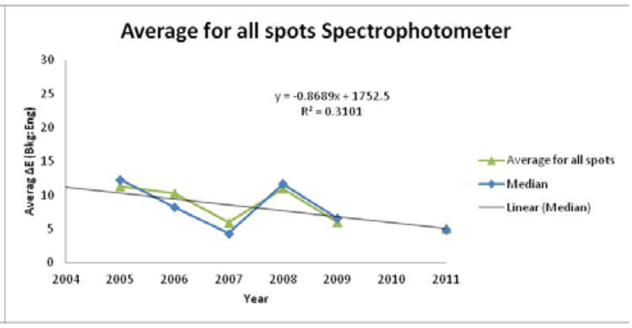


Site 7 Deep Gorge









Site 8 King Bay South

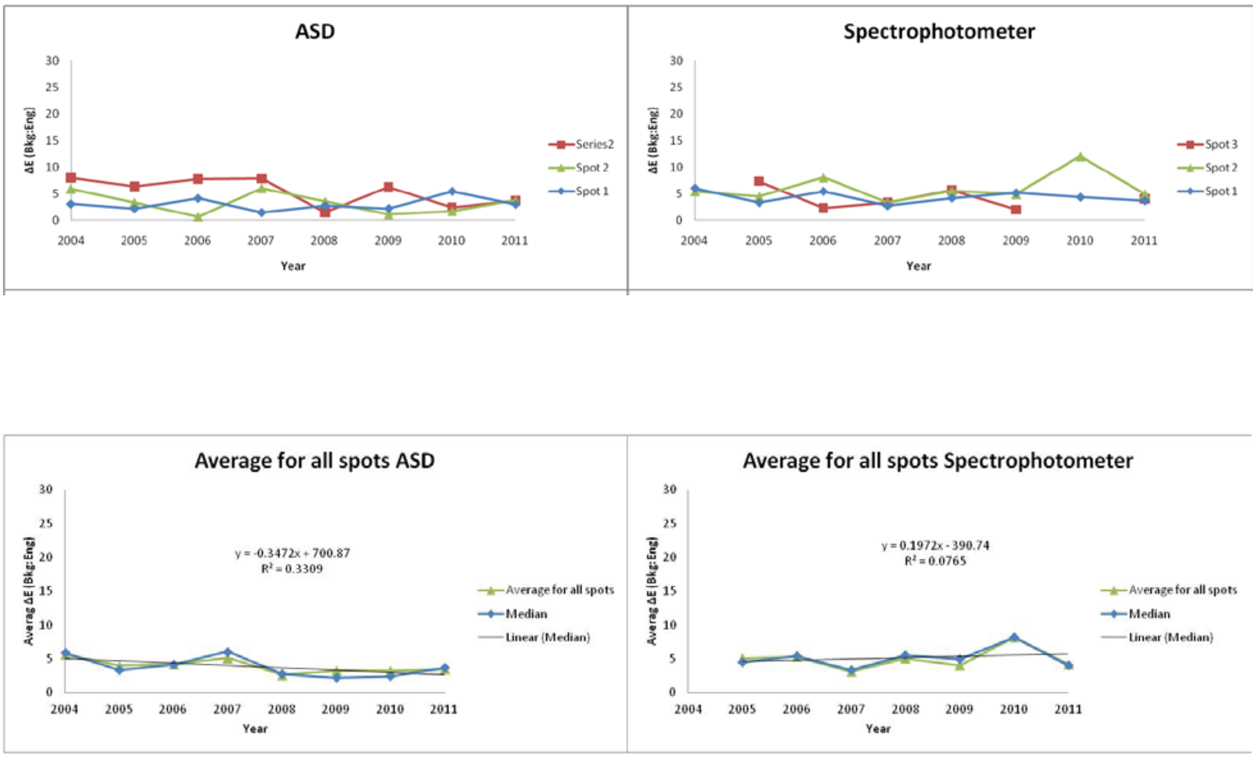


Figure 5. Comparison between spectrophotometer and ASD for the colour difference between the background and petroglyphs for the sites

Using the ASD instrument, over the last 8 years, no specific trends (either increasing or decreasing) were observed when comparing the Northern and Southern sites.

8 Conclusion of 2004-2011 study

A comparison of the colour changes measured with two spectrophotometer techniques, the ASD and BYK colour meter has been examined.

The degree of variance within the measurements is attributed to the instrument design and is a function of the ASD having a larger measurement window and exhibits less measurement variance while the BYK instrument has a smaller measurement window and therefore exhibits greater measurement variance, It can be seen that some sites with rougher surfaces (e.g., 5 and 7) have greater variance with both instruments compared with sites with smoother surfaces (e.g., 6) so there is consistency between the instruments.

In a comparison of both the Northern and Southern sites, there is no specific trend observed. Neither of the BYK or ASD instruments show a consistent upward or downward trend. In considering the Northern and Southern regions, neither show a consistent trend in an increasing or decreasing direction.

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