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Burrup Peninsula Aboriginal Petroglyphs: Colour Change & Spectral Mineralogy 2004–2012

Deborah Lau[1], Erick Ramanaidou[2], Lionel Fonteneau[2] and Tracey Markley[1]

1 CSIRO Materials Science and Engineering, Clayton, Victoria

2 CSIRO Earth Science and Resource Engineering, Kensington, Western Australia

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Important disclaimer

Contents

Figures

Tables

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Executive summary

The Burrup Peninsula is around 30 km long and 6 km wide and is located 1300 km from Perth (Western Australia) and was named after Mount Burrup, the highest topographic point. It was created when an island was connected to the mainland through the construction of a causeway. 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 one of Australia's largest ports. 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 9 years (2004 to 2012), 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 9 years. The Burrup Rock Art Monitoring Program is ongoing and will continue to be performed annually.

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 9 years no observed colour contrast change was detected.

1. Introduction

In response to tender number 34DIR0603 issued by the former WA Department of Industry and Resources and more recently under contract with the Department of Environment and Conservation (#DEC6210022011), CSIRO has measured selected petroglyphs on the Burrup Peninsula over a period of nine years. The requirements stipulated by the project were the measurement of re-identifiable sample points on petroglyphs annually for the measurement period.

For the last 9 years (2004 to 2012 - Ramanaidou and Caccetta, 2005; Ramanaidou and Wells 2006; Ramanaidou *et al*., 2007; Ramanaidou, et al., 2009a; Ramanaidou et al., 2009b; Lau et al., 2010; Lau et al., 2011; Lau et al., 2012), the petroglyphs at 7 specially selected sites in the Burrup Peninsula (Western Australia) were measured. Three spots on each engraving and 3 spots on each background rock were measured *in situ* using (1) a BYK photospectrometer and (2) an ASD spectrometer. For each engraving and background spot, seven spectra were acquired and averaged. The spectral variation for each spot (both engraving and background) was also assessed.

The 2004 spectral study (Ramanaidou and Caccetta, 2005) is the baseline dataset that has being used to monitor potential variation that occurred in the last 9 years. The nine-year study (2004-2012) has assessed the mineralogy, monitored and explained the mineralogical changes (if any) of seven rock art sites in the Burrup Peninsula.

2. Location and sampling of the petroglyphs

The sites for monitoring (Table 1 and 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 including members of Murujuga Aboriginal Corporation. 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

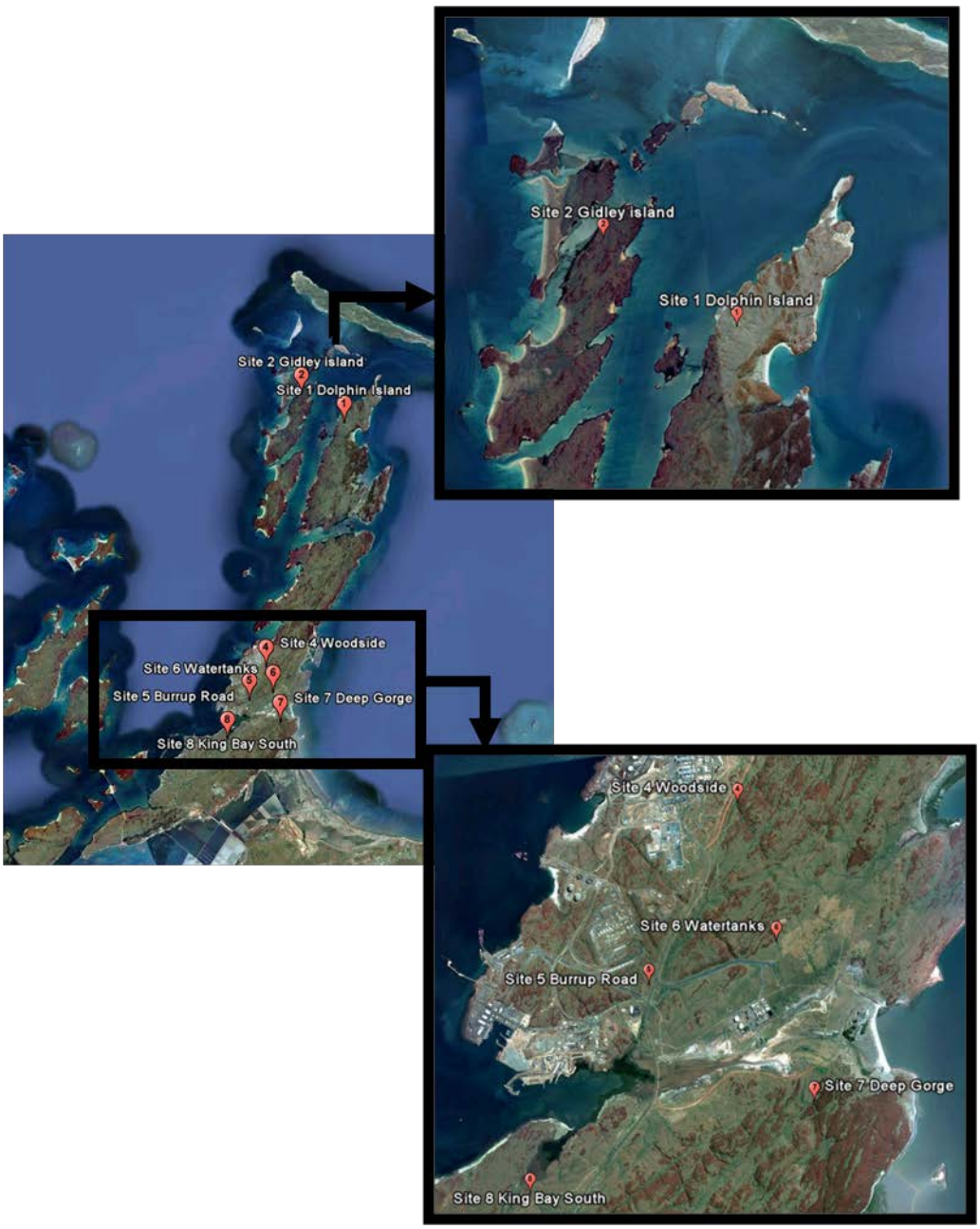


Figure 1: Google Earth® maps of the Burrup Peninsula with the petroglyphs location.

Sites 1 and 7 consist of gabbros whereas the rest of the sites are granophyres. Gabbro is dark, coarse-grained, intrusive mafic igneous rocks with 45-52% SiO_2 (Table 2). Granophyre is a subvolcanic rock that contains quartz and alkali feldspar in characteristic angular intergrowths. Granophyres are intrusive rocks with a chemical composition similar to those of granites (Table 2) occurring within layered igneous intrusions dominated by gabbro.

Table 2: Classification of igneous rocks

Type	**Ultramafic** **<45% SiO_2**	**Mafic** **45-52% SiO_2**	**Intermediate** **52-63% SiO_2**	**Intermediate-Felsic** **63-69% SiO_2**	**Felsic<45% SiO2** **>69%SiO_2**
Volcanic Rocks	Komatiite	Basalt	Andesite	Dacite	Rhyolite
Sub-Volcanic Rocks	Picrite	Dolerite			Pegmatite
Plutonic Rocks	Kimberlite, Lamproite, Peridotite	**Gabbro**	Diorite	Granodiorite	**Granite**

The primary minerals forming fresh granophyres include: quartz and K feldspar. The primary minerals forming fresh gabbro include: Ca feldspar; pyroxene; epidote; and chlorite. The primary minerals forming minor magnetite are apatite, sphene and rutile.

3. Colour Measurement

3.1 Introduction

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 (Mirti, 2004). 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.

In situ monitoring of degradative change through colour measurement has been reported by Mirmehdi *et al.* (2001), 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 for two reasons:

a) Template matching, as described by Mirmehdi *et al.* (2001), 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.

b) 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.

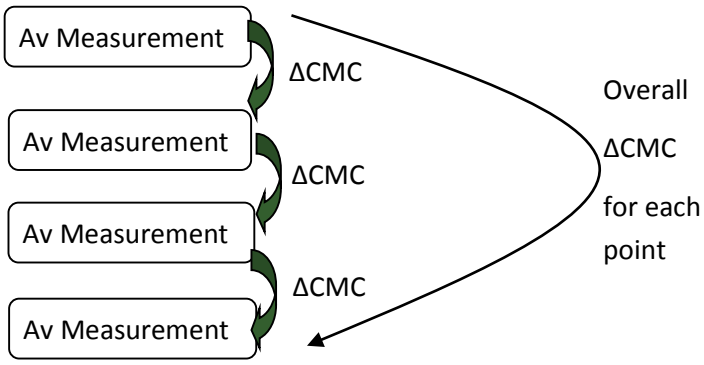
3.2 Experimental Methodology

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 ΔE 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 (Hunter, 1987). 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 Figure 2 and Table 3). 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

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

Table 3: 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**
2°; 10°	English; German; French; Italian; Spanish; Japanese	4 AA alkaline; NiCd or MH	50 to -110 °F (10 to -42 °C)	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 °C (95 °F)			

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.

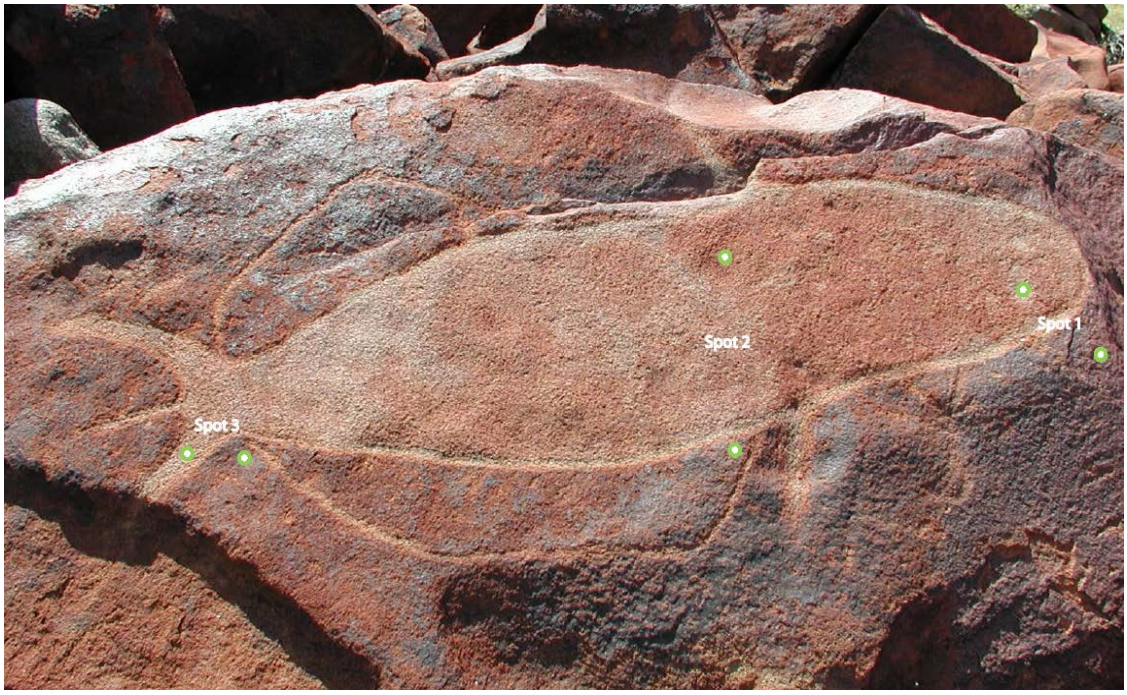


Figure 3: Site 1- Dolphin Island.

Table 4: Average Colour Measurements for Site 1 – Dolphin Island (2004 – 2012).

Sample	Colour scale L*	a*	b*	Colour difference* ΔE (change from previous year)
Site 8 Spot 1 Engraving				
Average 2012	34.97	14.69	16.85	2.42
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 2012	32.01	12.07	13.10	1.16
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 2012	32.51	13.66	15.29	1.86
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 2012	31.37	11.63	12.72	0.70
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 2012	31.53	15.07	18.52	3.45
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 2012	29.91	13.86	15.85	2.63
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	

Figure 4: Site 2 – Gidley Island.

Table 5: Average Colour Measurements for Site 2 – Gidley Island (2004 – 2012).

Sample	Colour scale L*	a*	b*	Colour difference* ΔE (change from previous year)
Site 2 Spot 1 Engraving				
Average 2012	38.22	8.35	14.71	2.23
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 2012	31.15	10.31	11.58	0.54
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 2012	42.26	11.10	20.79	0.68
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 2012	27.89	10.65	10.10	0.55
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 2012	39.65	12.38	19.79	1.29
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 2012	26.47	11.39	15.85	3.88
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	

Figure 5: Site 4 – Woodside.

Table 6: Average Colour Measurements for Site 4 – Woodside (2004 – 2012).

Sample	Colour scale L*	a*	b*	Colour difference* ΔE (change from previous year)
Site 4 Spot 1 Engraving				
Average 2012	32.92	15.92	18.59	0.24
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 2012	29.12	13.57	14.59	0.46
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 2012	31.77	15.10	18.40	0.76
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 2012	31.14	14.47	15.68	0.46
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 2012	34.52	15.96	19.47	1.09
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 2012	31.56	14.67	16.23	0.55
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	

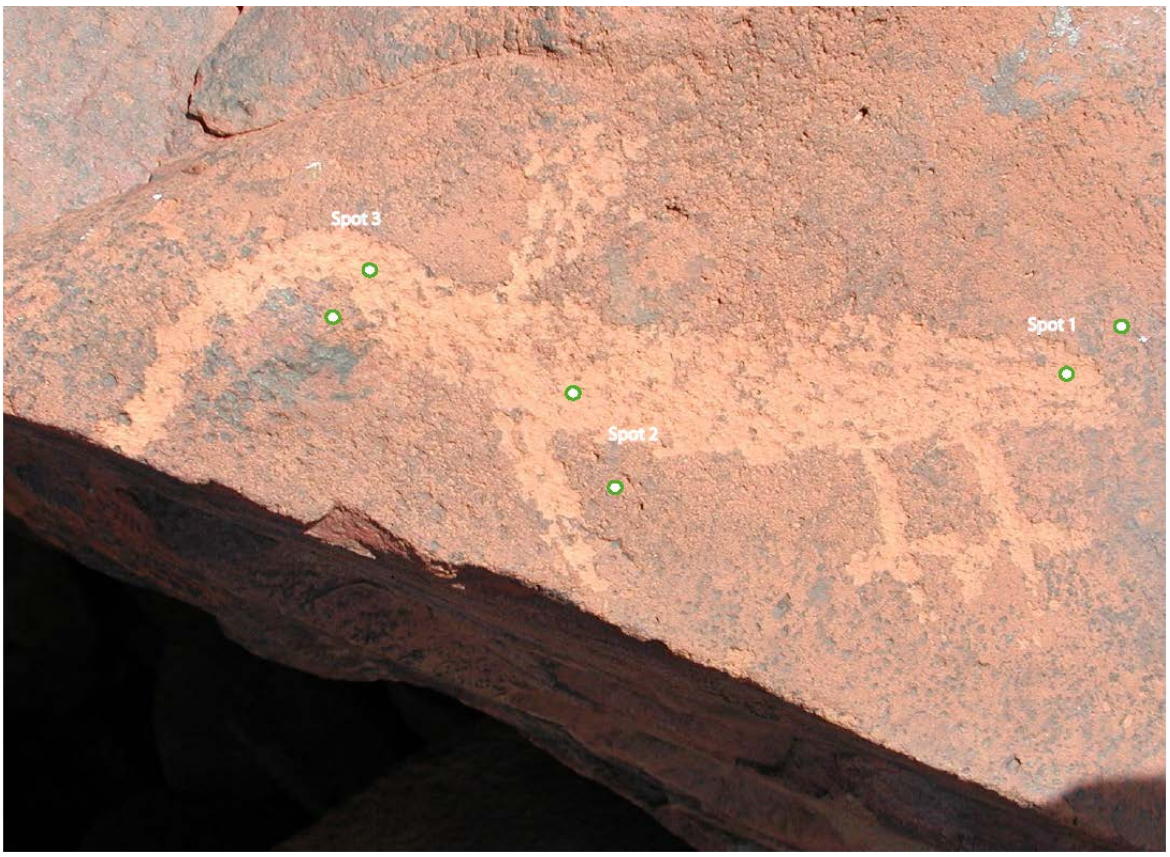


Figure 6: Site 5 – Burrup Road.

Table 7: Average Colour Measurements for Site 5 – Burrup Road (2004 – 2012).

Sample	Colour scale L*	a*	b*	Colour difference* ΔE (change from previous year)
Site 5 Spot 1 Engraving				
Average 2012	36.40	17.36	20.92	1.36
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 2012	34.16	14.98	16.39	2.99
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 2012	34.06	18.06	21.81	0.62
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 2012	31.01	14.54	15.57	1.28
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	N/A
Average 2004	No 2004 measurements			
Site 5 Spot 3 Engraving				
Average 2012	38.99	19.52	23.99	1.54
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 2012	33.05	10.92	11.58	5.44
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	

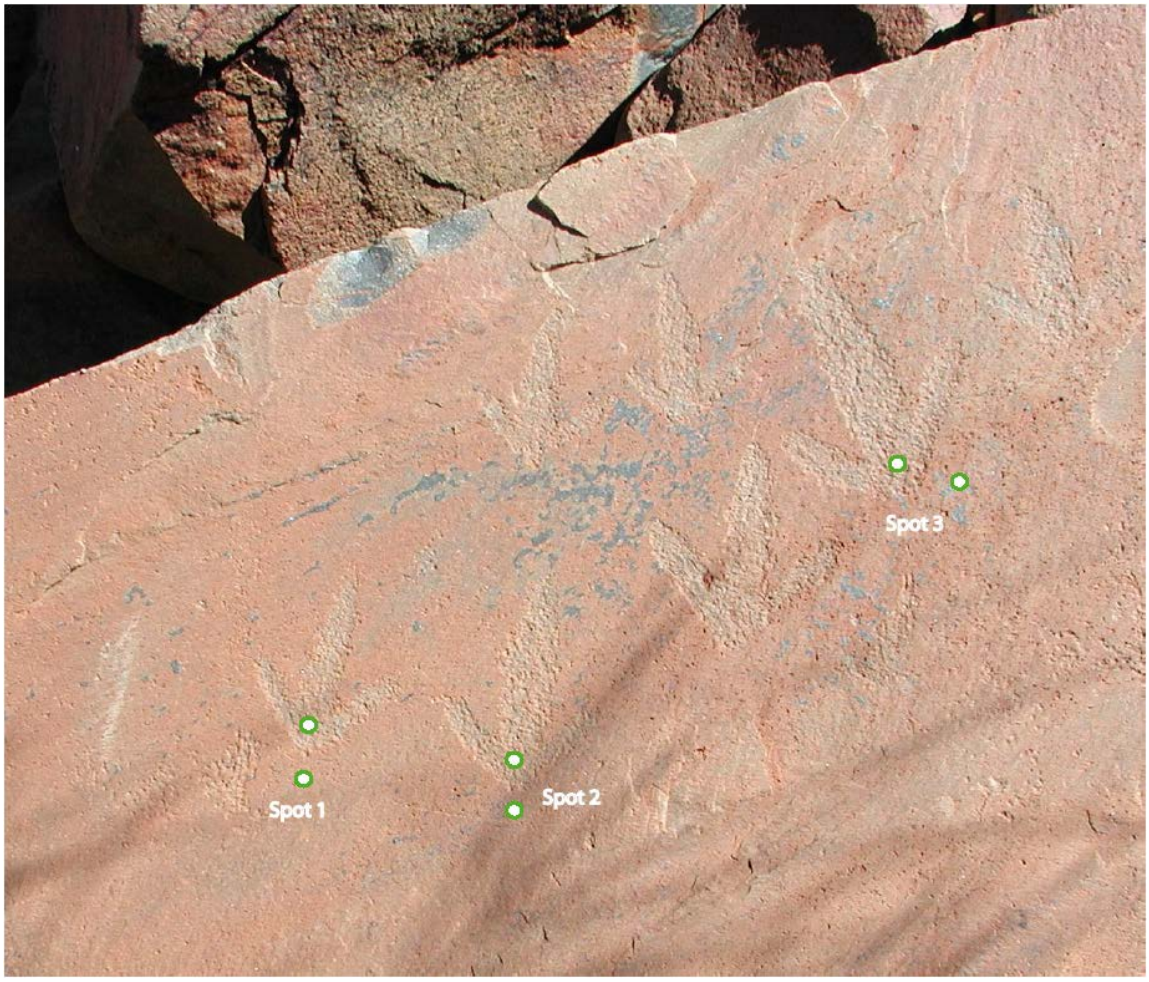


Figure 7: Site 6 – Water Tanks.

Table 8: Average Colour Measurements for Site 6 – Water Tanks (2004 – 2012).

Sample	Colour scale			Colour difference* ΔE (change from previous year)
	L*	a*	b*	
Site 6 Spot 1 Engraving				
Average 2012	40.18	11.59	17.36	0.35
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 2012	38.95	12.90	17.19	0.40
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 2012	38.17	11.92	17.05	1.34
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 2012	37.48	12.39	15.98	0.85
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 2012	38.67	11.60	16.39	1.03
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	9.74*
Average 2008	35.59	9.61	15.75	1.51
Average 2007	34.18	10.03	16.08	0.86
Average 2006	33.49	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 2012	37.12	12.50	15.98	1.22
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	

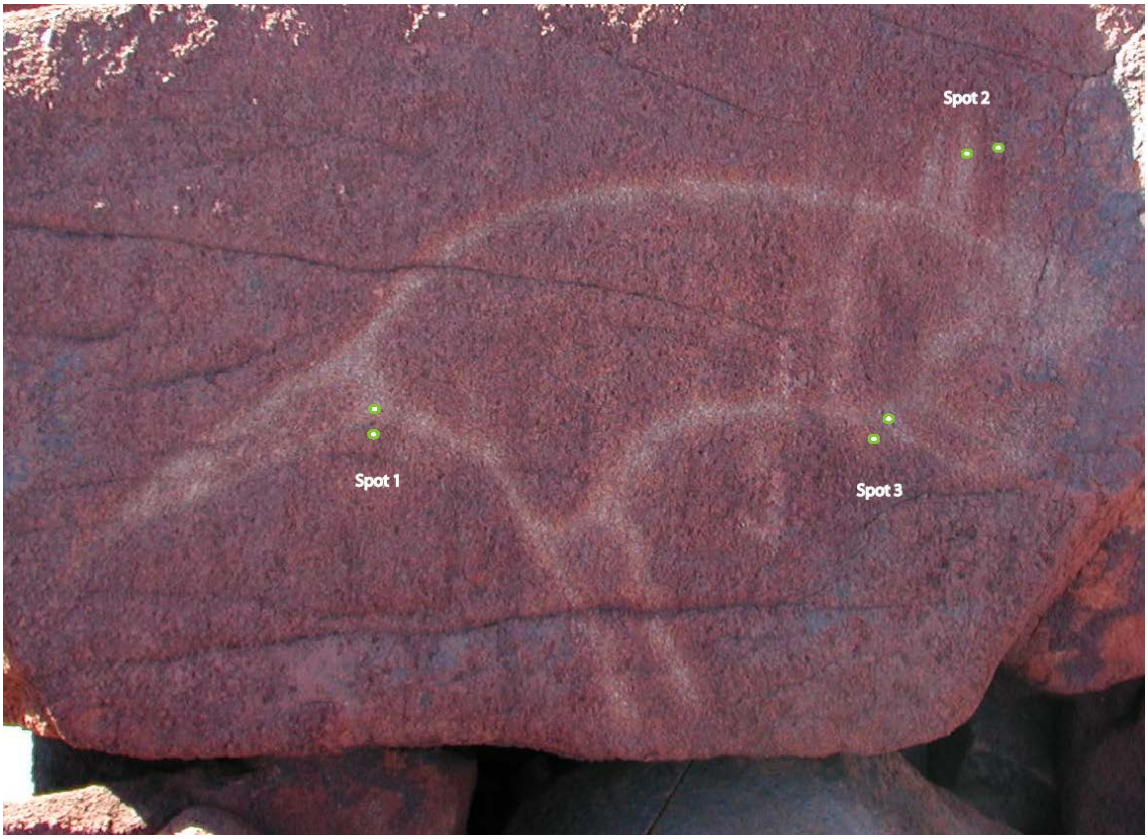


Figure 8: Site 7 – Deep Gorge.

