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Heritage Monitoring of 6 sites within 2 km of the Yara Pilbara Nitrates Pty Ltd plant site (Western Australia) 2015

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EP152895
30th April 2015

Yara Pilbara Nitrates Pty Ltd

Commercial-in-confidence

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Citation

Ramanaidou E and Lau D (2015). Heritage Monitoring of 6 sites within 2km of the Yara Pilbara Nitrates Pty Ltd plant site (Western Australia) 2015. CSIRO, Australia. Confidential Report # EP152895.

Copyright and disclaimer

Important disclaimer

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Acknowledgments

This work is performed in collaboration with Bill Carr as part of the Burrup Rock Art Monitoring Program, supported by Yara Pilbara Nitrates Pty Ltd, the Australian Government Department of the Environment and the Western Australian Government Department of Environment Regulation.

Executive summary

The Burrup Peninsula is located at around 1300 km from Perth in Western Australia and contains Australia's largest 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. Some of the petroglyphs are located next to these industrial areas and some concerns were expressed that the petroglyphs could be damaged by emissions from the industry. To respond to these concerns, The Western Australian government established the independent Burrup Rock Art Monitoring Management Committee (BRAMMC) that commissioned a number of studies to monitor the petroglyphs under the auspices of the Burrup Rock Art Technical Working Group monitoring program (BRATWG). They included, in particular, colour change and mineral spectroscopy studies undertaken by CSIRO for the last 10 years.

Yara Pilbara Nitrates Pty Ltd (YPNPL) is building a Technical Ammonium Nitrate Production Facility Project (or TAN) on the Burrup Peninsula. To respond to the requirements of the Environment Protection and Biodiversity Conservation Act 1999, YPNPL needs to engage a heritage monitor to survey the rock art sites within a two kilometre radius of the project site. CSIRO has been a heritage monitor for the West Australian Government Department for Environmental Regulation for the monitoring of the Burrup petroglyphs for the last decade and was considered appropriate to be the heritage monitor for YPNPL.

The rock art study dedicated for the TAN Project required the heritage monitoring of petroglyphs sites within 2km of the plant site. Selected sites were determined in consultation with members of Murujuga Aboriginal Corporation to respect the cultural laws of the traditional owners for the entitlement of access. The selected petroglyphs were firstly evaluated for their appropriateness for scientific study, including petroglyph size and quality, direction of exposure, elevation, dominant winds direction within 2 km of the TAN project location.

From the six selected monitoring sites; three were already part of the decade-old and ongoing BRATWG monitoring program and an additional three sites were also selected. In July 2014, the three new sites became part of the BRATWG monitoring program. On each monitored petroglyph panel, eight (8) sampling areas or "spots" were selected; four (4) areas classified as 'engraving' – defined by the pecking marks that constitute the image and four (4) area classified as 'background' – a section of the adjacent rock surface unmarked by the petroglyph.

Three types of measurements were carried out for the monitoring and included (1) colour contrast monitoring, (2) spectral mineralogy and (3) 3D visual imaging to assess the surface of the petroglyphs.

Based on the two years of monitoring, no significant change was detected.

1. Introduction

The Burrup Peninsula is around 30 km long and 6 km wide and is located 1300 km from Perth in Western Australia. 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 under the patronage of the Burrup Rock Art Technical Working Group monitoring program (BRATWG). 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 carried out by CSIRO. 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 10 years (2004 to 2013), 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.

Yara Pilbara Nitrates Pty Ltd (YPNPL), formerly Burrup Nitrates Pty Ltd (BNPL), is a joint venture between Yara, Orica and Apache. In November 2013, YPNPL approached CSIRO to assess its ability to become the heritage monitor for the TAN Project on the Burrup Peninsula and to provide a written endorsement of the proposed monitoring strategy. Yara Pilbara Nitrates Pty Ltd is constructing a Technical Ammonium Nitrate Production Facility on the Burrup Peninsula adjacent to the existing Yara Pilbara Fertilisers Pty Ltd ammonia plant. Environmental approval under the EPBC Act is subject to a number of conditions including a requirement for monitoring of rock art within two kilometres of the plant site. The site construction commenced on the 18th February 2013 and in agreement with the varied condition the first rock art monitoring associated with the TAN project should be completed by 18 June 2014. The approach for rock art monitoring is to involve monitoring sites within 2km of the plant site. Following a presentation at meeting of the Murujuga Circle of Elders and a subsequent visit to the proposed monitoring sites with two elders and a Murujuga ranger during December 2013, the Circle of Elders on 28 March 2014 provided their agreement to the use of the particular petroglyph panels for non-disturbance monitoring.