Table 9: Average Colour Measurements for Site 7 – Deep Gorge (2004 – 2012).

Sample	Colour scale L*	a*	b*	Colour difference* ΔE (change from previous year)
Site 7 Spot 1 Engraving				
Average 2012	30.36	13.50	16.92	3.88
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 2012	26.93	12.26	13.90	1.17
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 2012	26.92	13.44	15.39	1.43
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 2012	30.98	12.86	13.43	4.40
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 2012	27.79	12.39	14.72	0.86
Average 2011	27.01	12.69	14.95	N/A
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 2012	26.72	13.07	14.14	4.33
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	

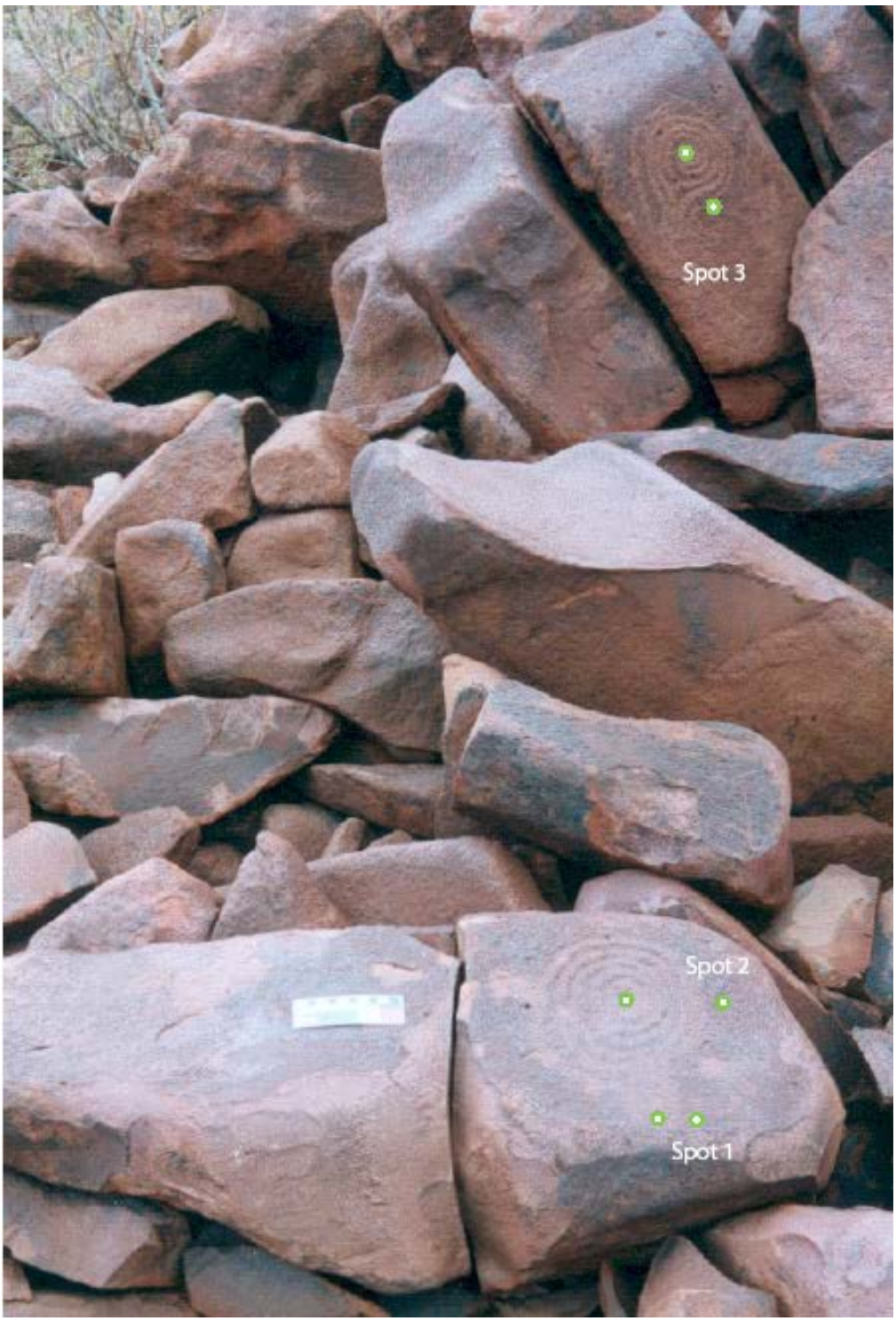


Figure 9: Site 8 – King Bay South.

Table 10: Average Colour Measurements for Site 8 – King Bay South (2004 – 2012).

Sample	Colour scale L*	a*	b*	Colour difference* ΔE (change from previous year)
Site 8 Spot 1 Engraving				
Average 2012	34.97	14.69	16.85	2.42
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 2012	32.01	12.07	13.10	1.16
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 2012	32.51	13.66	15.29	1.86
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 2012	31.37	11.63	12.72	0.70
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 2012	31.53	15.07	18.52	3.45
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 2012	29.91	13.86	15.85	2.63
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 11, 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 11: Averaged colour change for each site

Site	Averaged site-specific colour change							
	ΔE 11–12	ΔE 10–11	ΔE 09–10	ΔE 08–09	ΔE 07–08	ΔE 06–07	ΔE 05–06	ΔE 04–05
4	**0.59**	9.57	8.03	7.02	2.9	2.42	1.89	1.29
5	**2.21**	6.65	3.57	6.23	3.2	6.95	4.77	4.29
6	**0.87**	3.48	3.47	2.39	1.4	1.58	2.43	2.61
7	**2.68**	10.58	8.36	8.26	3.8	7.58	6.1	10.58
8	**2.04**	9.05	2.97	2.28	2.3	2.95	4.14	3.99
Overall southern sites average	**1.68**	7.87	5.28	5.24	2.72	4.30	3.87	4.55
1	**1.38**	11.85	5.24	6.46	4.1	4.5	3.12	2.97
2	**1.53**	5.58	4.25	3.86	4	2.38	3.01	3.56
Overall northern sites average	**1.45**	8.71	4.75	5.16	4.05	3.44	3.07	3.27

The nine 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 2004–12, which indicates the colour change over the nine year interval from 2004 to 2012, site 7 consistently displayed the greatest year to year colour change. For sites 4, 6 and 8 (southern), the colour change values for the interval 2004–12 were lower than northern sites 1 and 2, with the exception of Site 4 for the interval 2008 - 2010. 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 (see Figure 6) which means that colour measurement is much more dependent on instrument placement at that spot. The site with the smoothest rock face (site 6, Figure 7), however, did not consistently record the lowest colour change values so measurement repeatability is therefore dependent on more than just surface roughness. 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

The colour difference between the background and petroglyph for each spot is presented in Table 12

Table 12 and plotted in Figure 10 – 16.

The two data absences in the 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 spot 1 and 2 for the same petroglyph.

In the colour change report from 2010 [4], 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 (Figure 10-16).

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, the measurements at Site seven are 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 10-16, any trend towards less contrast between the background and engraved image in the southern test sites has not been observed to be markedly different from that observed in the northern control sites data.

Table 12: Colour difference between background and petroglyph

Spot 1	Site 1	Site 2	Site 4	Site 5	Site 6	Site 7	Site 8
Average 2012	**6.6**	**8.0**	**6.0**	**5.6**	**1.8**	**4.7**	**5.5**
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 2012	**7.7**	**17.9**	**2.9**	**7.8**	**1.4**	**4.5**	**3.5**
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 2012	**9.7**	**13.8**	**4.6**	**16.2**	**1.8**	**1.4**	**3.3**
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

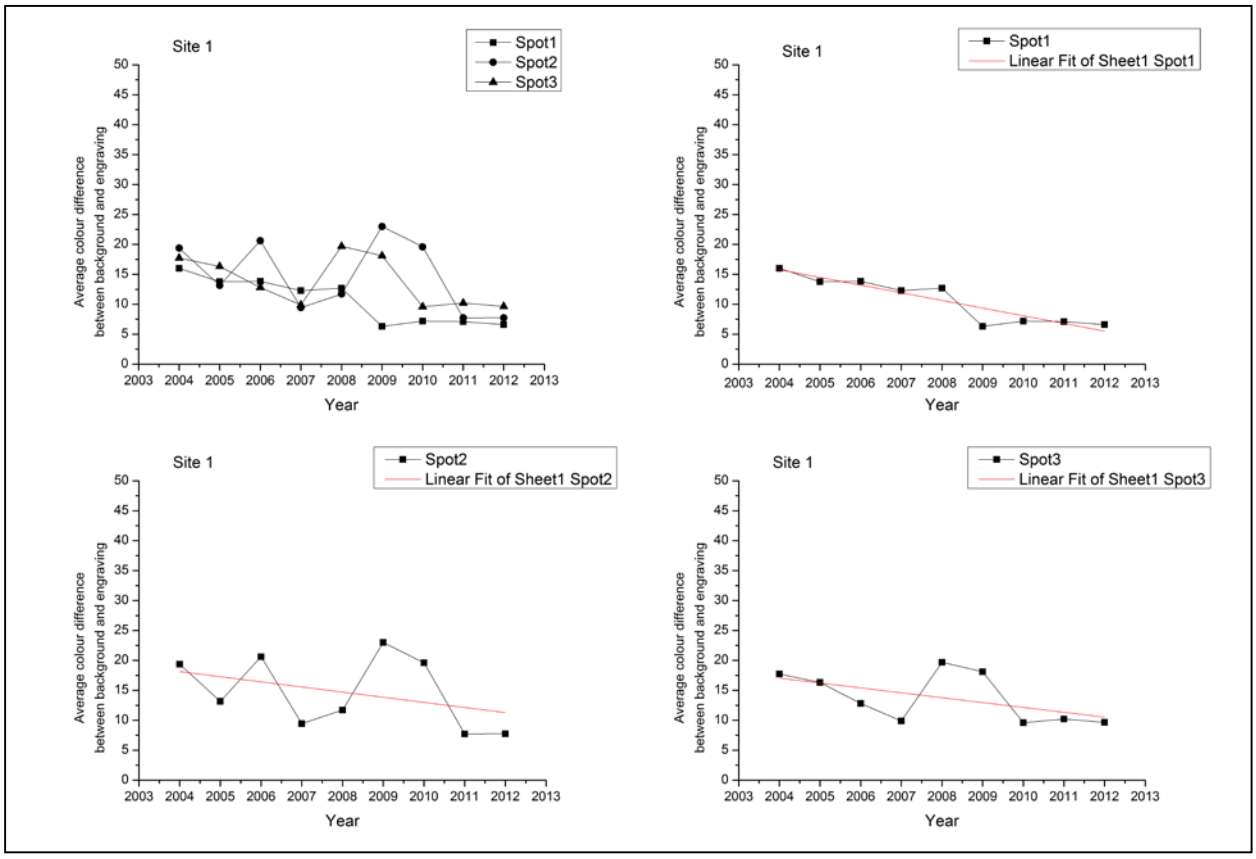


Figure 10: Colour differences between engraving and background for each spot examined at Site 1 – Dolphin Island.

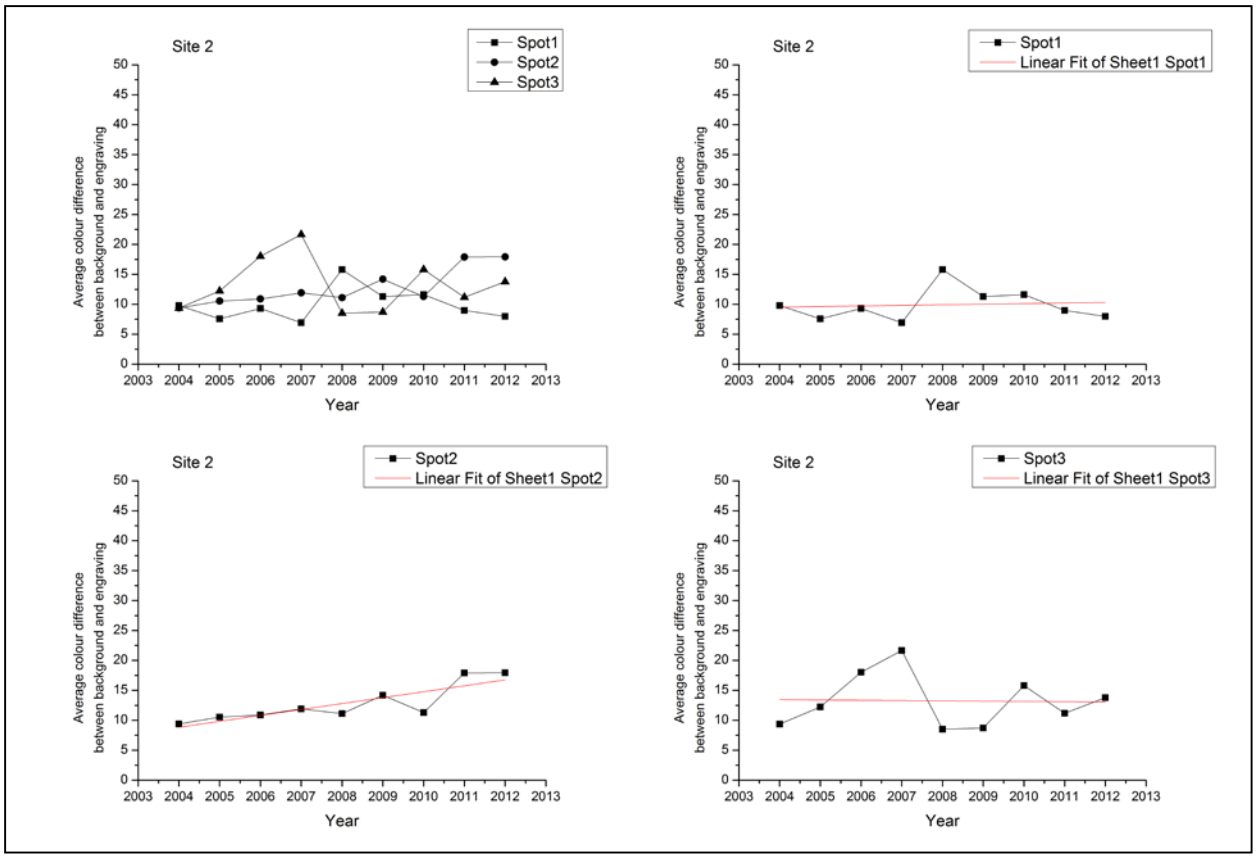


Figure 11: Colour differences between engraving and background for each spot examined at Site 2 – Gidley Island.

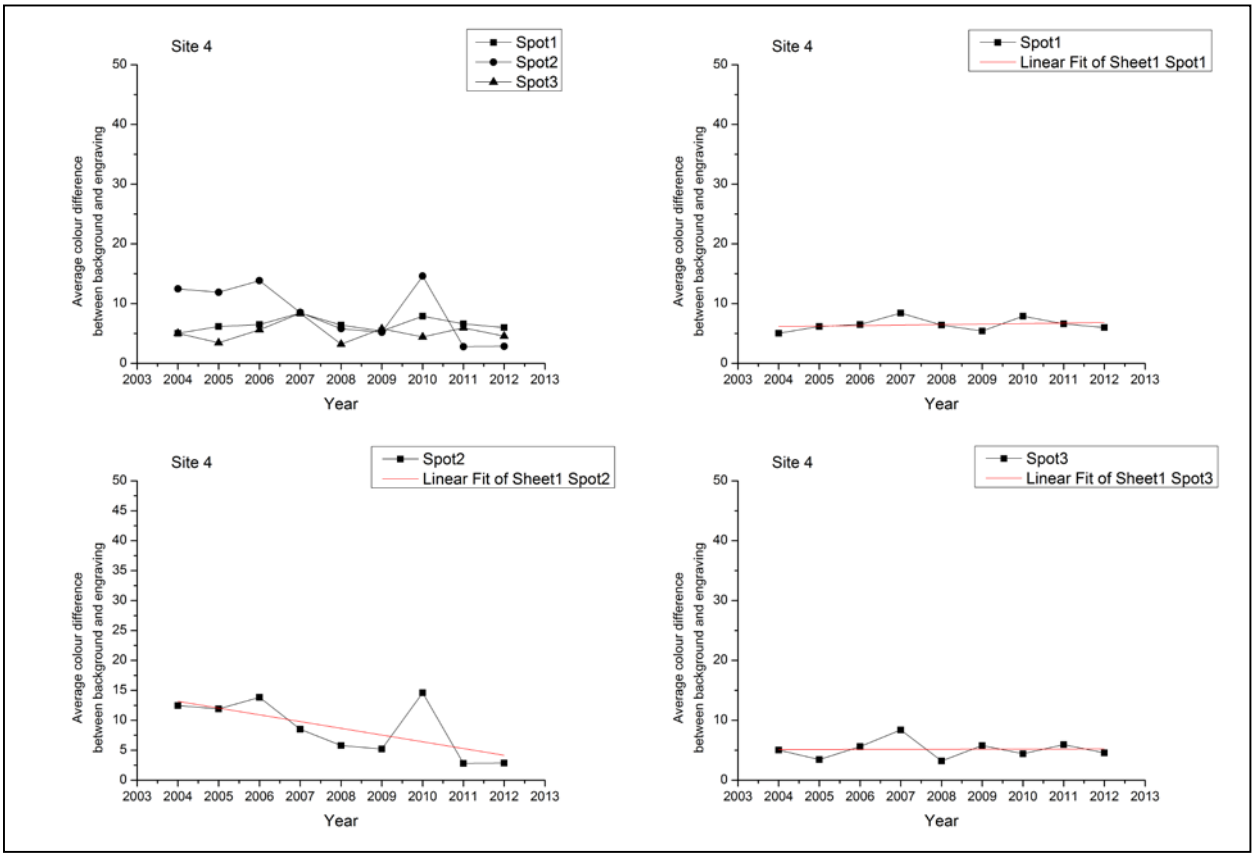


Figure 12: Colour differences between engraving and background for each spot examined at Site 4 – Woodside.

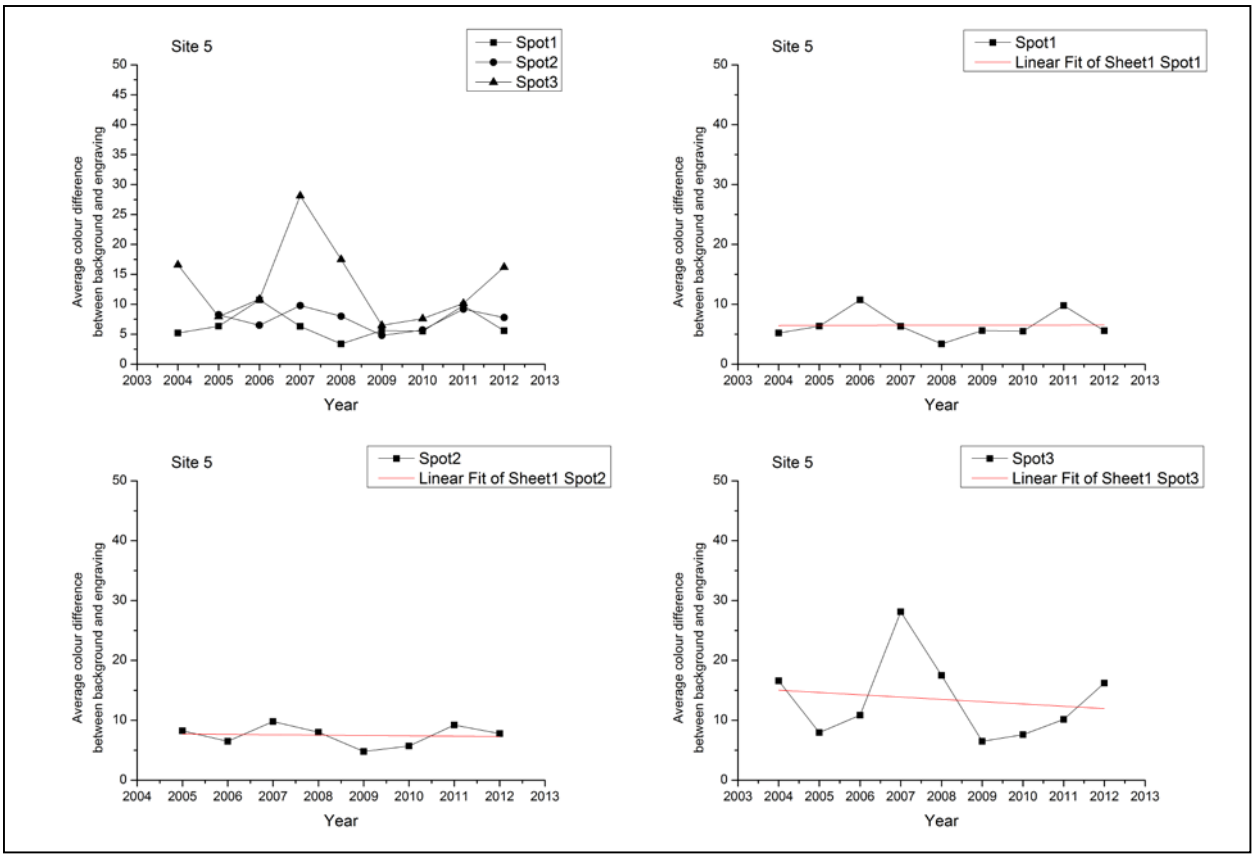


Figure 13: Colour differences between engraving and background for each spot examined at Site 5 – Burrup Road. Site 5 spot 3 is believed to exhibit high variance in single years due to irregular measurements.

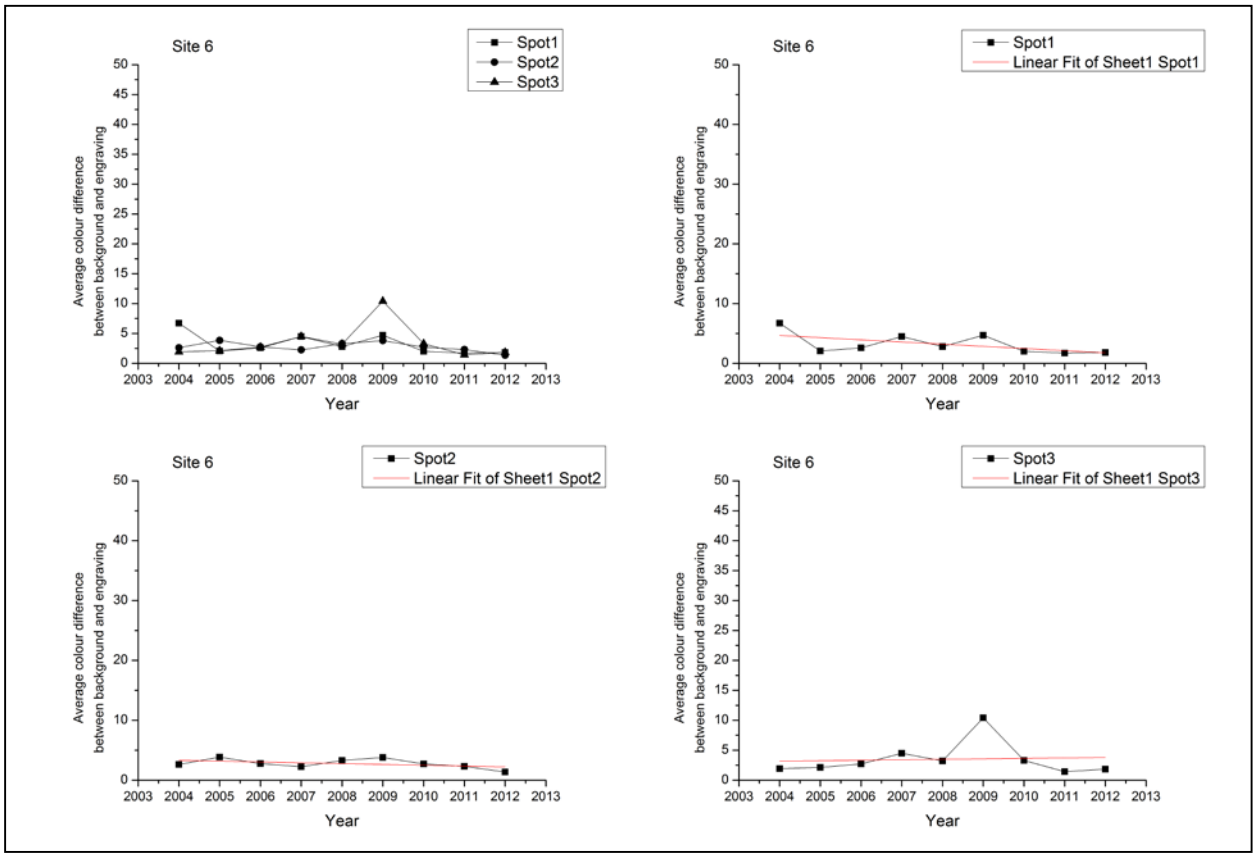


Figure 14: Colour differences between engraving and background for each spot examined at Site 6 – Water Tanks.

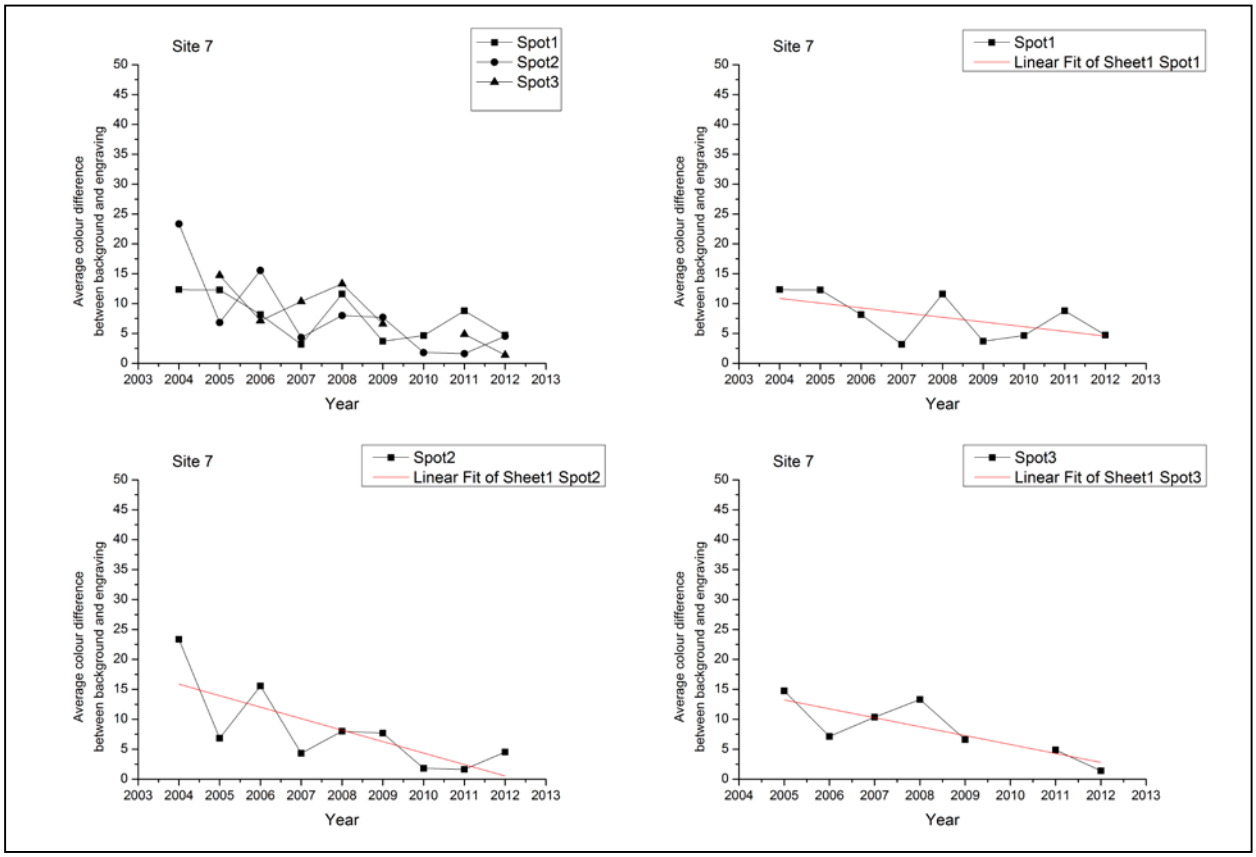


Figure 15: Colour differences between engraving and background for each spot examined at Site 7 – Deep Gorge. Site 7 spot 2 is believed to exhibit high variance in single years due to irregular measurements.

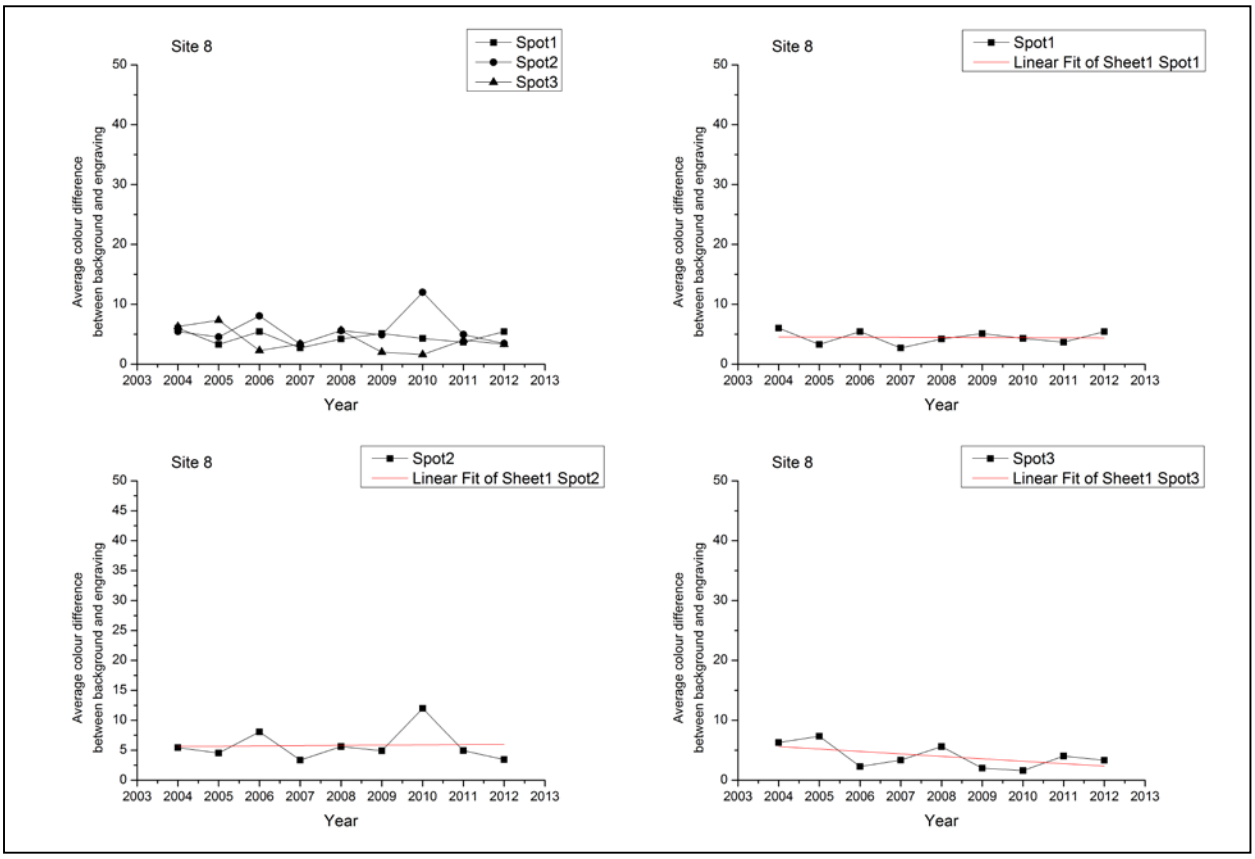


Figure 16: Colour differences between engraving and background for each spot examined at Site 8 – King Bay South.

4. Conclusions

The measurements made in September 2012 continue the annual collection of 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 test sites were not consistently different to those at the northern control sites, with three slightly higher and two slightly lower than the controls. Therefore the current indication is there was no consistent perceptible increase in colour change over the period 2004–12 at either the control or test sites.

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. Spectral Mineralogy

5.1 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 et al., 2008 and references within) 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.

5.2 Spectral Results for 2004-2012

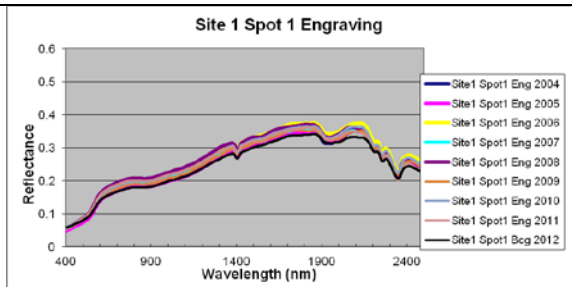
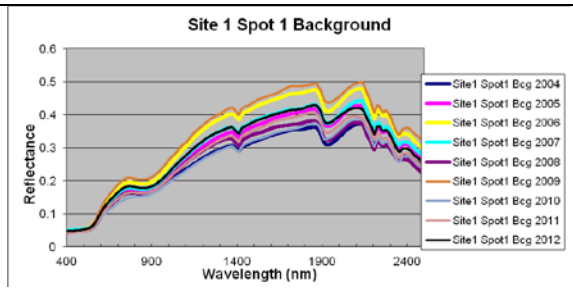
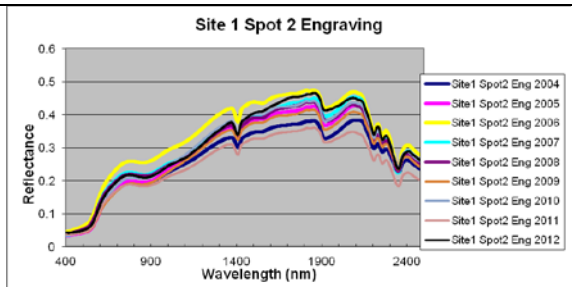
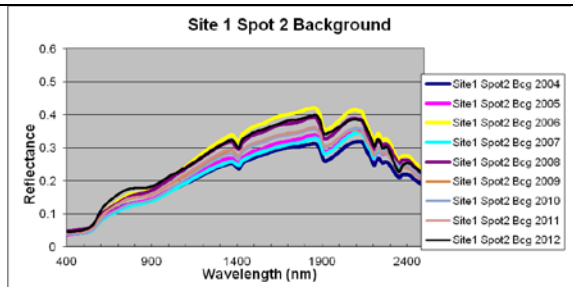
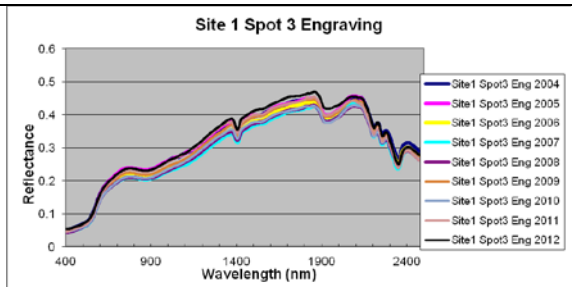
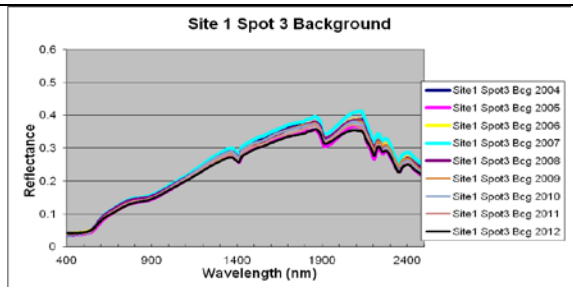
5.2.1 PICTURES AND SPECTRA

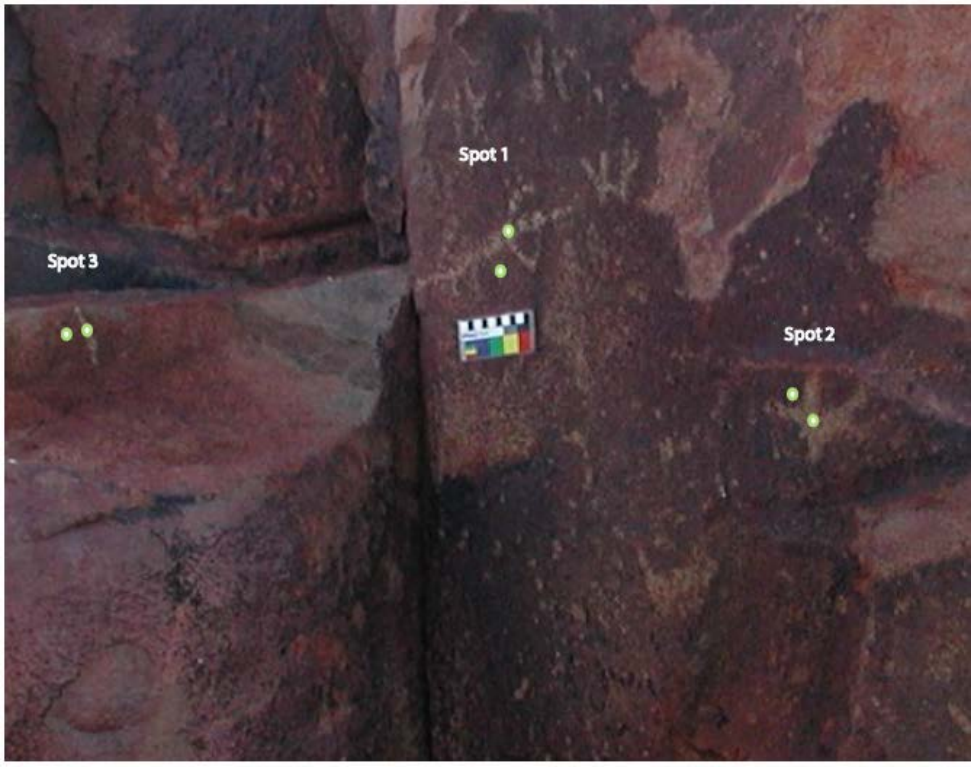
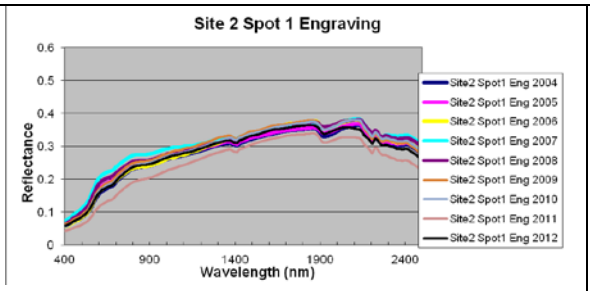
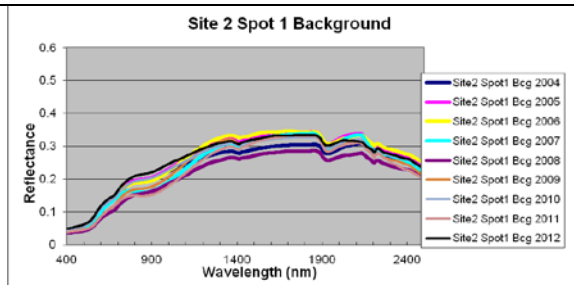
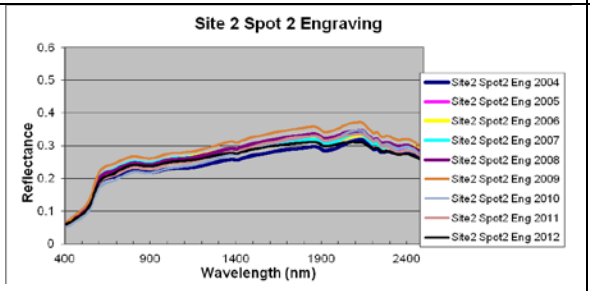
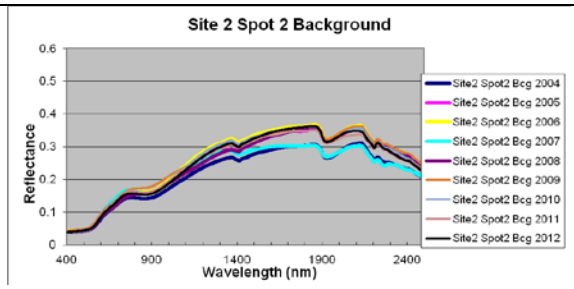
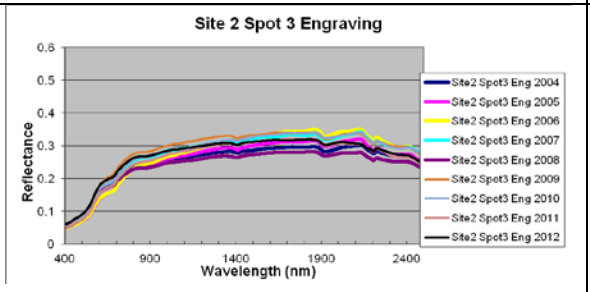
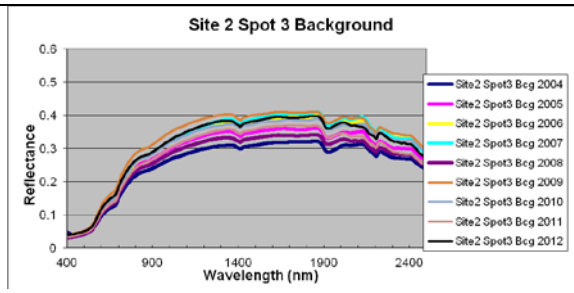
For each site, the description and interpretation include:

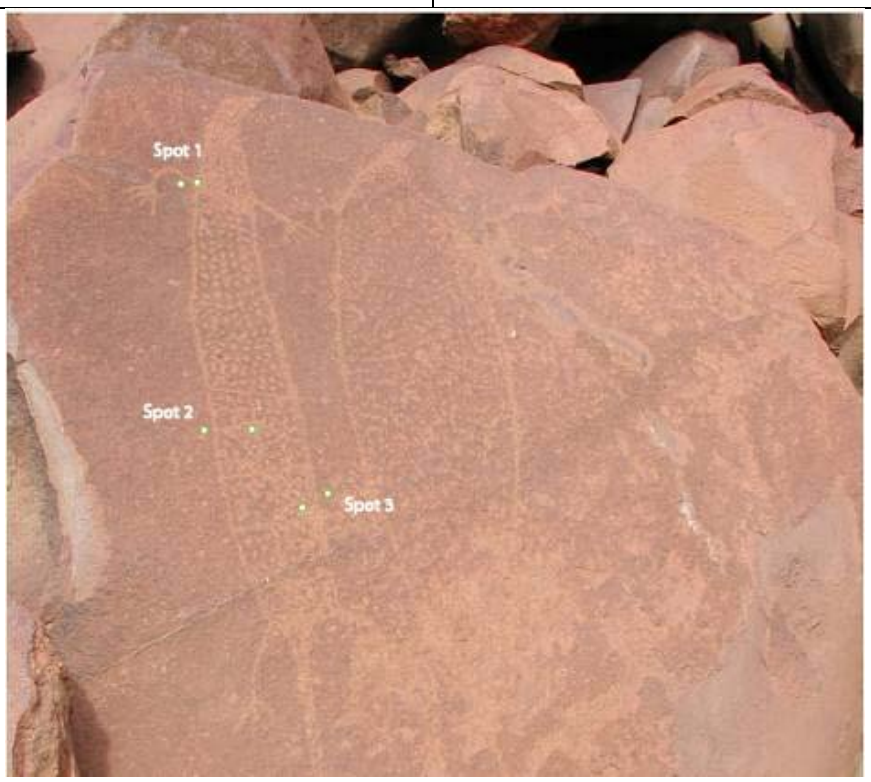
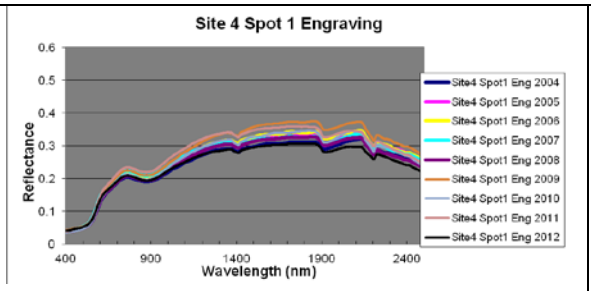
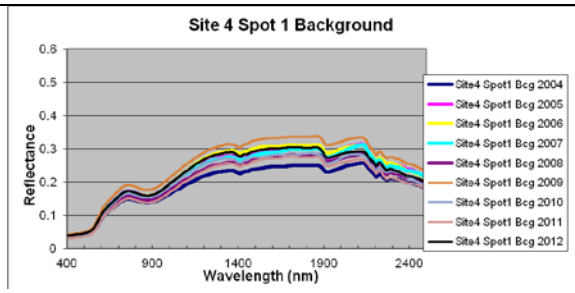
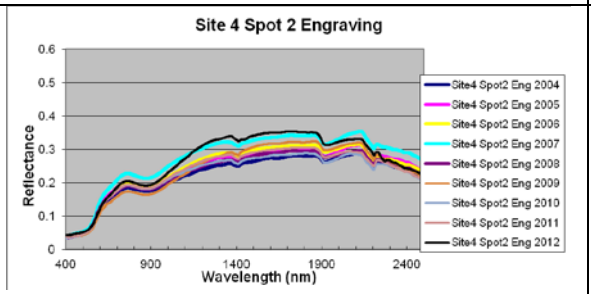
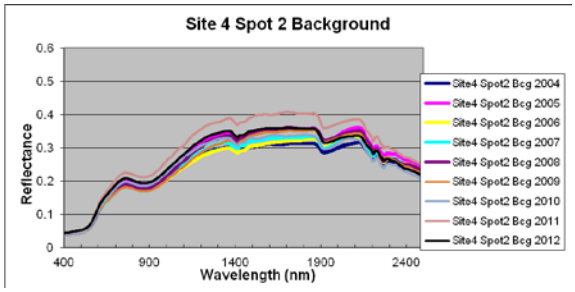
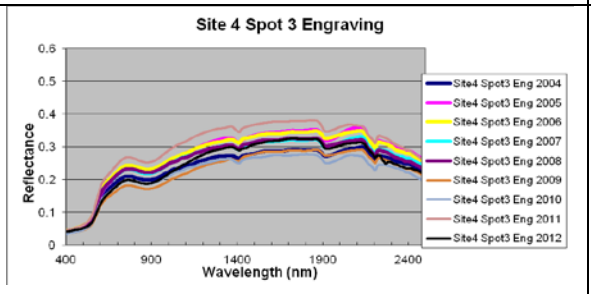
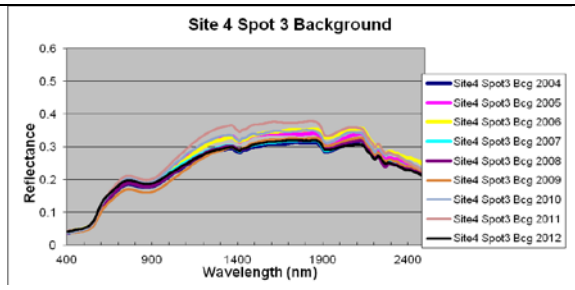
- A digital image of the engraving with the location of the measurements (spot 1, 2 and 3 for both engraving and background).
- Comparison of the average spectra for the engravings and background for each of the three spots between 2004 and 2012.