CSIRO was to assess the location and number of monitoring sites within 2 km of the YPNLT plant site and to conduct, colour contrast monitoring, field spectral mineralogy and 3D visual imaging of rock art at the three sites on the Burrup Peninsula.

2. Location and sampling of the petroglyphs

For the BRATWG study, the sites for monitoring 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). For this study, a similar approach was chosen that takes into account the location of the plant site and its 2 km radius relative to the wind main directions through the year (Figure 1 and Figure 2). The ultimate decision was made by the Elders of the Murujuga Aboriginal Corporation. The monitoring consists of six monitoring sites within 2km of the plant site. Three existing sites labelled 5 or Burrup Road, 6 or Water Tanks and 7 or Deep Gorge (Figure 1) from the (BRATWG) monitoring program and three additional monitoring sites within 2km of plant site labelled 21 or Yara West, 22 or Yara North East and 23 or Yara East (Figure 1, Figure 2 and Table 1). In July 2014, the three additional sites (21, 22 and 23) will become part of the BRATWG monitoring program with a new total of 10 monitoring sites.

On each monitored petroglyph panel, sampling areas were chosen based on a uniform colour over a minimum area of 20 mm, so that comparative measurements could be made between the various measuring instruments. For the BRATWG study, originally, three pairs of sampling 'spots' on each of the seven selected petroglyphs were identified (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.

In 2013, an additional pair of sampling "spots" was measured bringing the total pairs of spots for each site to 4 (4 engravings and 4 backgrounds).

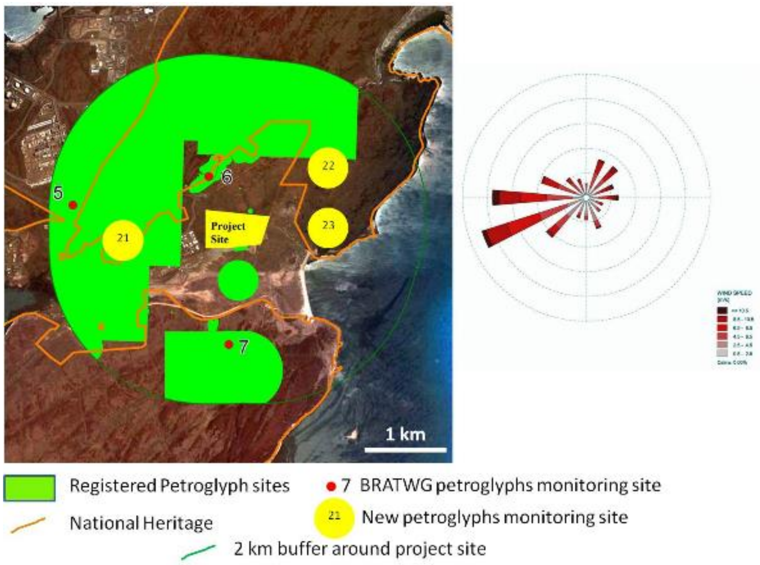


Figure 1 Proposed new sites (Yellow numbers) with dominant wind directions and speed in the rose wind