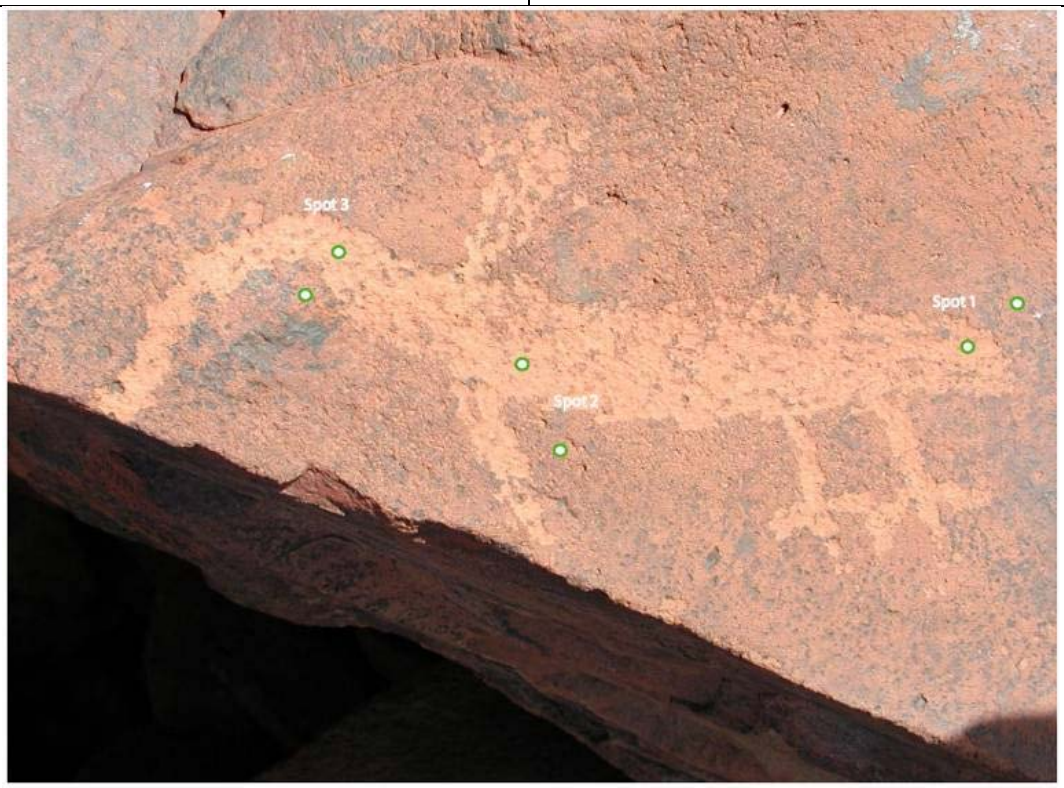
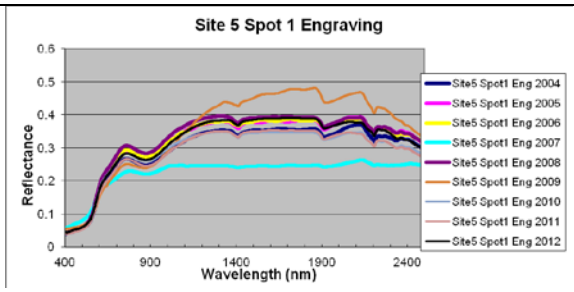
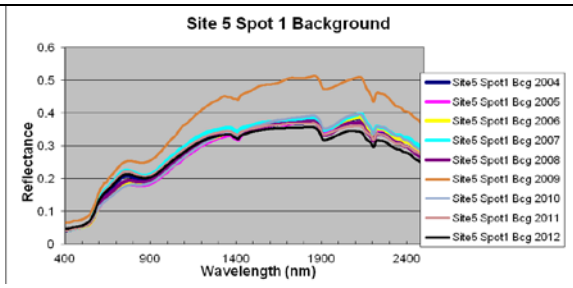
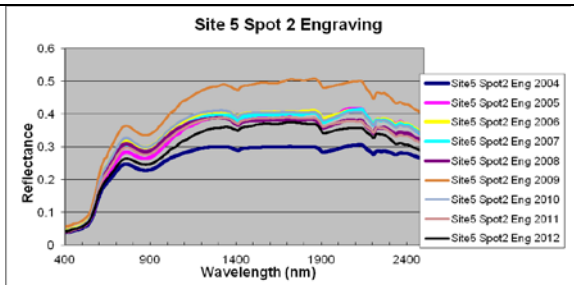
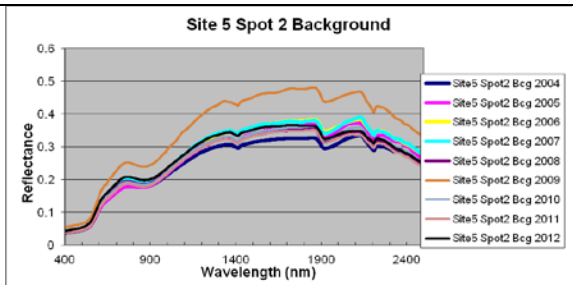
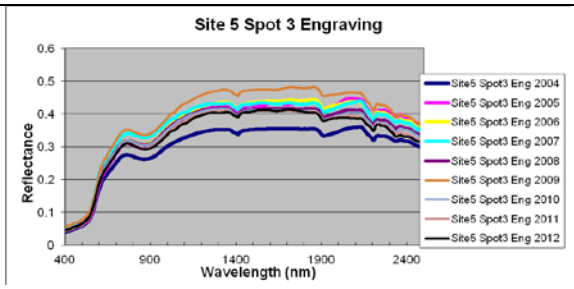
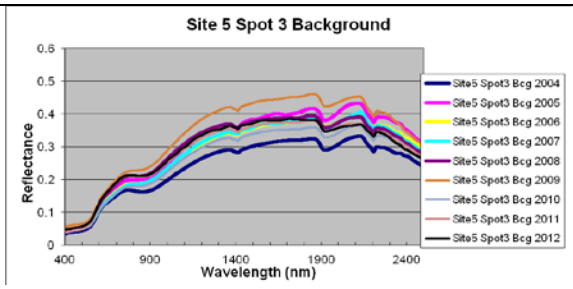
5.2.2 SPECTRAL DATA USING THE CURRENT ASD SPECTROMETER

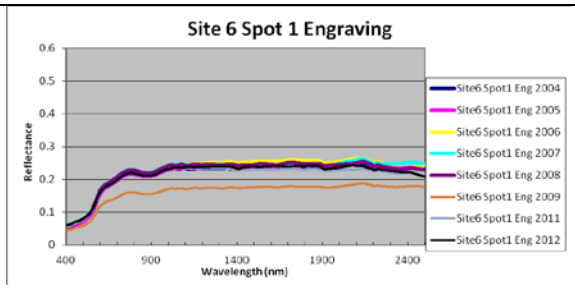
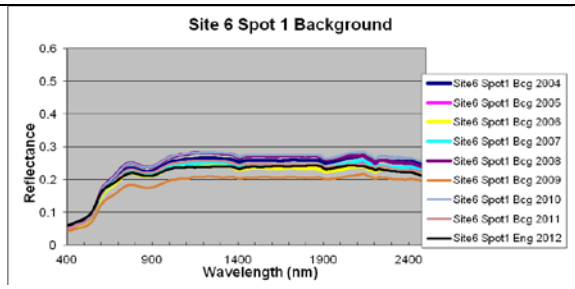
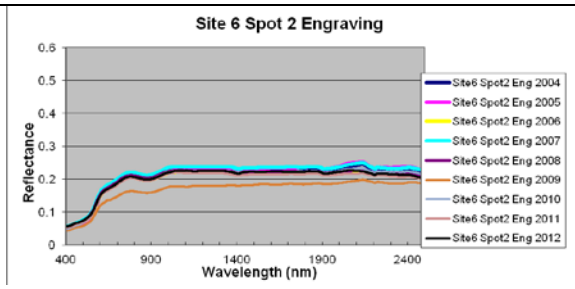
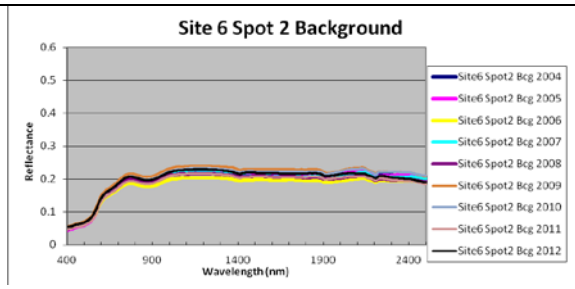
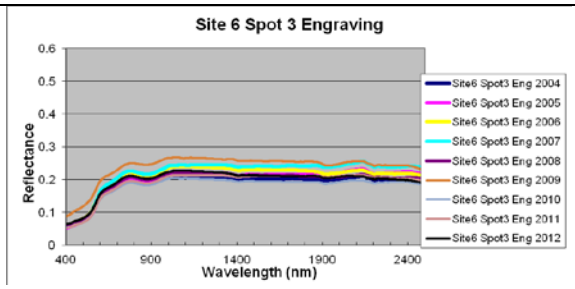
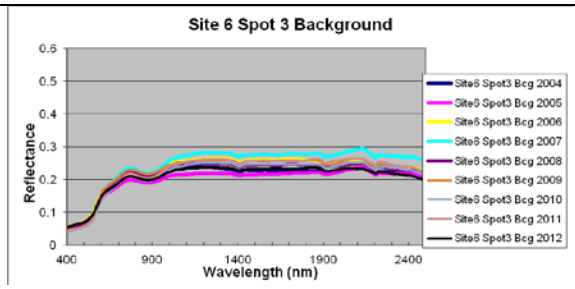
Figure 17: ASD FieldSpecPro operating on petroglyphs in the Burrup Peninsula (2005)

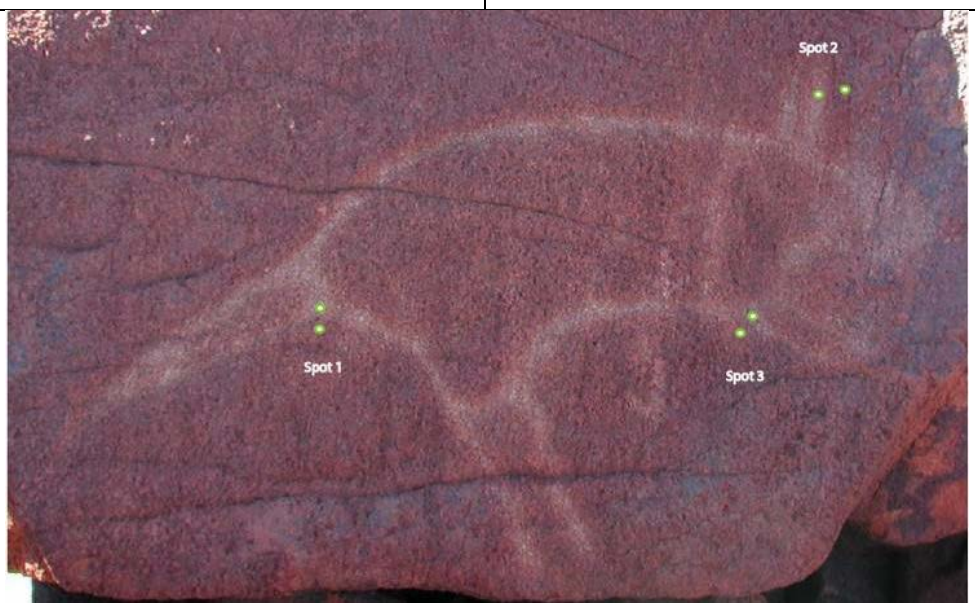
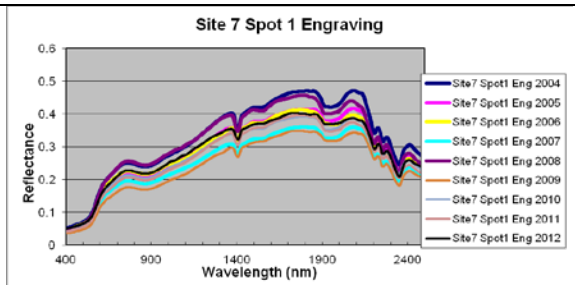
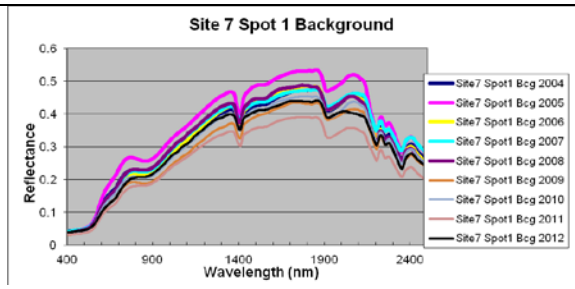
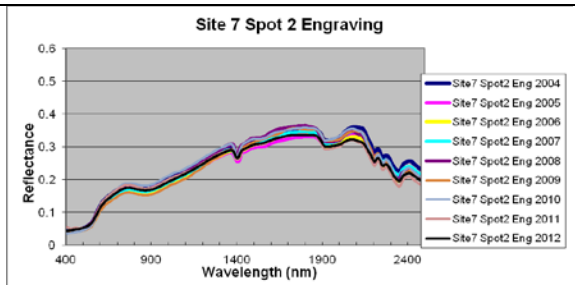
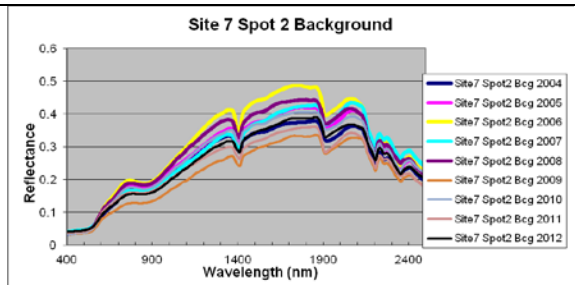
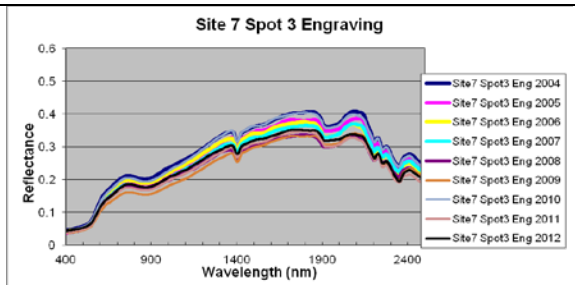
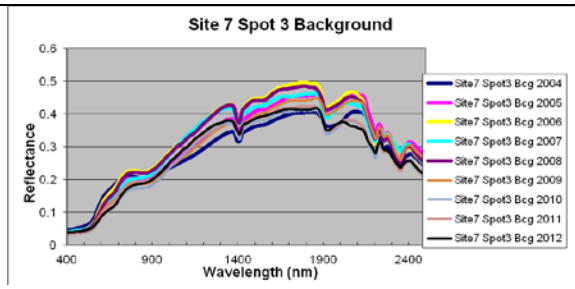
Location	Spectra Engraving	Spectra Background
Site 1		
Site 1 Spot 1		
Site 1 Spot 2		
Site 1 Spot 3		

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

Location	Spectra Engraving	Spectra Background
Site 4		
Site 4 Spot 1		
Site 4 Spot 2		
Site 4 Spot 3		

Location	Spectra Engraving	Spectra Background
		
Site 5 Spot 1		
Site 5 Spot 2		
Site 5 Spot 3		

Location	Spectra Engraving	Spectra Background
		
Site 6 Spot 1		
Site 6 Spot 2		
Site 6 Spot 3		

Location	Spectra Engraving	Spectra Background
		
Site 7 Spot 1		
Site 7 Spot 2		
Site 7 Spot 3		

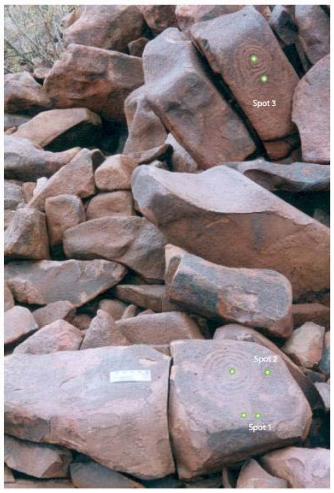
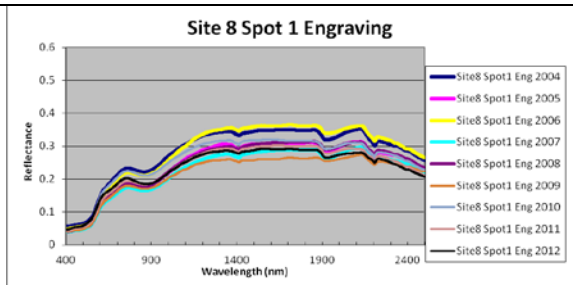
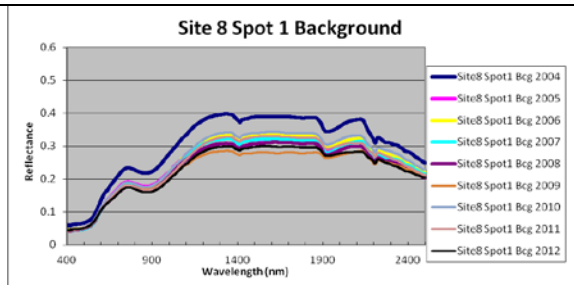
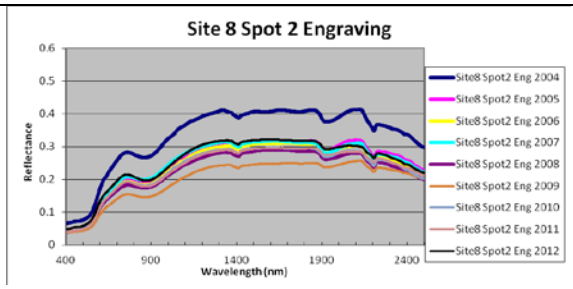
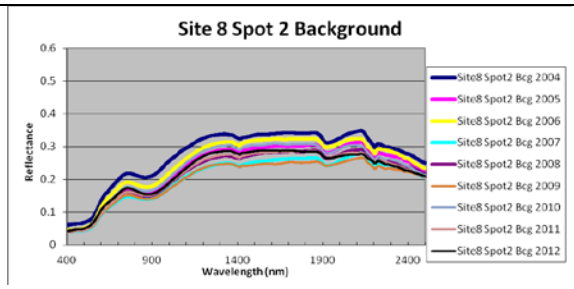
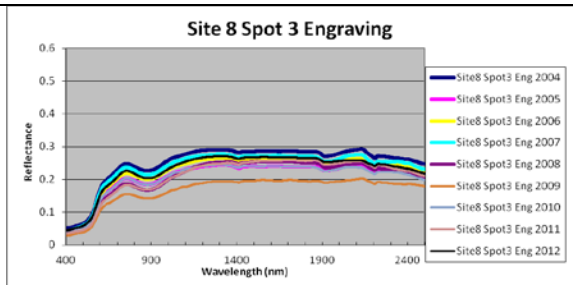
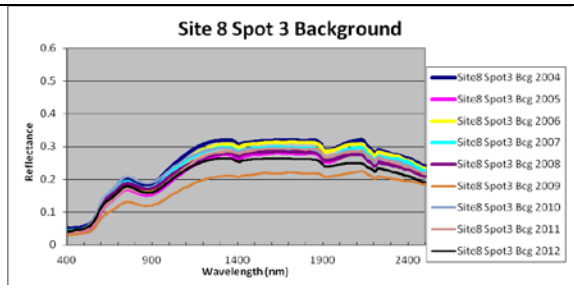
Location	Spectra Engraving	Spectra Background
Site 8		
Site 8 Spot 1		
Site 8 Spot 2		
Site 8 Spot 3		

Figure 18: 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 2012.