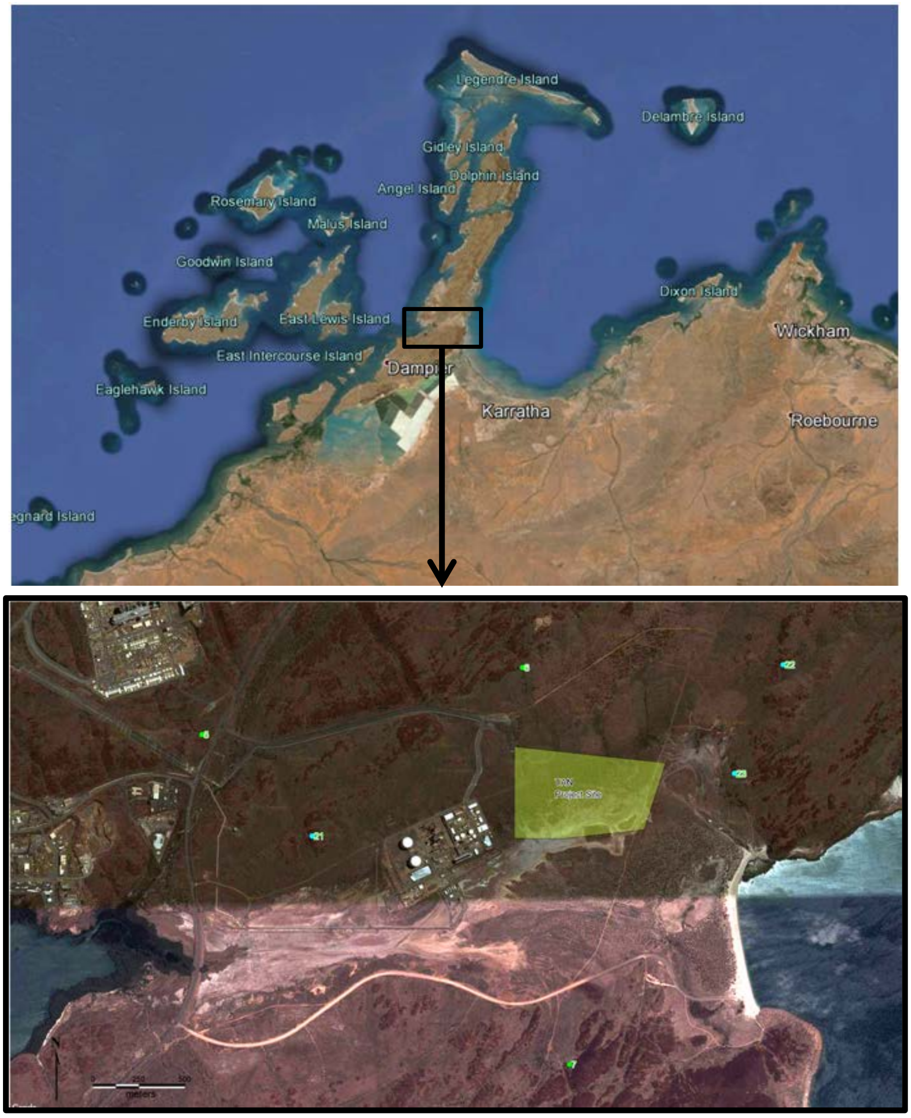


Figure 2: Google Earth® maps of the Burrup Peninsula with the petroglyphs location.

Table 1 Coordinates (GDA 94, Zone 50) of the 6 sites measured for the TAN monitoring project

Site	Site name	Coordinates (GDA 94, Zone 50)	
5	Burrup Rd	475,959	7,719,771
6	Water Tanks	477,698	7,720,137
7	Deep Gorge	477,956	7,717,987
21	Yara West	476,558	7,719,223
22	Yara North East	479,112	7,720,155
23	Yara East	478,849	7,719,565

3. Instrumentation

3.1 Spectrophotometer

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.

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.

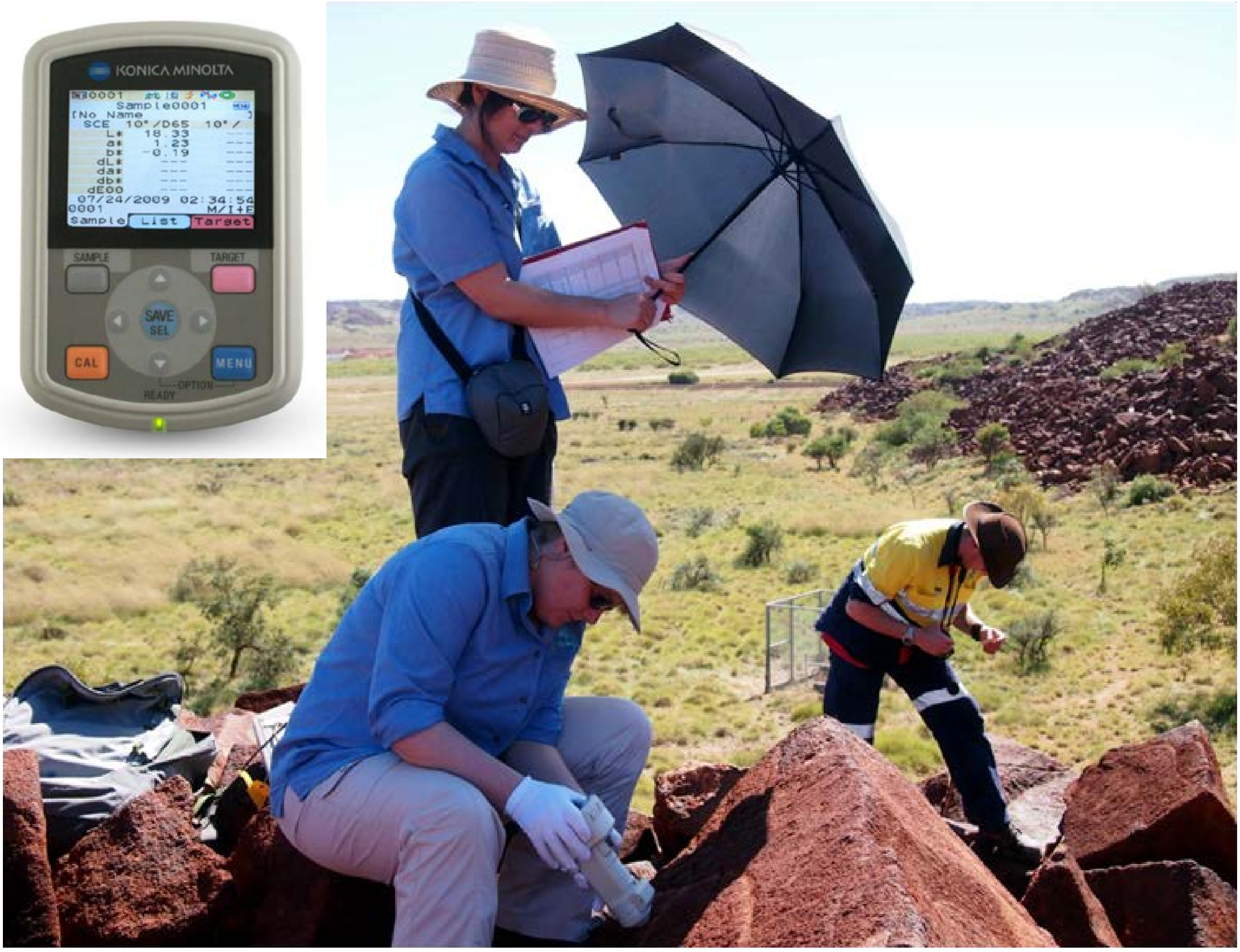


Figure 3. Konica Minolta Photospectrometer in use for the measurement of Petroglyphs (Site 7)

The instrument used for colour measurement is a portable Konica Minolta CM-700/600d spectrophotometer with inbuilt spectral illuminants (Figure 3).

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.

At each monitoring spot, 21 separate measurements were made, lifting the instrument head off the surface between each measurement.

3.2 Reflectance spectrometer

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).

Reflectance spectroscopy, the analysis of reflected light, between 380 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 380 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 380-2500 nm with a spectral resolution of 3 nm at 700 nm using 3 detectors: a 512 element Si photodiode array for the 380-1000 nm range and two separate, TE cooled, graded index InGaAs photodiodes for the 1000-2500 nm range. The input is through a 1.4 m optic fibre. 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 380 to 2500 nm wavelength range. For this study, the second option for lighting was used as it eliminates any external light interference.

The measurements involved 10 sets of measurements at each monitoring spot - five readings were taken for each set, then the sampling head was lifted off and repositioned on the surface for the next set.

Figure 4 ASD FieldSpecPro and Konica Minolta CM-700dspectrophotometer operating on petroglyphs in the Burrup Peninsula (2013)

3.3 3D imaging camera

The 3D mapping to monitor sub-millimetre depth change to both the engravings and the background was completed using a very high resolution digital Nikon D200 camera with an AF Micro Nikkro 60 mm 1:2.8 D lens. A first photograph is acquired at a known distance from the petroglyph followed by the acquisition of a second photograph at the same distance from the petroglyph but moved laterally at 1/6 of the first photograph to generate a 3 D image. Two rulers are visible in the pictures and provide scale.