5.2.3 SPECTRAL PARAMETERS

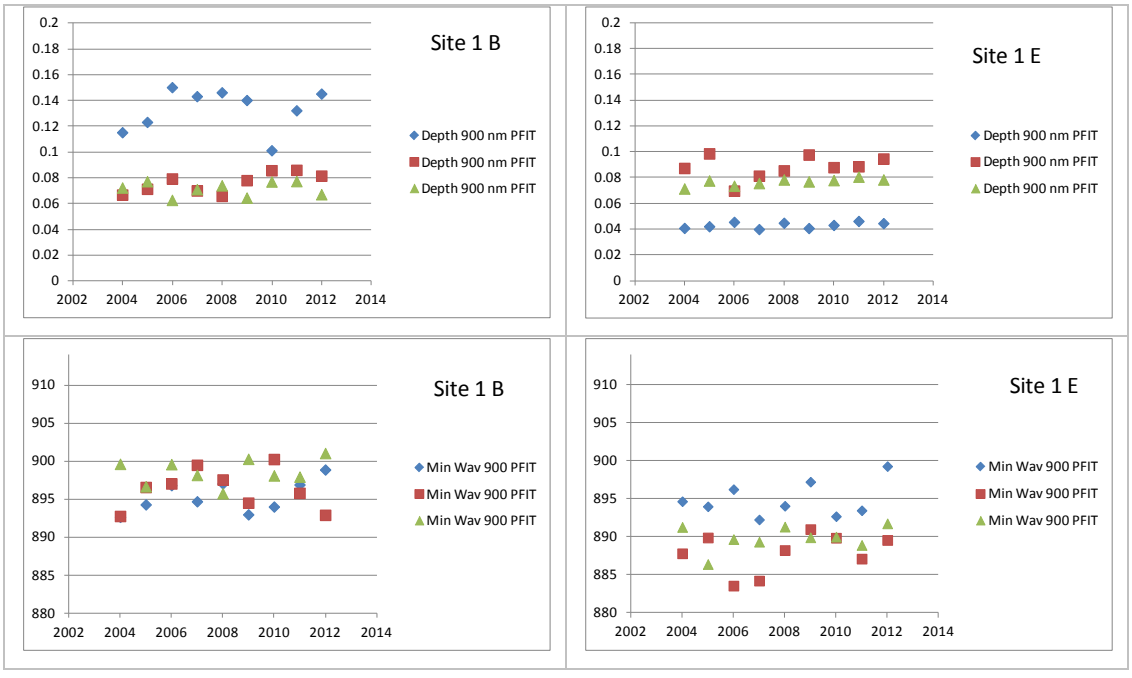
Spectral parameters were extracted from the spectra and include:

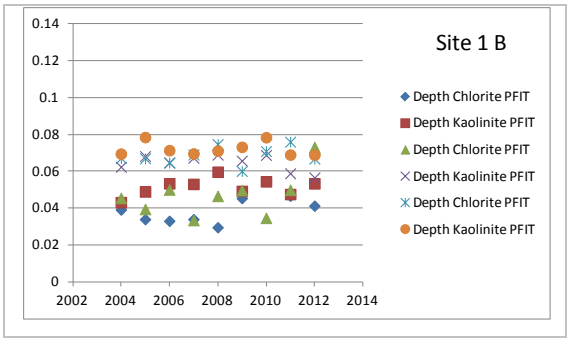
1. The depth (Depth 900 nm) and minimum wavelength (Min Wav 900 nm) of the large 900nm centred absorption providing information on the iron oxides
2. The depth of the chlorite absorption - Depth Chlorite (residual mineral from the fresh rocks)
3. The depth of the kaolinite (Depth Kaolinite) and, when present, gibbsite (Depth Gibbsite) absorptions (secondary minerals resulting from the weathering of the primary minerals)

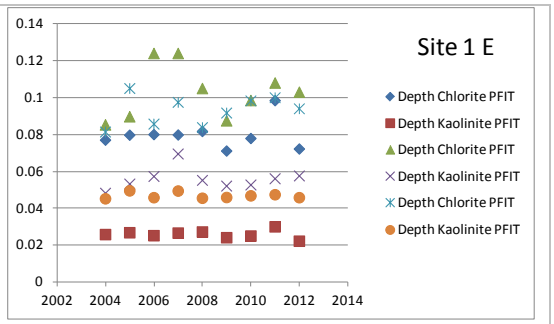
The statistical analysis of the 378 measurements is shown in Table 13 below.

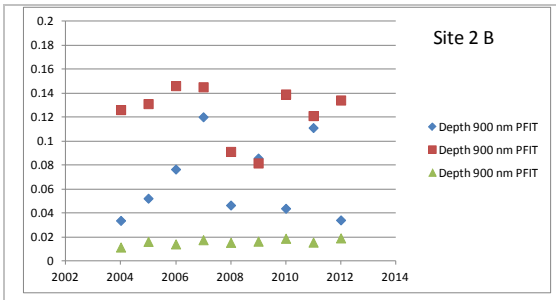
Table 13: Statistical analysis of spectral parameters (378 measurements)

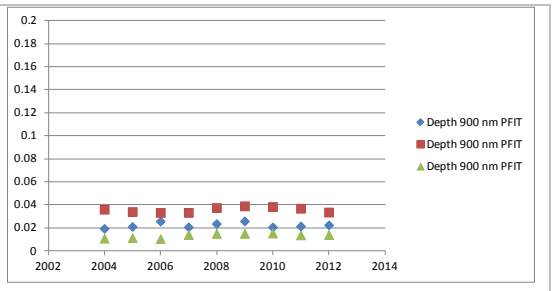
	Mean	Standard Deviation	Minimum	Maximum
Depth 900 nm	0.101	0.04	0.01	0.18
Min Wav 900 nm	893.2	5.8	881.7	912.9
Depth Chlorite	0.021	0.03	0	0.124
Depth Kaolinite	0.0396	0.017	0.003	0.115

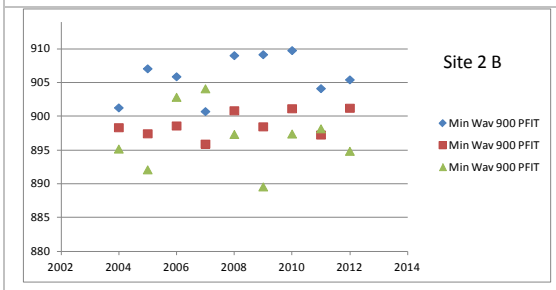


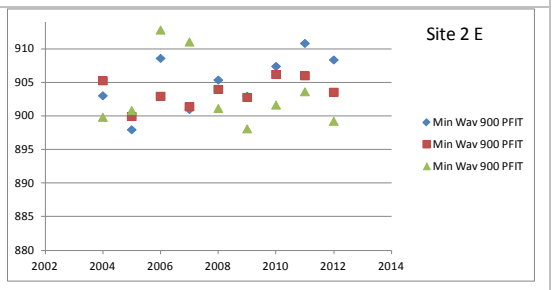

Site 1 B
Depth Chlorite PFIT
Depth Kaolinite PFIT
Depth Chlorite PFIT
Depth Kaolinite PFIT
Depth Chlorite PFIT
Depth Kaolinite PFIT

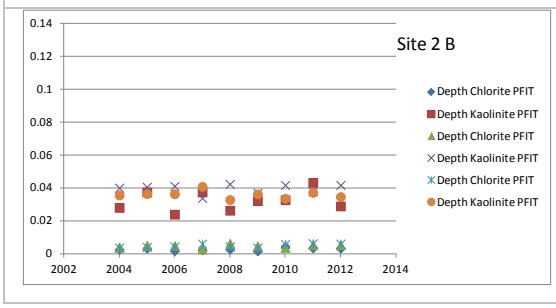

Site 1 E
Depth Chlorite PFIT
Depth Kaolinite PFIT
Depth Chlorite PFIT
Depth Kaolinite PFIT
Depth Chlorite PFIT
Depth Kaolinite PFIT

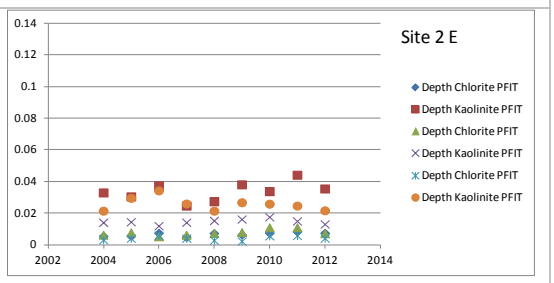

Site 2 B
Depth 900 nm PFIT
Depth 900 nm PFIT
Depth 900 nm PFIT

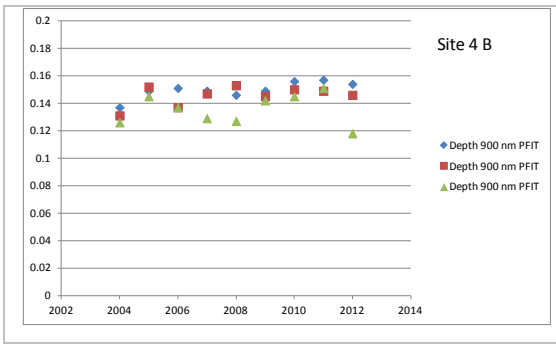

Depth 900 nm PFIT
Depth 900 nm PFIT
Depth 900 nm PFIT

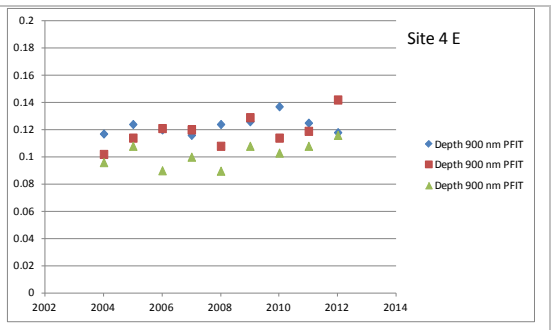

Site 2 B
Min Wav 900 PFIT
Min Wav 900 PFIT
Min Wav 900 PFIT

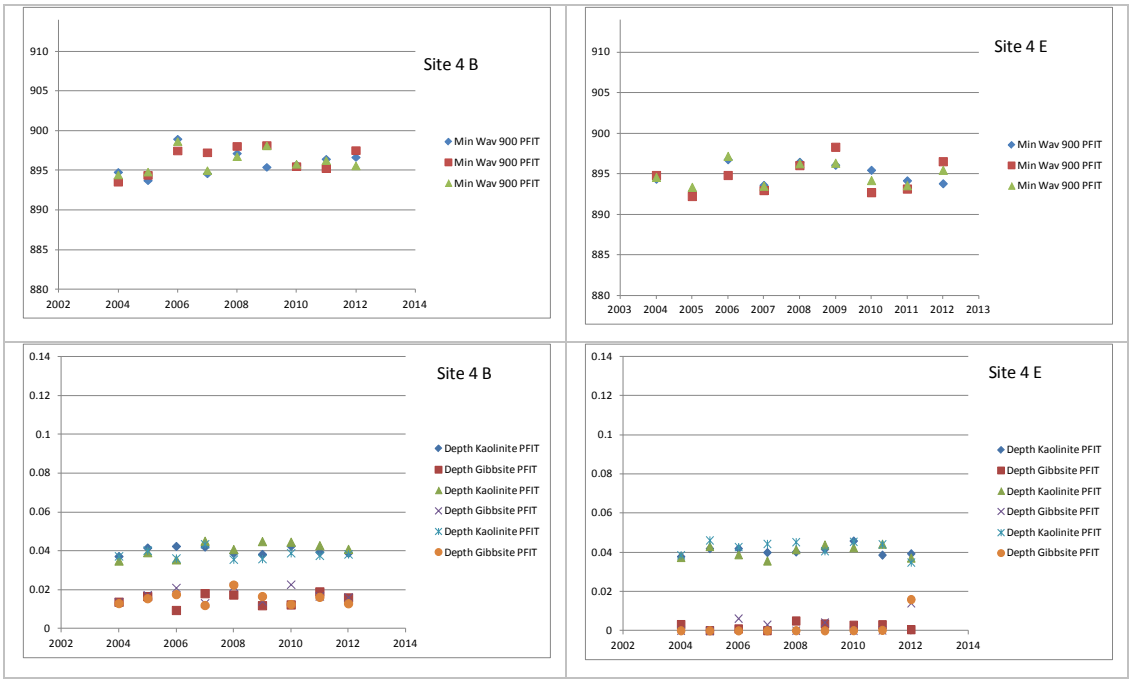

Site 2 E
Min Wav 900 PFIT
Min Wav 900 PFIT
Min Wav 900 PFIT


Site 2 B
Depth Chlorite PFIT
Depth Kaolinite PFIT
Depth Chlorite PFIT
Depth Kaolinite PFIT
Depth Chlorite PFIT
Depth Kaolinite PFIT

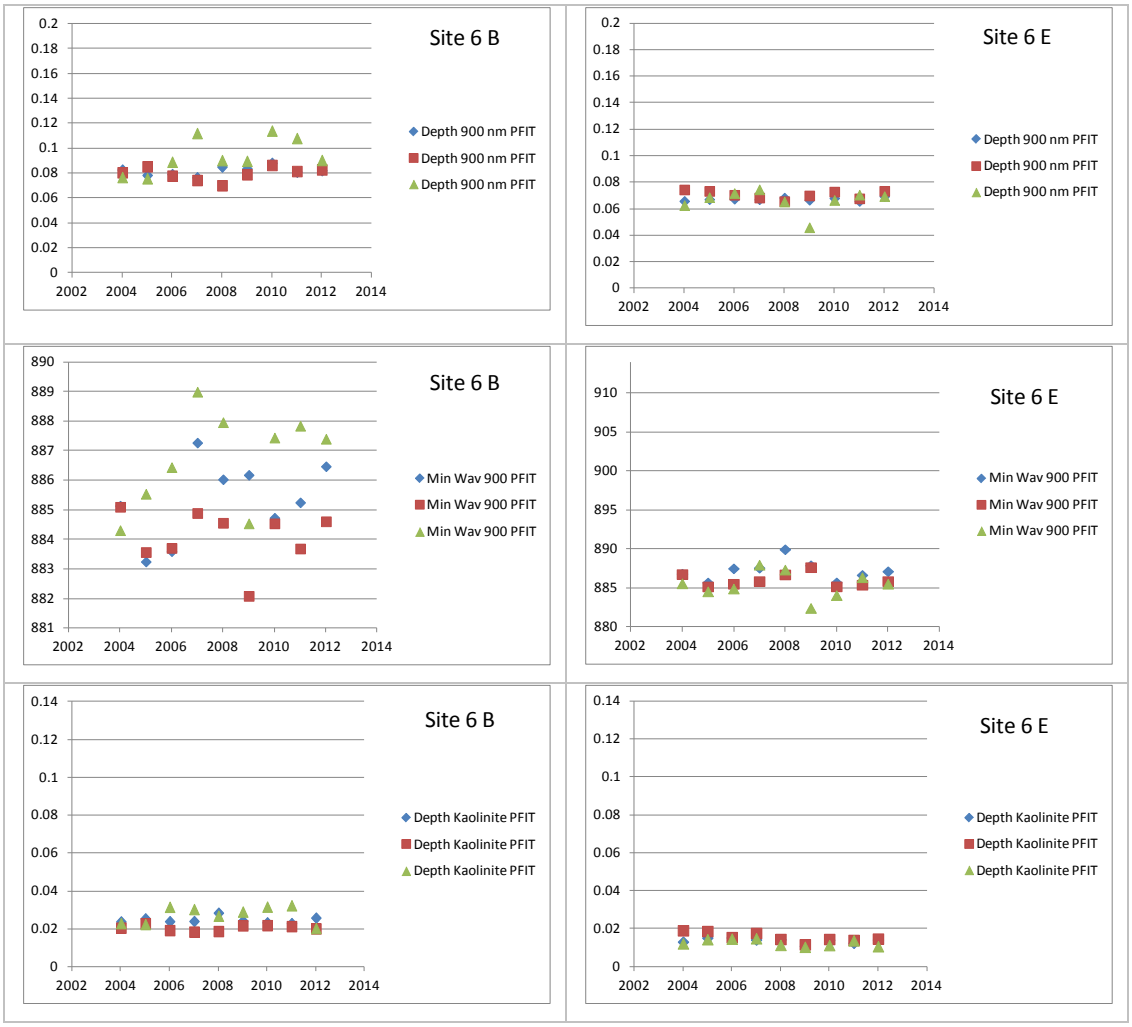

Site 2 E
Depth Chlorite PFIT
Depth Kaolinite PFIT
Depth Chlorite PFIT
Depth Kaolinite PFIT
Depth Chlorite PFIT
Depth Kaolinite PFIT

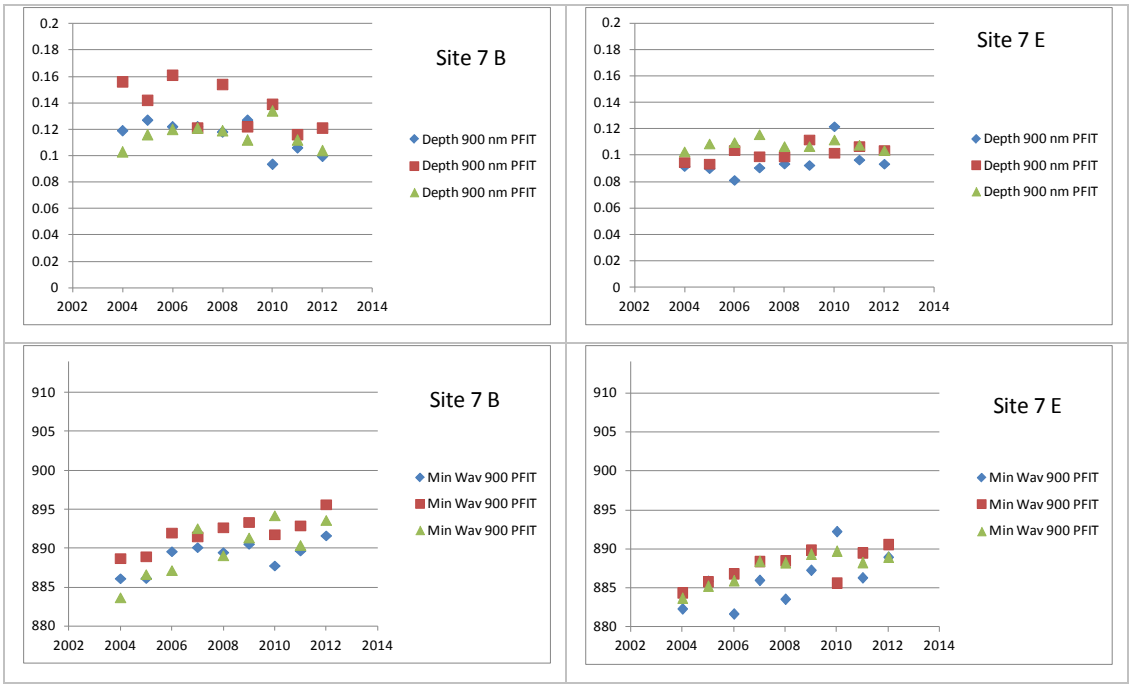

Site 4 B
Depth 900 nm PFIT
Depth 900 nm PFIT
Depth 900 nm PFIT


Site 4 E
Depth 900 nm PFIT
Depth 900 nm PFIT
Depth 900 nm PFIT


Site 4 B
Min Wav 900 PFIT
Min Wav 900 PFIT
Min Wav 900 PFIT
Site 4 E
Min Wav 900 PFIT
Min Wav 900 PFIT
Min Wav 900 PFIT
Site 4 B
Depth Kaolinite PFIT
Depth Gibbsite PFIT
Depth Kaolinite PFIT
Depth Gibbsite PFIT
Depth Kaolinite PFIT
Depth Gibbsite PFIT
Site 4 E
Depth Kaolinite PFIT
Depth Gibbsite PFIT
Depth Kaolinite PFIT
Depth Gibbsite PFIT
Depth Kaolinite PFIT
Depth Gibbsite PFIT


Site 5 B
Depth 900 nm PFIT
Depth 900 nm PFIT
Depth 900 nm PFIT
Site 5 E
Depth 900 nm PFIT
Depth 900 nm PFIT
Depth 900 nm PFIT
Site 5 B
Min Wav 900 PFIT
Min Wav 900 PFIT
Min Wav 900 PFIT
Site 5 E
Min Wav 900 PFIT
Min Wav 900 PFIT
Min Wav 900 PFIT
Site 5 B
Depth Kaolinite PFIT
Depth Kaolinite PFIT
Depth Kaolinite PFIT
Site 5 E
Depth Kaolinite PFIT
Depth Kaolinite PFIT
Depth Kaolinite PFIT


Site 6 B
Depth 900 nm PFIT
Depth 900 nm PFIT
Depth 900 nm PFIT
Site 6 E
Depth 900 nm PFIT
Depth 900 nm PFIT
Depth 900 nm PFIT
Site 6 B
Min Wav 900 PFIT
Min Wav 900 PFIT
Min Wav 900 PFIT
Site 6 E
Min Wav 900 PFIT
Min Wav 900 PFIT
Min Wav 900 PFIT
Site 6 B
Depth Kaolinite PFIT
Depth Kaolinite PFIT
Depth Kaolinite PFIT
Site 6 E
Depth Kaolinite PFIT
Depth Kaolinite PFIT
Depth Kaolinite PFIT


Site 7 B
Depth 900 nm PFIT
Depth 900 nm PFIT
Depth 900 nm PFIT
Site 7 E
Depth 900 nm PFIT
Depth 900 nm PFIT
Depth 900 nm PFIT
Site 7 B
Min Wav 900 PFIT
Min Wav 900 PFIT
Min Wav 900 PFIT
Site 7 E
Min Wav 900 PFIT
Min Wav 900 PFIT
Min Wav 900 PFIT

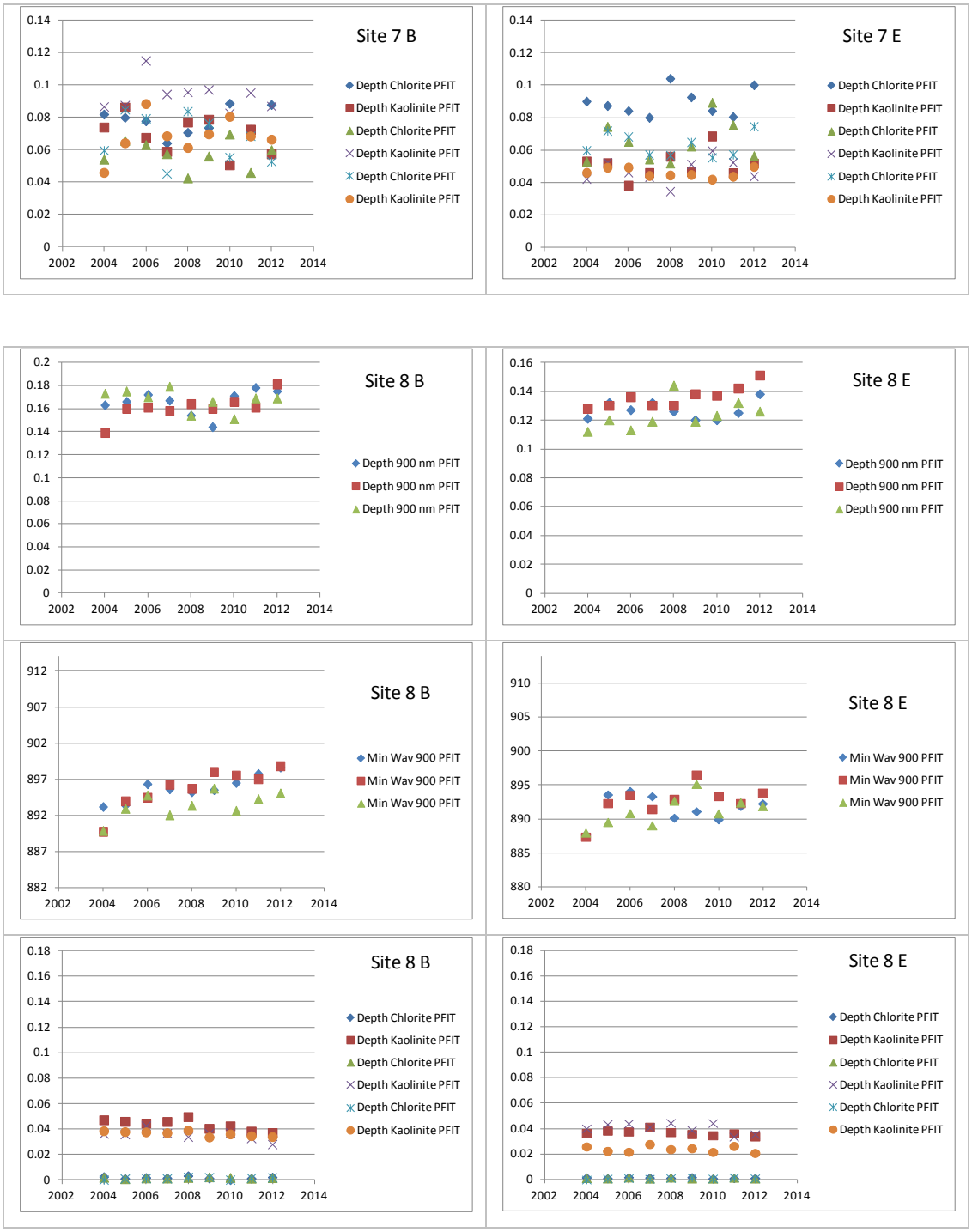


Figure 19: Spectral parameters for all sites

5.2.4 RESULTS FROM THE SPECTRAL PARAMETERS

The spectral parameters extracted from the reflectance spectra of all sites and, all backgrounds and engravings, combined with the statistical analysis show that the small changes are within expected variations. The spectral parameters, depth and minimum wavelength of the 900 nm iron oxides features for site 7 backgrounds and engravings and site 8 backgrounds have been looked at in details (Figure 20).

Although, some localised trends could be interpreted from Figure 19, the detailed analysis (Figure 20) shows that the observed variations are within statistical deviation.

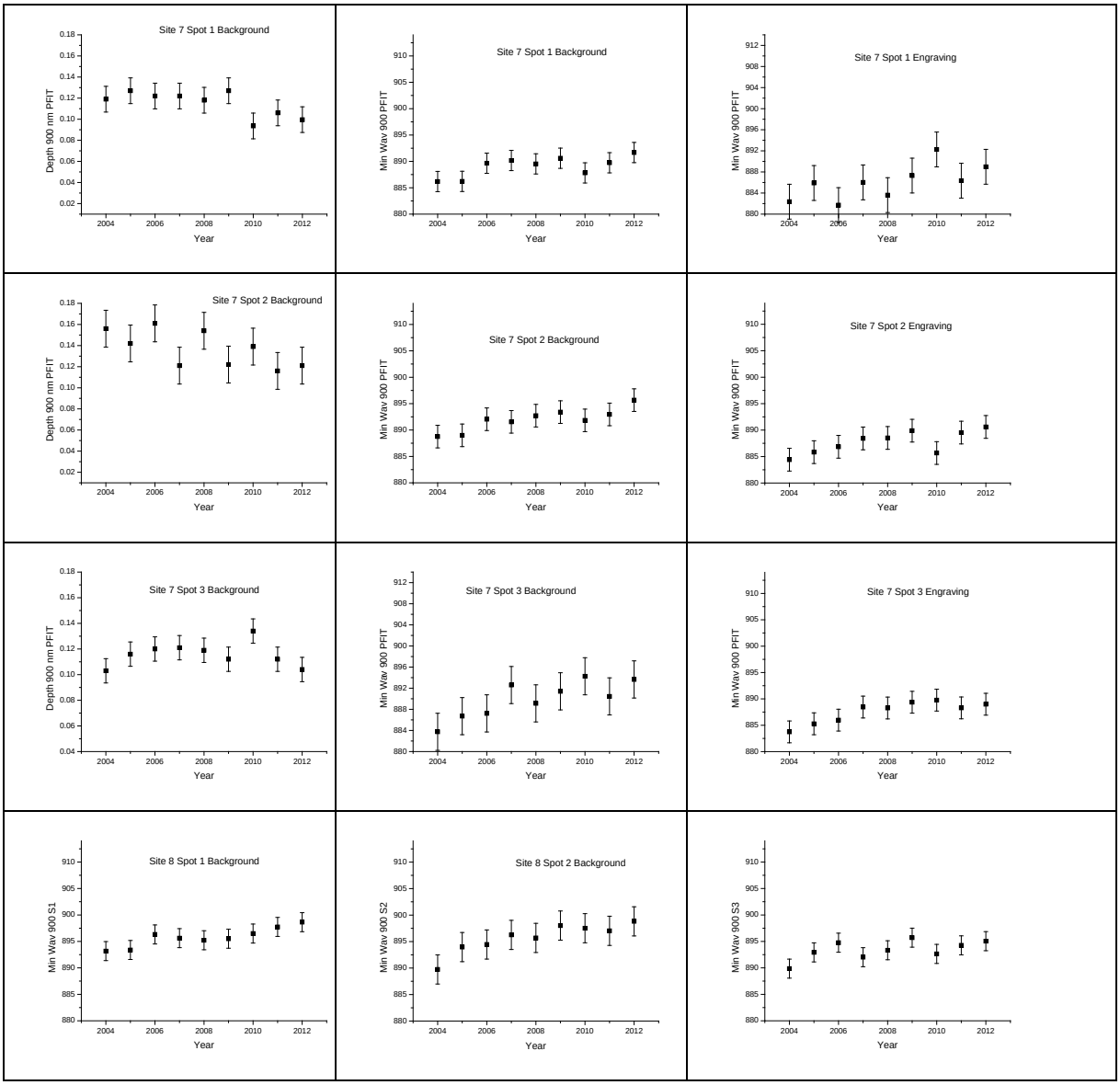
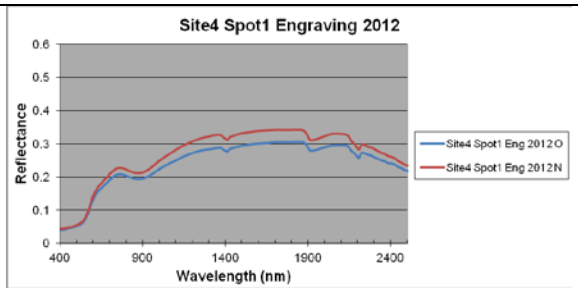
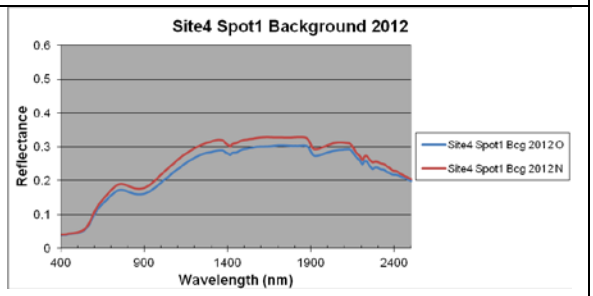
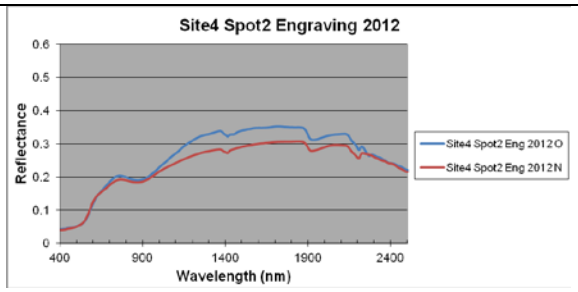
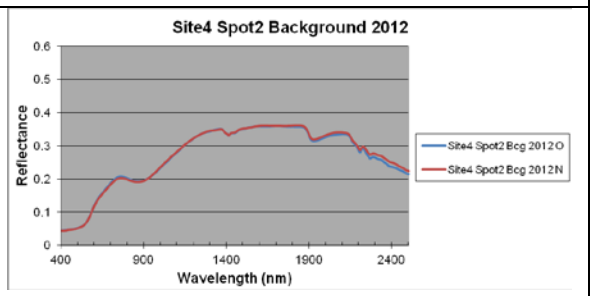
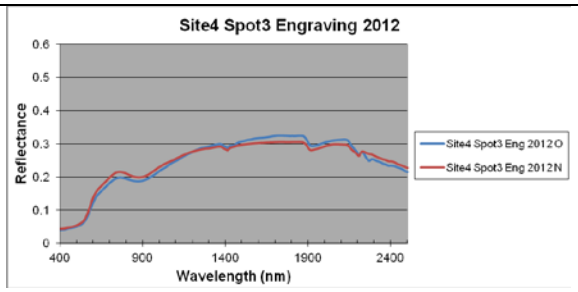
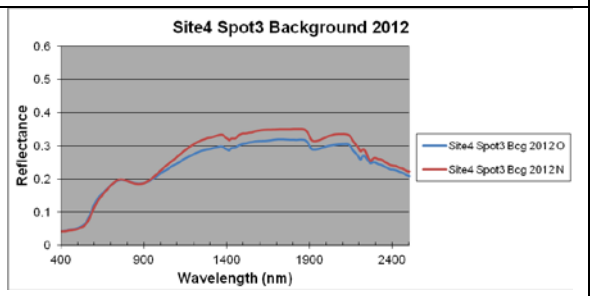


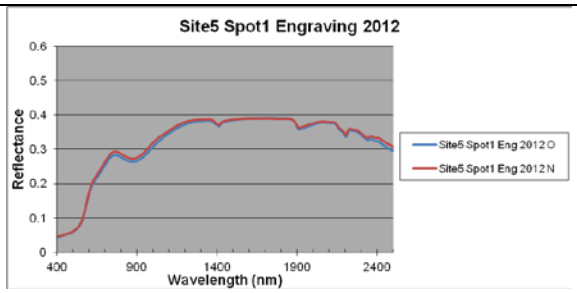
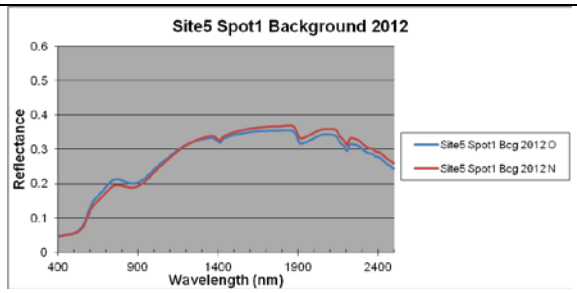
Figure 20: Detailed analysis of the spectral parameters for site 7 and 8

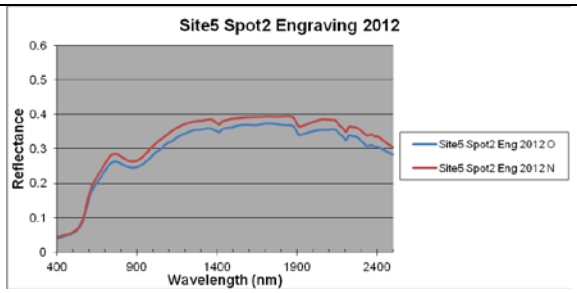
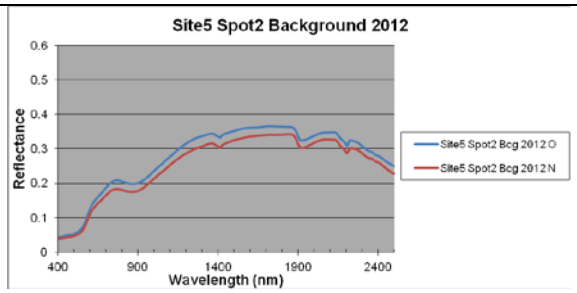
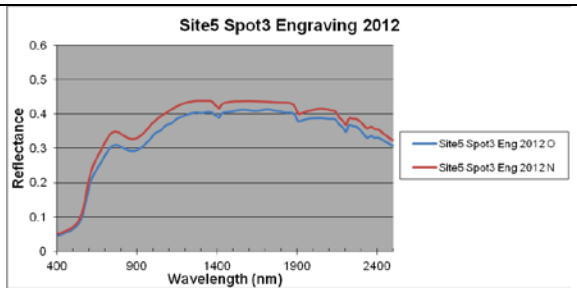
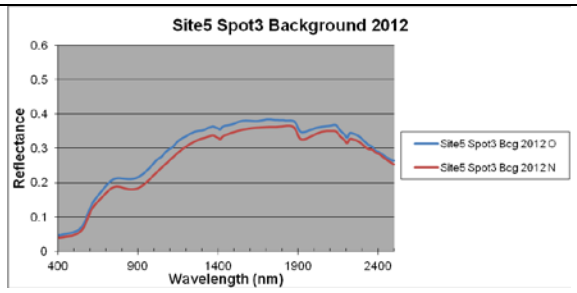
5.2.5 COMPARISON BETWEEN THE TWO SPECTROMETERS FOR SITES 4 TO 8

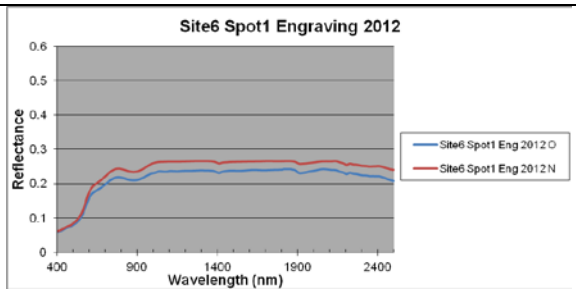
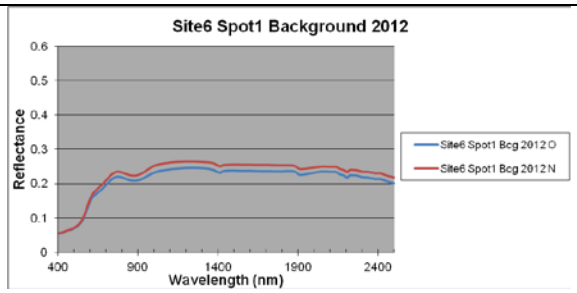
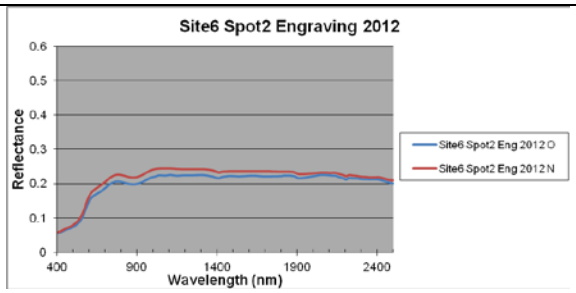
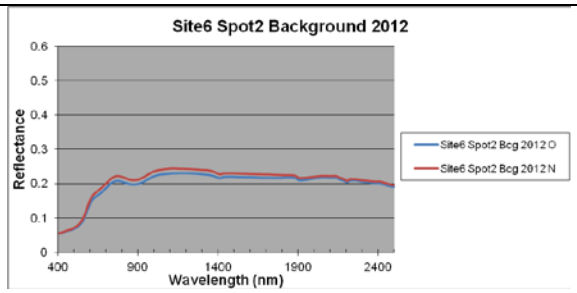
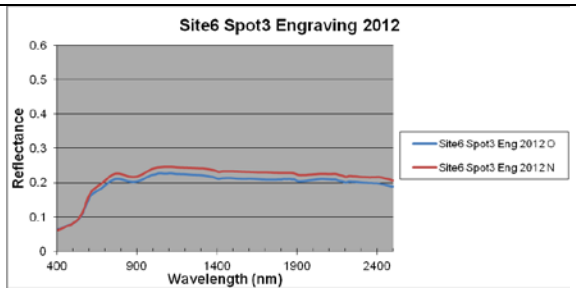
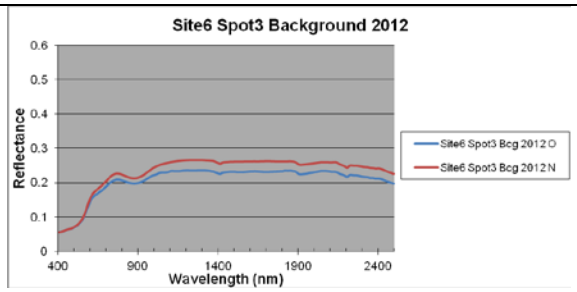
In 2012, 2 ASD spectrometers (the “old” one used for the previous measurements and a new instrument of the same model) were used to measure both background and engravings for Sites 4 to 8. Sites 1 and 2 were not measured as carrying the two spectrometers during boat transportation and through long walk with loose and unforgiving rocks was not deemed safe. The same spectral parameters that we used in the

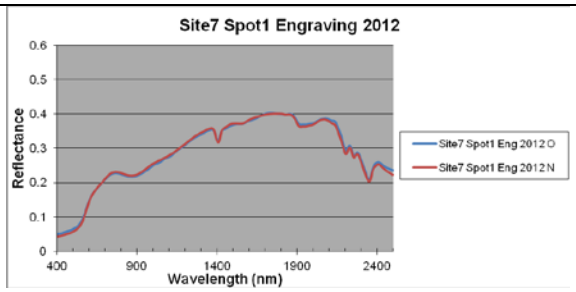
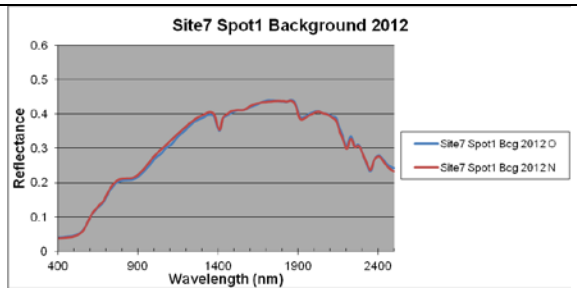
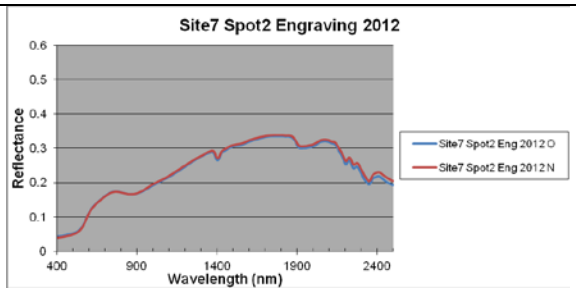
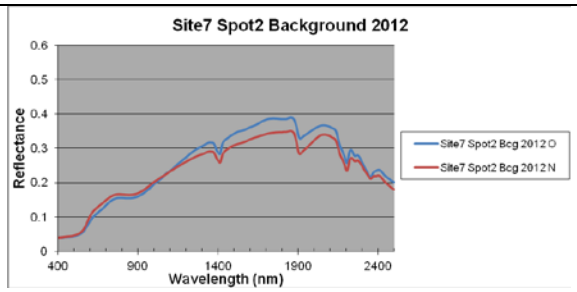
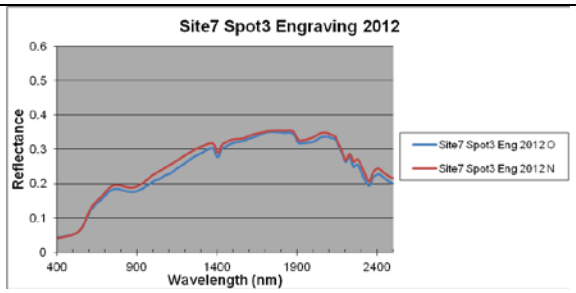
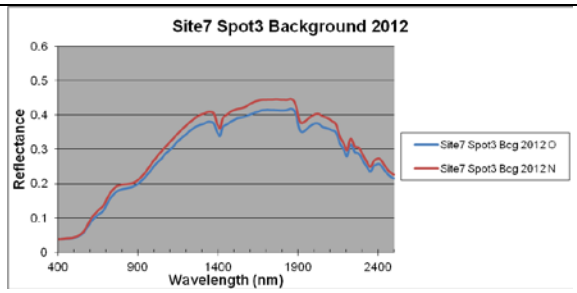
annual comparison were also extracted from the spectra of both spectrometers respectively called Old (O) and New (N).