4. Results

4.1 Petroglyphs engraving and background spots

Four engravings and four background spots were chose for each of the six petroglyphs locations (Sites 5, 6, 7, 21, 22 and 23) and their pictures and locations are shown in Table 2. The original three original sites from the decade-old BRATWG monitoring study include 5, 6 and 7. Site 5 or "Burrup Road" consists of a 26 x 15 cm waterbird engraved on a weathered granophyre. Site 6 or "Water Tanks" exhibits a 50 x 25cm petroglyph with pecked bird footprints also on weathered granophyre. Site 7 or "Deep Gorge" shows a 70 x 35cm macropod on a weathered gabbro. The new sites include 21, 22 and 23. Site 21 or "Yara West" consists of a 65 x 60cm petroglyph with anthropomorphs and turtle engraved on a weathered granophyre. Site 22 or "Yara North East" shows a 13 x 9cm geometric figure as part of 40 x 40cm panel of circles chiseled on a weathered gabbro. Site 23 or "Yara East" exhibits a 57 x 67cm petroglyph depicting a fishing net on weathered gabbro. On each petroglyph 4 pairs of spots have been selected. Each pair includes 1 engraving and 1 background (Table 2).

4.2 Colour and spectral information

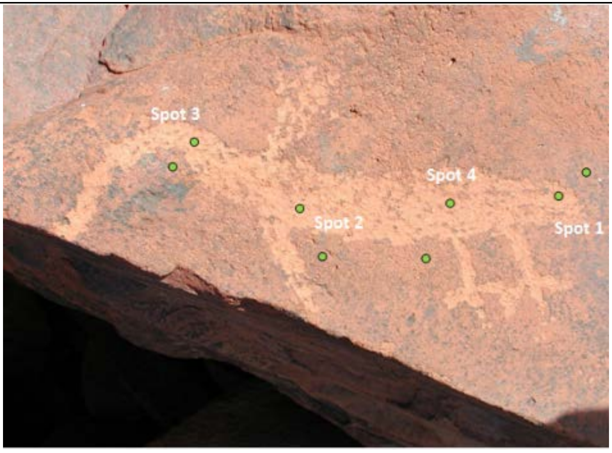
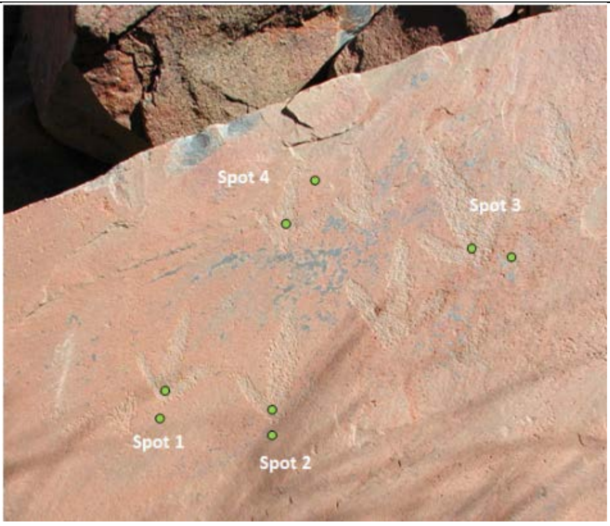
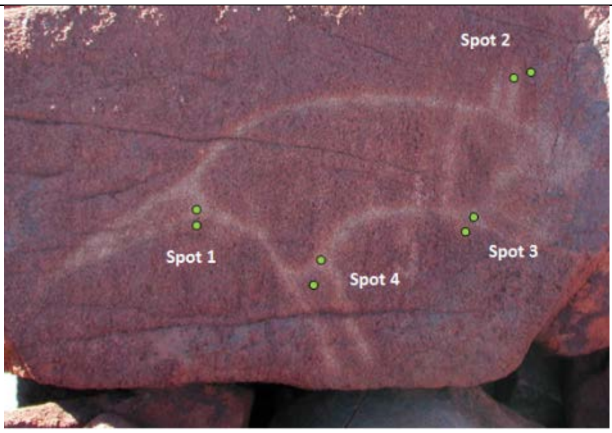
All the reflectance spectra, colour values and colour differences between engravings and background are provided in Table 3, Table 4, Table 5, Table 6, Table 7, Table 8 and Table 9 for the 6 sites.

All the reflectance spectra have been averaged per engraving and background spots.