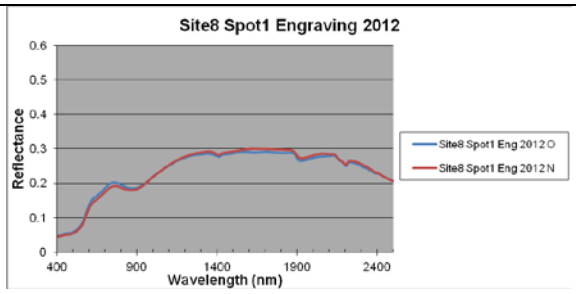
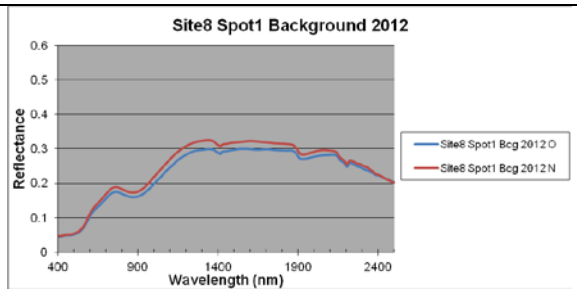
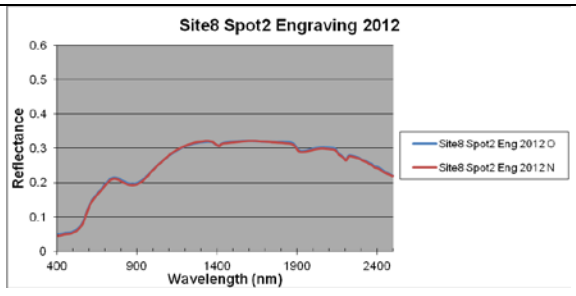
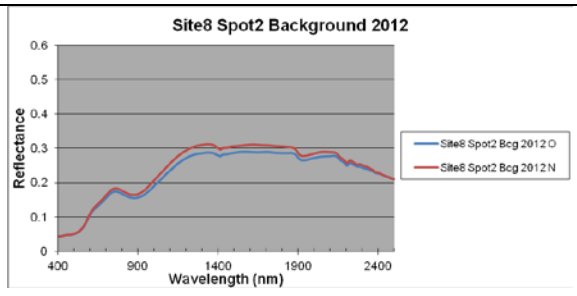
Location	Spectra Engraving	Spectra Background
Site 4 Spot 1		
Site 4 Spot 2		
Site 4 Spot 3		

Location	Spectra Engraving	Spectra Background
Site 5 Spot 1		

Site 5 Spot 2		
Site 5 Spot 3		

Location	Spectra Engraving	Spectra Background
Site 6 Spot 1		
Site 6 Spot 2		
Site 6 Spot 3		

Location	Spectra Engraving	Spectra Background
Site 7 Spot 1		
Site 7 Spot 2		
Site 7 Spot 3		

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

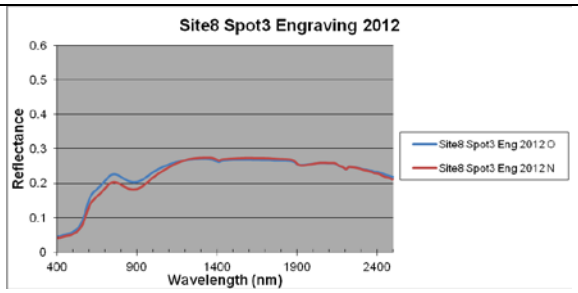
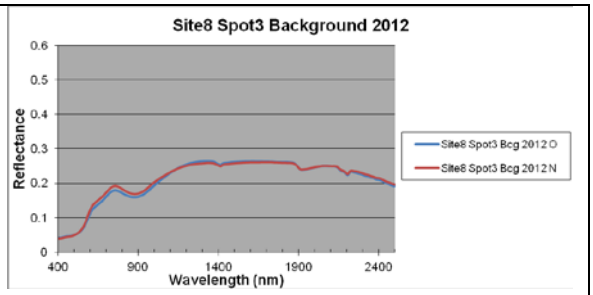
Site 8 Spot 3		

Figure 21: Spectral comparison between “old” and “new” spectrometers

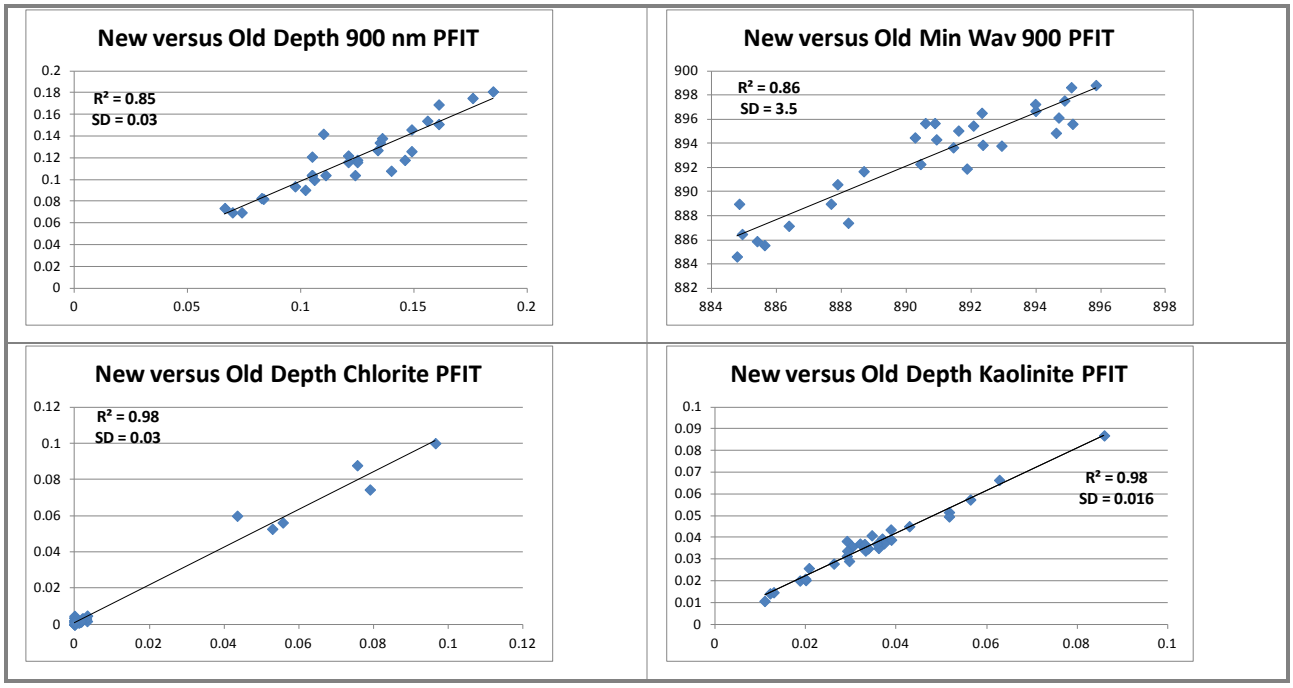


Figure 22: Spectral parameters comparison between “old” and “new” spectrometers

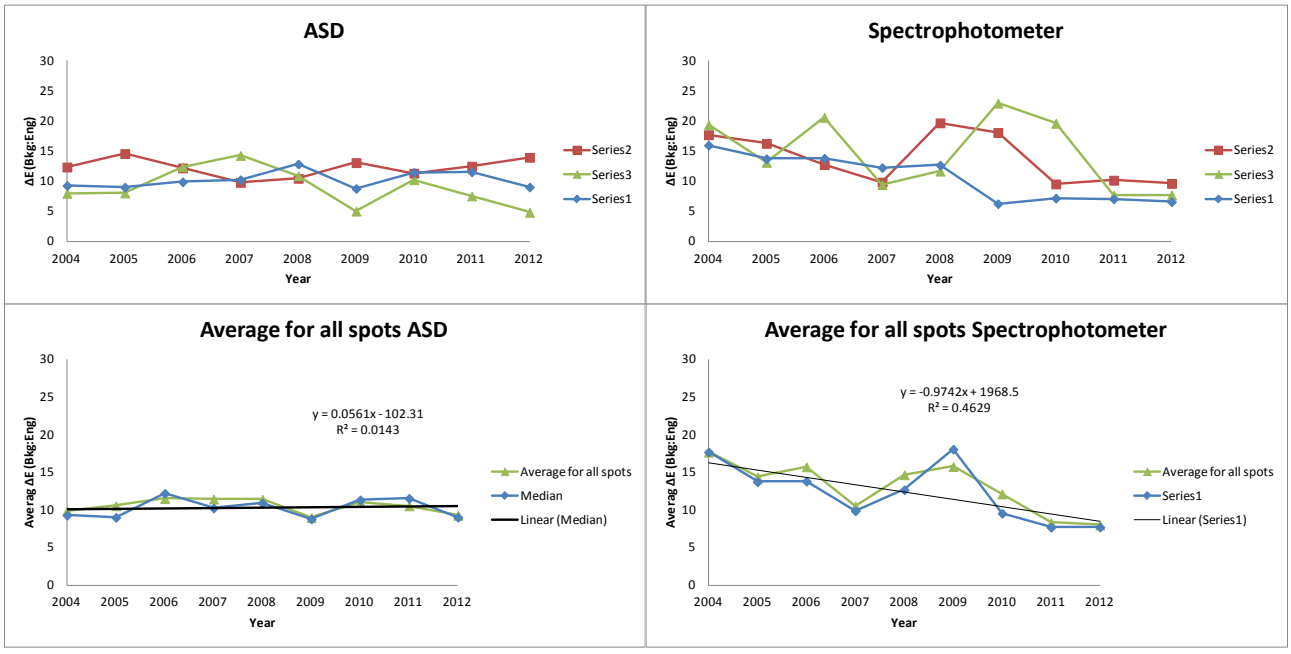
The correlations between the old and the new ASD for all spectral parameters are good, in particular for the depth of the chlorite and kaolinite features. All the points are within 1 standard deviation (SD).

6. Comparison between spectrophotometer and ASD for the colour difference between the background and engraving

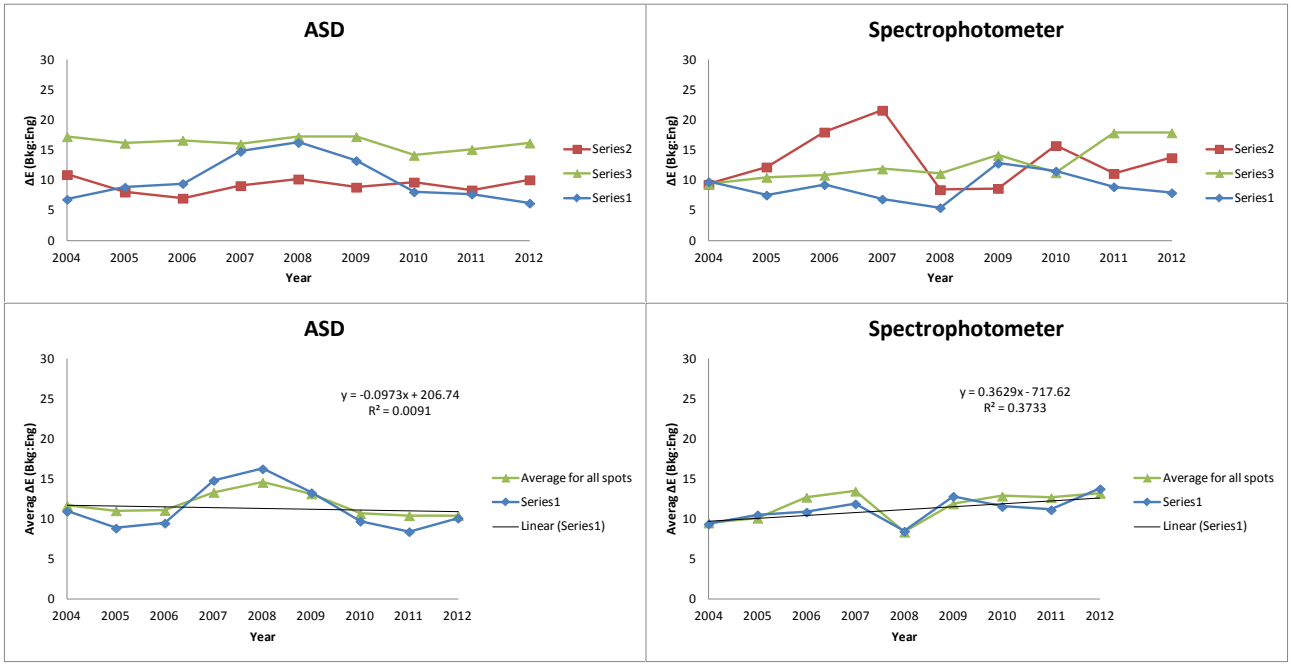
Figure 23 shows comparisons of the colour difference between engravings and background using the ASD and spectrophotometer at all sites. In most cases, the average ΔE values obtained from each of the techniques are comparable, and the gradients of the linear fit of the average data show good correlation between the techniques.

The most obvious discrepancy between data collected using the two techniques can be observed at Site 7. The ASD results show ΔE values that are relatively stable over the data collection period, while the spectrophotometer results show a slight decrease in ΔE values with time. As discussed in Section 3.3.1, Site 7 had the roughest surface and the larger measurement used for ASD may have been more effective at negating any instrument placement effects on colour measurements. Colour inhomogeneity of the sample area was also discussed as a possible cause of measurement variance, and the smaller sample port of the spectrophotometer would make the measurements more likely to be impacted by this aspect.

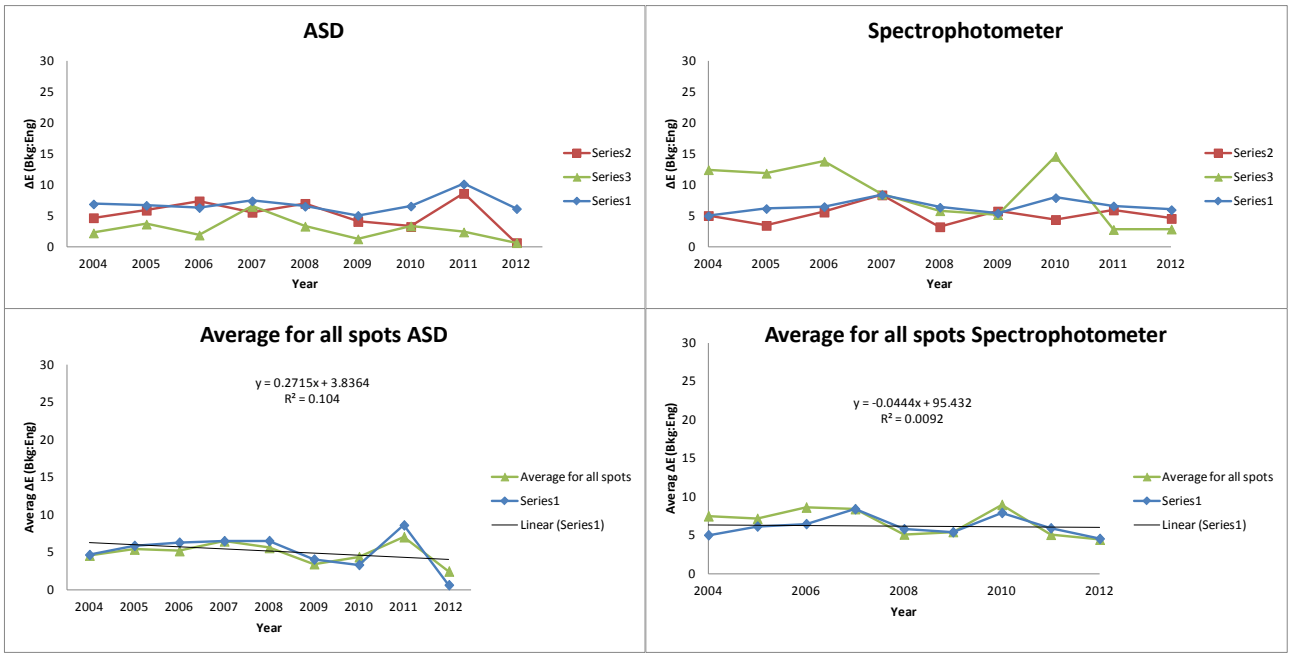
Site 1 Dolphin Island



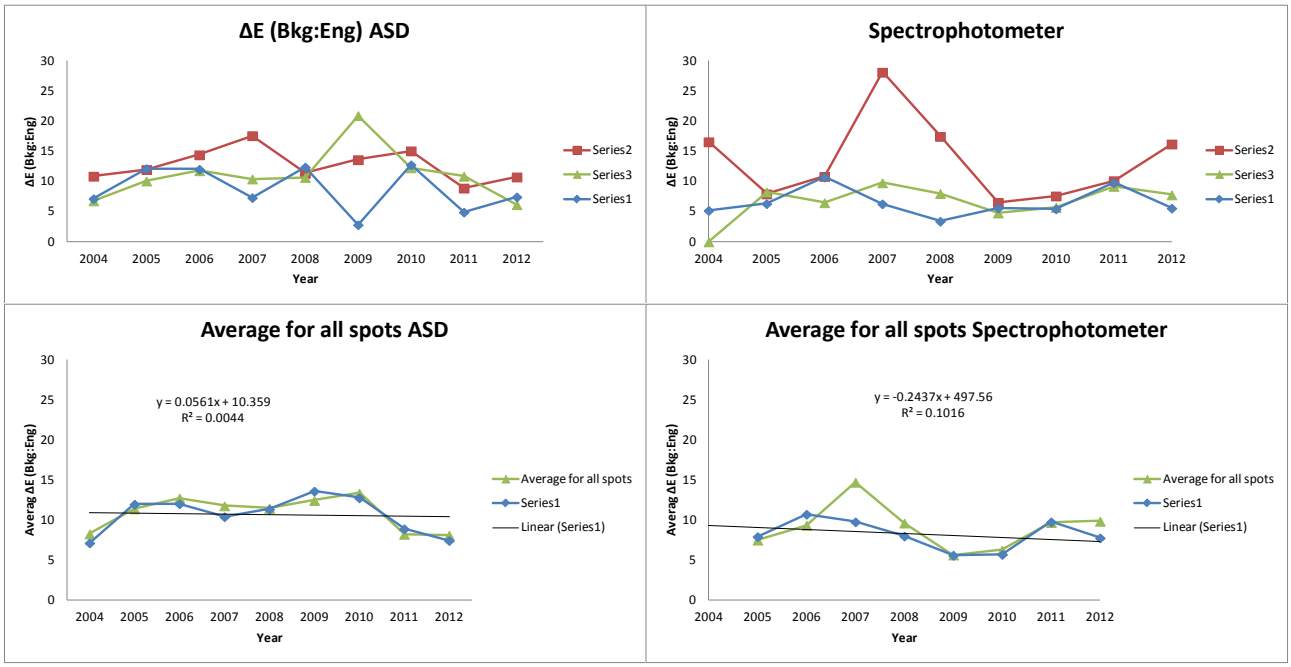
Site 2 Gidley Island



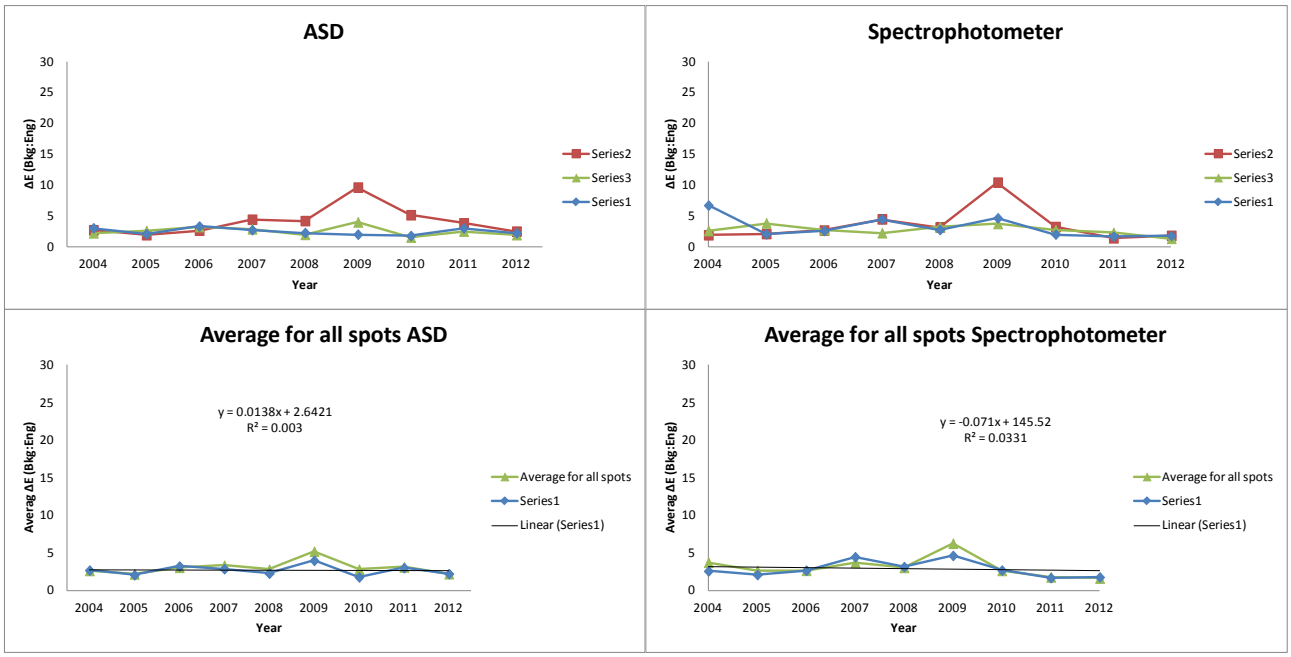
Site 4 Woodside



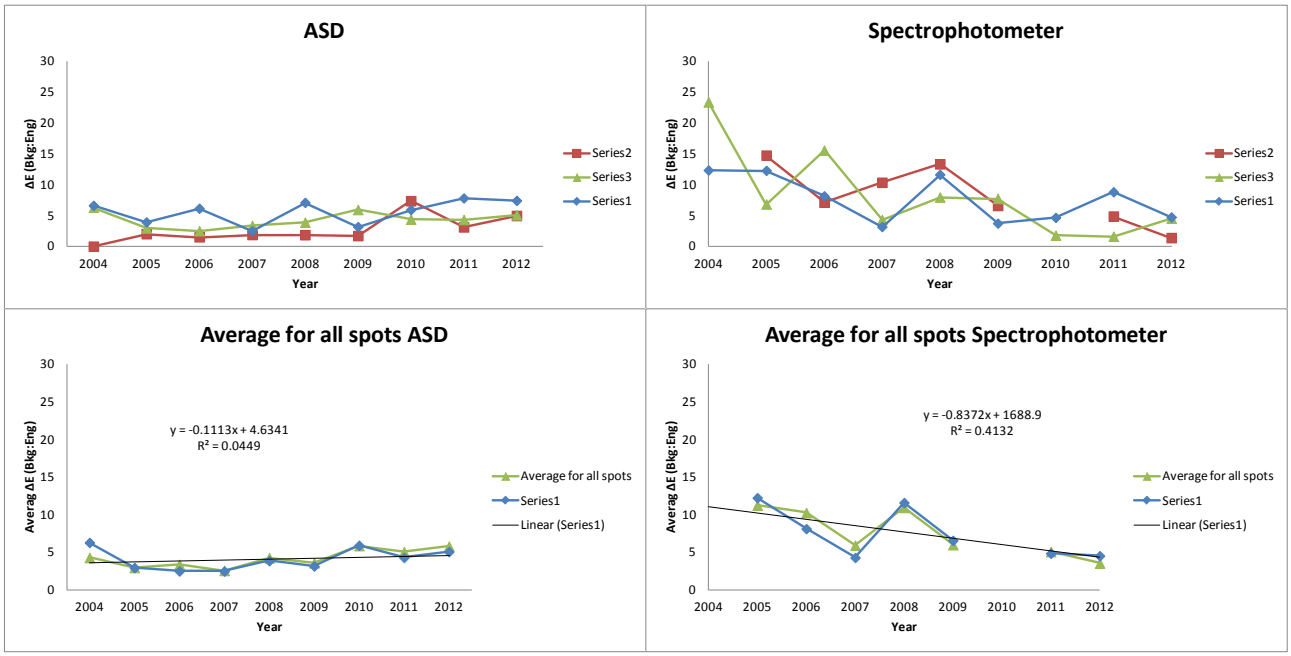
Site 5 Burrup Rd



Site 6 Water Tanks



Site 7 Deep Gorge



Site 8 King Bay South

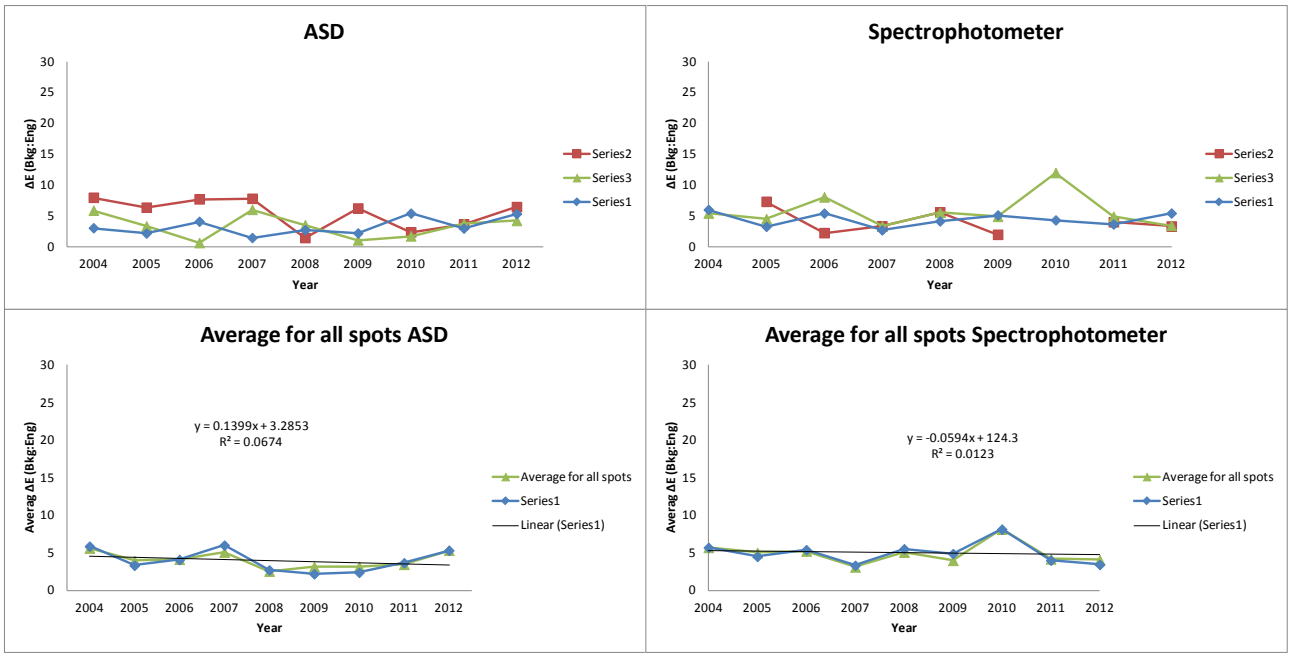


Figure 23: Comparison of ASD reflectance spectrometer and colour spectrophotometer colour measurements for each site, 2004-2012.