To statistically evaluate the variability of the colour measurements, 21 independent measurements were taken at each sample point, to reduce sample variance introduced by surface heterogeneity or roughness, and by systematic error. For clarity, the raw L*a*b* data data has not been included here, but averages of the data are presented with the colour difference measurements calculated with the standard CIE methods.

These spectra and colour values are the data that will be used as baseline for the future studies: that is new data acquired in the next three years starting in July 2014 will be compared to the current dataset to estimate potential changes for colour and spectral mineralogy.

Table 2 Location of the engravings and background spots for the 6 petroglyphs

Location and description of the petroglyphs	Photographs with engravings and background spots location
Site 5 Burrup Road 26 x 15cm waterbird on granophyre	
Site 6 Water Tanks 50 x 25cm pecked bird footprints on granophyre	
Site 7 Deep Gorge 70 x 35cm macropod on gabbro	

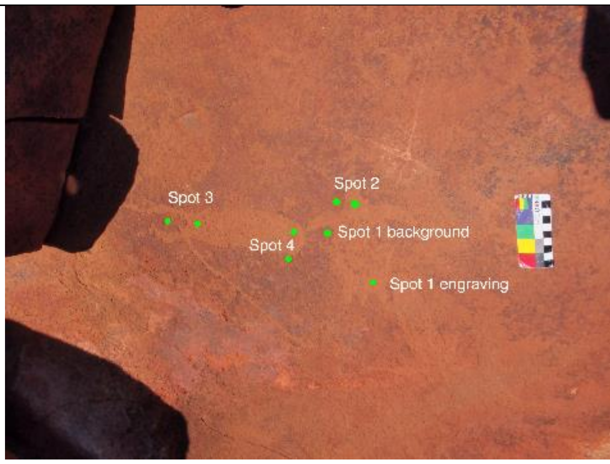
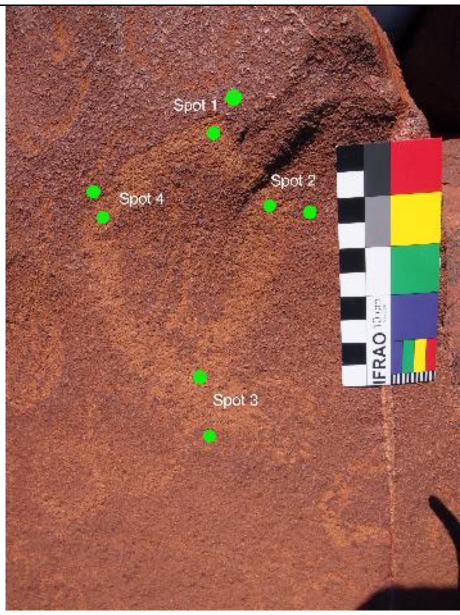
Site 21 Yara West 65 x 60cm anthropomorphs and turtle on granophyre	
Site 22 Yara North East 13 x 9cm geometric figure as part of 40 x 40cm panel of circles on gabbro	
Site 23 Yara East 57 x 67cm fishing net on gabbro	

Table 3: Average Colour Measurements for Site 5 – Burrup Road (2013 – 2014).

Sample	Colour scale L*	a*	b*	Colour difference* ΔE (change from previous year)
Site 5 Spot 1 Engraving				
Average 2014	36.69	16.83	19.25	0.80
Average 2013	35.93	16.78	19.48	
Site 5 Spot 1 Background				
Average 2014	34.88	14.65	15.33	2.65
Average 2013	35.78	15.77	17.56	
Site 5 Spot 2 Engraving				
Average 2014	38.59	20.21	23.54	3.98
Average 2013	35.15	18.61	22.35	
Site 5 Spot 2 Background				
Average 2014	30.28	14.76	15.20	0.94
Average 2013	31.09	14.44	14.87	
Site 5 Spot 3 Engraving				
Average 2014	39.00	18.68	23.08	0.86
Average 2013	38.21	18.94	22.85	1.46
Site 5 Spot 3 Background				
Average 2014	32.62	11.61	12.22	1.01
Average 2013	32.53	12.21	13.02	
Site 5 Spot 4 Engraving				
Average 2014	37.27	19.30	22.02	0.49
Average 2013	37.69	19.24	22.26	
Site 5 Spot 4 Background				
Average 2014	32.93	15.58	16.40	1.13
Average 2013	32.44	14.87	15.68	

Table 4: Average Colour Measurements for Site 6 – Water Tanks (2013 – 2014).