7. Comparison between 2 spectrophotometers for colour measurement

The initial measurements (2004 to 2009) were acquired using only the BYK colour meter. In 2009 some of the automated memory retention functions of the BYK spectrophotometer started to become less reliable, requiring laborious manual data saving. Calibration and instrument performance were unaffected. It was decided to pair the BYK instrument with a more modern Konica Minolta spectrophotometer and perform measurements using both instruments to explore the possibility of substituting instruments. Since 2009, each site has been measured in duplicate using the two instruments. This section reports on the correlation between L*, a* and b* colour measurements obtained between the 2 instruments and the possibility of replacing the BYK by the KM spectrophotometer altogether for field measurements. Analyses in this report suggest that background and engraving KM measurements can be predicted with statistical accuracy from those BYK at the sites and spots for which data is available.

Analysis of variance for regression of KM data on BYK data for each of L*, a* and b* is given in Tables 14-16. (Regression analysis is more meaningful on the three component measurements of colour rather than on the combined ΔE statistic. This also removes the dependence of ΔE on the initial colour.) It would be useful in general to be able to predict KM measurements from BYK; however, for the purposes of this calibration, only predictions of background and engraving colour at the chosen sites and spots are required.

Since the data were collected in a structured way, it is possible to predict KM measurements with reasonable accuracy simply from the site, spot and type (engraving or background) of the measurement. Including this data improves prediction markedly. However, and reassuringly, within each site, spot and engraving type the BYK measurement is an effective predictor of KM measurement, particularly for L* and a*.

Observations: L*

Table 14 shows lightness to vary significantly across the sites and the spots at each site. Also the engravings tend to be lighter than the background, to varying extents at each site and each spot. Allowing for these effects, however, the BYK measurement of L* is a very strongly significant predictor of the KM measurement of L*. (There is also some evidence that the relationship of measurements from the two machines differs at different spots.)

Table 14: Analysis of variance table for predicting KM measurements of L* from BYK measurements of L*.

Source of variation	df	SS	MS	F	p
site	6	710.3	118.4	91.9	0.00001
spot	14	132.2	9.4	6.2	0.0008
engraving	1	923.7	923.7	4842.7	0.009

engraving × site	6	321.3	53.5	79.0	0.00002
engraving × spot	14	104.4	7.5	5.2	0.002
L	1	65.9	65.9	83.0	0.00000000002
L × site	6	7.7	1.3	1.6	0.166
L × spot	14	21.5	1.5	1.9	0.051
L × engraving	1	0.2	0.2	0.2	0.627
L × engraving × site	6	4.1	0.7	0.9	0.537
L × engraving × spot	14	20.1	1.4	1.8	0.071
error	41	32.6	0.8		

Figure 24 shows that the KM measurements can be modelled fairly accurately using BYK measurements and site, spot and engraving information (and interactions among the latter variables). The value of R^2 is 0.96, indicating 96 % of the variation in L* observations is explained by the model. (This is the square of the correlation coefficient for the data in Figure 1.) The residual standard error is 1.025 units.

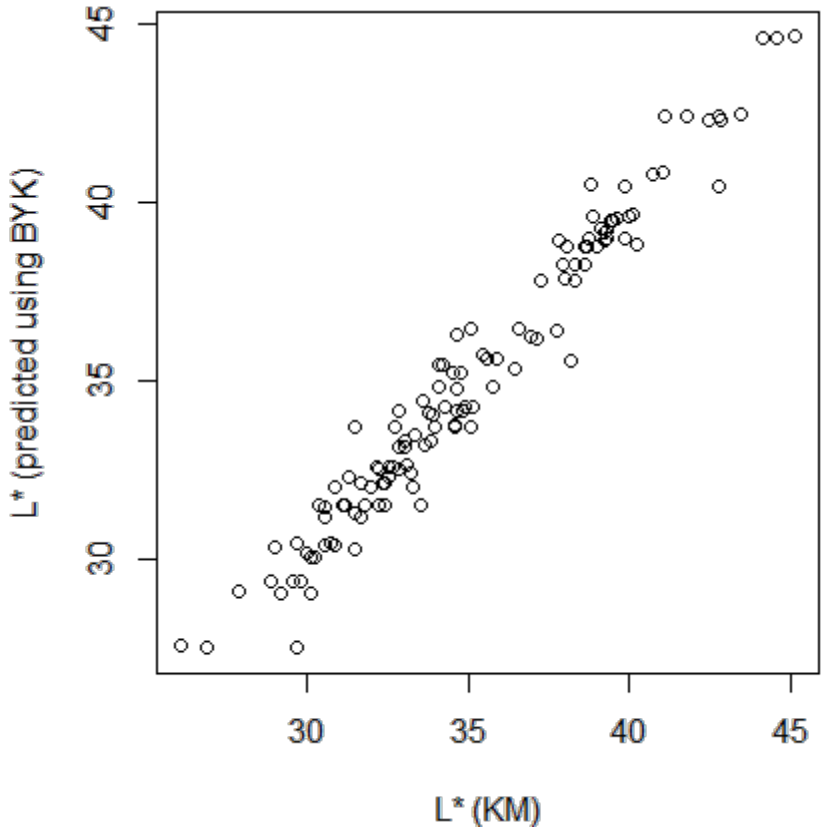


Figure 24: L* measurements on the KM machine and their predictions using BYK observations

Observations: a*

The a* observations are largely similar to those for L* measurements. Table 15 shows the red-green contrast to vary significantly across the sites and the spots at each site. Also the engraving and background differ in their a* measurements, to varying extents at each site and each spot. Allowing for these effects, however, the BYK measurement of a* is a very strongly significant predictor of the KM measurement of a*. The relationship of measurements from the two machines also differs at different spots.

Table 15 : Analysis of variance table for predicting KM measurements of a* from BYK measurements of a*.

Source of variation	df	SS	MS	F	p
site	6	430.3	71.7	501.3	0.00000008
spot	14	64.2	4.6	3.8	0.009
engraving	1	61.2	61.2	247985.9	0.001
engraving × site	6	158.5	26.4	73.2	0.00002
engraving × spot	14	54.5	3.9	4.2	0.006
a	1	10.5	10.5	21.8	0.00003
a × site	6	0.9	0.1	0.3	0.935
a × spot	14	16.8	1.2	2.5	0.012
a × engraving	1	0.0002	0.0002	0.0005	0.982
a × engraving × site	6	2.2	0.4	0.7	0.613
a × engraving × spot	14	13.0	0.9	1.9	0.051
error	41	19.8	0.5		

Figure 25 shows that the KM measurements can be modelled fairly accurately using site and spot and their interactions with BYK measurements and engraving information. The value of R^2 is again 0.96 and the residual standard error is 0.75 units.

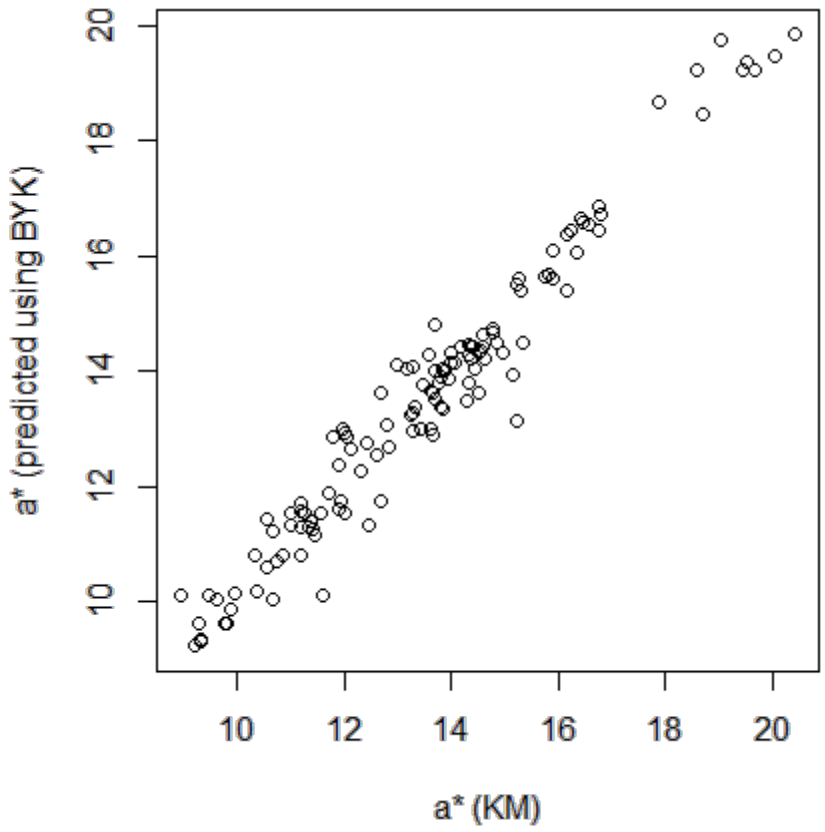


Figure 25: a* measurements on the KM machine and their predictions using BYK observations

Observations: b*

The results for b* are less clear-cut. Figure 26 shows the yellow-blue contrast to vary significantly across the sites and between background and engraving, with this difference varying at different sites and different spots at each site. Allowing for these effects, there is some evidence that the BYK measurement of b* predicts the KM measurement of b*, but stronger evidence that this effect varies at different spots. A model including both these effects is chosen (though the BYK measurements are less informative for yellow-blue contrast than they were for lightness or red-green contrast).

Table 16: Analysis of variance table for predicting KM measurements of a* from BYK measurements of a*

Source of variation	df	SS	MS	F	p
site	6	244.9	40.8	130.4	0.000004
spot	14	94.3	6.7	2.3	0.067
engraving	1	636.4	636.4	55768.4	0.003
engraving × site	6	248.2	41.4	46.7	0.00009
engraving × spot	14	44.3	3.2	5.0	0.002
b	1	4.4	4.4	3.7	0.062
b × site	6	1.9	0.3	0.3	0.952
b × spot	14	41.2	2.9	2.5	0.013
b × engraving	1	0.01	0.01	0.01	0.923
b × engraving × site	6	5.3	0.9	0.7	0.622
b × engraving × spot	14	8.8	0.6	0.5	0.903
error	41	49.2	1.2		

Figure 26 shows the KM measurements can be modelled fairly accurately using the chosen model. The value of R^2 is 0.95 and the residual standard error is 1.01 units.

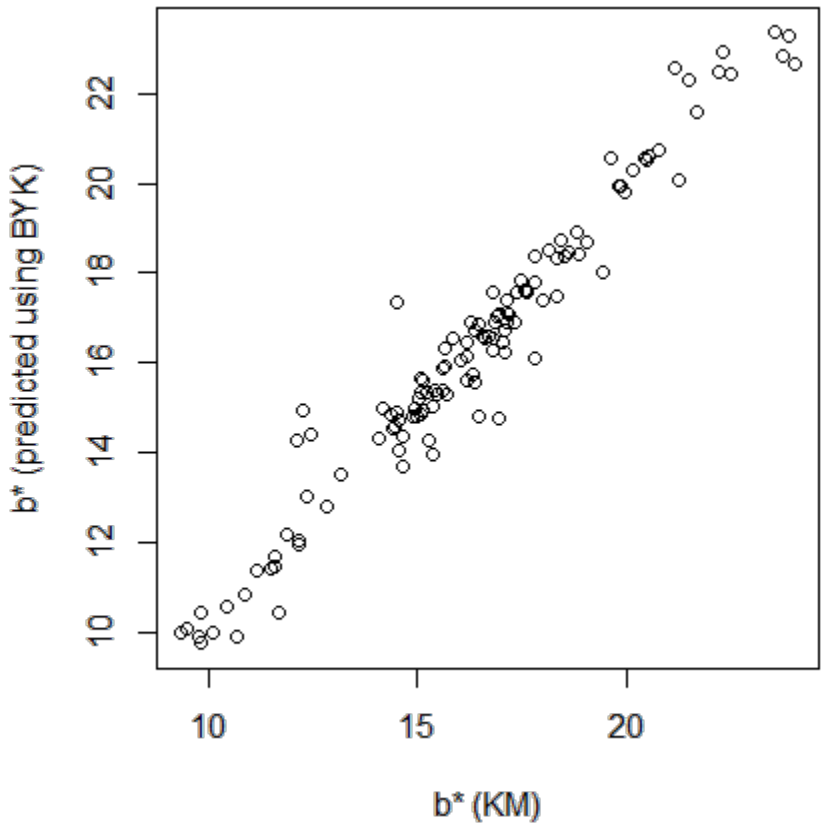


Figure 26: b* measurements on the KM machine and their predictions using BYK observations.

8. Conclusion of 2004-2012 study

The petroglyphs at 7 sites in the Burrup Peninsula were measured annually from 2004 to 2012. The same engravings and background rocks were measured *in situ*. Measurement of the annual colour changes utilised two spectrophotometer techniques, the Analytical Spectral Device (ASD) and the BYK colour spectrophotometer. An examination of the colour measurements as a function of time, as well as a comparison of the two measurement techniques, has been conducted.

The degree of variance within the measurements obtained using the different techniques is largely 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 also has a larger planar surface which is more susceptiple to coarse grain surface roughness. 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. In considering the Northern control sites and Southern test sites, neither show a consistent trend in an increasing or decreasing direction, but rather a stable degree of colour difference between engravings and background.

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10. Appendix 1

The models for KM measurements are:

L* =

```
32.5897 + 1.8544 typee - 0.0088 BL + 0.8412 site1:spot1 - 1.1356 site2:spot1 -
0.8454 site4:spot1 + 1.4091 site5:spot1 + 7.2404 site6:spot1 - 3.2839
site7:spot1 + 0.2407 site8:spot1 - 0.7995 site1:spot2 - 2.94 site2:spot2 -
0.1867 site4:spot2 - 0.8154 site5:spot2 + 6.0087 site6:spot2 - 2.0135
site7:spot2 + 0.2684 site8:spot2 - 2.2728 site1:spot3 - 1.9294 site2:spot3 -
0.2726 site4:spot3 + 2.5164 site5:spot3 + 6.5082 site6:spot3 - 4.8493
site7:spot3 + 7.3502 site1:spot1:typee + 7.4851 site2:spot1:typee + 2.1525
site4:spot1:typee + 3.2365 site5:spot1:typee - 0.5179 site6:spot1:typee +
5.5494 site7:spot1:typee + 0.8457 site8:spot1:typee - 0.0638 site1:spot2:typee
+ 13.4698 site2:spot2:typee - 0.2725 site4:spot2:typee + 4.5048
site5:spot2:typee - 0.5028 site6:spot2:typee + 1.8822 site7:spot2:typee +
1.1819 site8:spot2:typee + 7.087 site1:spot3:typee + 10.2407 site2:spot3:typee
+ 2.345 site4:spot3:typee + 2.5702 site5:spot3:typee - 1.6006 site6:spot3:typee
+ 4.9272 site7:spot3:typee
```

(where BL means the BYK measurement of L*, and terms involving typee are only added if the prediction is for an engraving; terms involving siteX are only added if the prediction is for site X; and terms involving spotY are only added if the prediction is for spot Y). Similarly,

a* =

```
2.0456 + 0.9627 typee + 0.8288 Ba + 8.7343 site1:spot1 + 6.7633 site2:spot1 +
13.6193 site4:spot1 + 17.4323 site5:spot1 + 12.5433 site6:spot1 + 13.0634
site7:spot1 + 18.7365 site8:spot1 + 8.2463 site1:spot2 + 7.8262 site2:spot2 +
12.4414 site4:spot2 + 9.5111 site5:spot2 + 3.159 site6:spot2 + 15.1255
site7:spot2 + 8.8064 site8:spot2 + 8.757 site1:spot3 + 7.7198 site2:spot3 +
9.3544 site4:spot3 + 11.5273 site5:spot3 + 8.217 site6:spot3 + 10.0399
site7:spot3 - 2.1327 site1:spot1:typee - 1.6425 site2:spot1:typee + 1.4085
site4:spot1:typee + 5.1063 site5:spot1:typee - 3.0632 site6:spot1:typee -
0.3253 site7:spot1:typee + 1.3757 site8:spot1:typee + 5.484 site1:spot2:typee -
0.9094 site2:spot2:typee + 0.2295 site4:spot2:typee + 3.4335 site5:spot2:typee
- 1.4391 site6:spot2:typee - 1.5584 site7:spot2:typee + 1.3942
site8:spot2:typee + 3.2192 site1:spot3:typee - 2.2022 site2:spot3:typee +
1.0986 site4:spot3:typee + 4.6315 site5:spot3:typee - 2.449 site6:spot3:typee +
0.2277 site7:spot3:typee - 0.8263 site1:spot1:Ba - 0.6983 site2:spot1:Ba -
0.9514 site4:spot1:Ba - 1.2171 site5:spot1:Ba - 0.9342 site6:spot1:Ba - 0.9283
site7:spot1:Ba - 1.4849 site8:spot1:Ba - 0.8478 site1:spot2:Ba - 0.6801
site2:spot2:Ba - 0.8328 site4:spot2:Ba - 0.6175 site5:spot2:Ba - 0.2275
```

```
site6:spot2:Ba - 1.0133 site7:spot2:Ba - 0.7547 site8:spot2:Ba - 0.8903
site1:spot3:Ba - 0.5863 site2:spot3:Ba - 0.6294 site4:spot3:Ba - 0.8247
site5:spot3:Ba - 0.6094 site6:spot3:Ba - 0.768 site7:spot3:Ba
```

b* =

-8.5918 + 0.453 typee + 1.4137 Bb + 19.7657 site1:spot1 + 16.3202 site2:spot1 + 26.2775 site4:spot1 + 26.1983 site5:spot1 + 27.312 site6:spot1 + 24.5753 site7:spot1 + 38.9535 site8:spot1 + 19.8905 site1:spot2 + 23.1526 site2:spot2 + 22.9584 site4:spot2 + 19.9827 site5:spot2 + 4.4523 site6:spot2 + 25.1907 site7:spot2 + 17.2042 site8:spot2 + 19.3164 site1:spot3 + 23.9051 site2:spot3 + 20.3192 site4:spot3 + 21.3086 site5:spot3 + 24.1403 site6:spot3 + 21.4016 site7:spot3 + 7.1661 site1:spot1:typee + 4.1347 site2:spot1:typee + 4.625 site4:spot1:typee + 8.6356 site5:spot1:typee - 0.9679 site6:spot1:typee + 3.4649 site7:spot1:typee + 6.3 site8:spot1:typee + 6.953 site1:spot2:typee + 13.2094 site2:spot2:typee + 2.3973 site4:spot2:typee + 5.652 site5:spot2:typee - 0.4845 site6:spot2:typee + 1.1067 site7:spot2:typee + 1.9315 site8:spot2:typee + 8.329 site1:spot3:typee + 2.7233 site2:spot3:typee + 3.385 site4:spot3:typee + 7.4321 site5:spot3:typee - 1.0743 site6:spot3:typee + 2.3982 site7:spot3:typee - 1.5351 site1:spot1:Bb - 1.101 site2:spot1:Bb - 1.6306 site4:spot1:Bb - 1.6065 site5:spot1:Bb - 1.4799 site6:spot1:Bb - 1.4968 site7:spot1:Bb - 2.7502 site8:spot1:Bb - 1.4947 site1:spot2:Bb - 1.7826 site2:spot2:Bb - 1.353 site4:spot2:Bb - 1.1678 site5:spot2:Bb - 0.1691 site6:spot2:Bb - 1.5342 site7:spot2:Bb - 1.1322 site8:spot2:Bb - 1.4765 site1:spot3:Bb - 1.3405 site2:spot3:Bb - 1.17 site4:spot3:Bb - 1.2992 site5:spot3:Bb - 1.3405 site6:spot3:Bb - 1.3521 site7:spot3:Bb