Sample	Colour scale L*	Colour scale a*	Colour scale b*	Colour difference* ΔE (change from previous year)
Site 6 Spot 1 Engraving				
Average 2014	40.29	10.89	16.68	1.47
Average 2013	40.92	11.80	17.65	
Site 6 Spot 1 Background				
Average 2014	39.47	12.75	17.08	0.25
Average 2013	39.24	12.65	17.11	
Site 6 Spot 2 Engraving				
Average 2014	39.24	11.96	17.10	0.90
Average 2013	39.86	11.36	16.85	
Site 6 Spot 2 Background				
Average 2014	37.08	12.16	15.21	2.14
Average 2013	38.52	12.80	16.66	
Site 6 Spot 3 Engraving				
Average 2014	38.18	11.36	15.93	0.86
Average 2013	38.92	11.68	16.22	
Site 6 Spot 3 Background				
Average 2014	38.72	11.79	15.83	1.62
Average 2013	38.48	13.00	16.88	
Site 6 Spot 4 Engraving				
Average 2014	39.47	11.26	16.42	1.68
Average 2013	41.12	10.97	16.58	
Site 6 Spot 4 Background				
Average 2014	38.94	13.10	16.68	0.68
Average 2013	39.43	13.37	17.05	

Table 5: Average Colour Measurements for Site 7 – Deep Gorge (2013 – 2014).

Sample	Colour scale L*	a*	b*	Colour difference* ΔE (change from previous year)
Site 7 Spot 1 Engraving				
Average 2014	37.24	14.40	18.37	3.10
Average 2013	34.24	13.87	17.79	
Site 7 Spot 1 Background				
Average 2014	31.05	15.58	16.21	3.14
Average 2013	29.54	13.15	14.93	
Site 7 Spot 2 Engraving				
Average 2014	31.22	15.24	16.45	1.95
Average 2013	32.87	14.21	16.49	
Site 7 Spot 2 Background				
Average 2014	27.38	12.73	12.27	0.91
Average 2013	27.39	12.91	13.16	
Site 7 Spot 3 Engraving				
Average 2014	32.53	14.04	16.07	1.60
Average 2013	34.09	14.02	16.40	
Site 7 Spot 3 Background				
Average 2014	30.38	14.52	15.19	0.95
Average 2013	30.87	14.55	16.01	
Site 7 Spot 4 Engraving				
Average 2014	35.81	14.81	18.28	2.47
Average 2013	38.03	15.29	19.25	
Site 7 Spot 4 Background				
Average 2014	27.38	12.07	12.65	3.27
Average 2013	30.26	12.88	13.97	

Table 6: Average Colour Measurements for Site 21- Yara West (2013 - 2014).

Sample	Colour scale L*	Colour scale a*	Colour scale b*	Colour difference* ΔE (change from previous year)
Site 21 Spot 1 Engraving				
Average 2014 (July)	39.07	17.29	22.14	1.59
Average 2014 (February)	38.04	16.35	21.38	
Site 21 Spot 1 Background				
Average 2014 (July)	32.85	14.03	13.75	1.37
Average 2014 (February)	31.59	13.76	13.26	
Site 21 Spot 2 Engraving				
Average 2014 (July)	37.55	15.55	20.36	1.52
Average 2014 (February)	36.08	15.33	20.04	
Site 21 Spot 2 Background				
Average 2014 (July)	34.94	14.40	16.13	1.19
Average 2014 (February)	33.77	14.19	16.23	
Site 21 Spot 3 Engraving				
Average 2014 (July)	38.54	17.96	22.82	2.56
Average 2014 (February)	38.57	16.01	21.17	
Site 21 Spot 3 Background				
Average 2014 (July)	31.95	14.23	15.22	0.63
Average 2014 (February)	31.56	13.99	15.64	
Site 21 Spot 4 Engraving				
Average 2014 (July)	38.71	15.71	20.23	2.80
Average 2014 (February)	37.41	17.28	22.16	
Site 21 Spot 4 Background				
Average 2014 (July)	32.89	13.69	14.83	2.16
Average 2014 (February)	31.53	12.39	13.77	

Table 7: Average Colour Measurements for Site 22 – Yara North East (2013 - 2014).

Sample	Colour scale			Colour difference* ΔE (change from previous year)
	L*	a*	b*	
Site 22 Spot 1 Engraving				
Average 2014 (July)	39.12	13.54	19.02	2.91
Average 2014 (February)	36.82	13.54	17.23	
Site 22 Spot 1 Background				
Average 2014 (July)	34.08	12.21	12.63	0.39
Average 2014 (February)	33.80	12.11	12.37	
Site 22 Spot 2 Engraving				
Average 2014 (July)	37.08	14.33	18.65	2.60
Average 2014 (February)	35.15	13.64	17.04	
Site 22 Spot 2 Background				
Average 2014 (July)	33.85	12.72	13.90	1.54
Average 2014 (February)	32.32	12.52	14.00	
Site 22Spot 3 Engraving				
Average 2014 (July)	38.34	14.49	19.51	1.71
Average 2014 (February)	37.11	14.41	18.33	
Site 22 Spot 3 Background				
Average 2014 (July)	33.71	12.53	13.82	0.53
Average 2014 (February)	34.06	12.75	14.15	
Site 22 Spot 4 Engraving				
Average 2014 (July)	36.12	13.99	17.71	1.43
Average 2014 (February)	37.32	14.11	18.48	
Site 22 Spot 4 Background				
Average 2014 (July)	33.96	12.41	13.31	1.07
Average 2014 (February)	33.63	11.92	12.42	

Table 8: Average Colour Measurements for Site 23 - Yara East (2013 - 2014).

Sample	Colour scale			Colour difference* ΔE (change from previous year)
	L*	a*	b*	
Site 23 Spot 1 Engraving				
Average 2014 (July)	36.71	9.61	16.09	1.72
Average 2014 (February)	38.39	9.59	16.49	
Site 23 Spot 1 Background				
Average 2014 (July)	34.54	11.54	15.42	1.00
Average 2014 (February)	35.16	12.08	16.00	
Site 23 Spot 2 Engraving				
Average 2014 (July)	32.86	11.53	18.35	2.93
Average 2014 (February)	35.36	12.90	19.05	
Site 23 Spot 2 Background				
Average 2014 (July)	37.26	14.00	19.05	0.43
Average 2014 (February)	36.93	14.28	19.04	
Site 23 Spot 3 Engraving				
Average 2014 (July)	37.71	10.69	17.28	0.48
Average 2014 (February)	38.17	10.72	17.42	
Site 23 Spot 3 Background				
Average 2014 (July)	31.86	14.14	16.13	0.70
Average 2014 (February)	31.70	13.65	15.65	
Site 23 Spot 4 Engraving				
Average 2014 (July)	37.82	10.65	17.36	1.47
Average 2014 (February)	36.39	10.94	17.20	
Site 23 Spot 4 Background				
Average 2014 (July)	32.12	7.46	10.56	3.24
Average 2014 (February)	31.61	9.92	12.60	

Table 9: Colour difference between background and petroglyph

Spot 1	Site 1	Site 2	Site 4	Site 5	Site 6	Site 7	Site 8	Site 21	Site 22	Site 23
Average 2014	**10.9**	**6.5**	**7.0**	**4.8**	**2.1**	**6.7**	**4.4**	**10.9**	**8.2**	**3.0**
Average 2013	12.4	10.0	7.1	2.2	2.0	5.5	5.1	10.7	5.9	4.1
Spot 2										
Average 2014	**12.0**	**19.2**	**3.9**	**13.0**	**2.9**	**6.2**	**6.5**	**5.1**	**6.0**	**5.1**
Average 2013	10.7	18.7	3.4	9.5	2.0	6.5	6.4	4.6	4.3	2.1
Spot 3										
Average 2014	**11.3**	**8.9**	**5.5**	**14.4**	**0.7**	**2.4**	**6.6**	**10.7**	**7.6**	**6.9**
Average 2013	11.4	9.8	6.7	13.2	1.5	3.3	5.8	9.2	5.4	7.3
Spot 4										
Average 2014	**7.6**	**6.7**	**6.3**	**8.0**	**1.9**	**10.5**	**5.6**	**8.2**	**5.2**	**9.4**
Average 2013	12.1	7.1	6.4	9.4	3.0	9.7	5.3	11.4	7.4	6.7

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.

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 fibre 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.

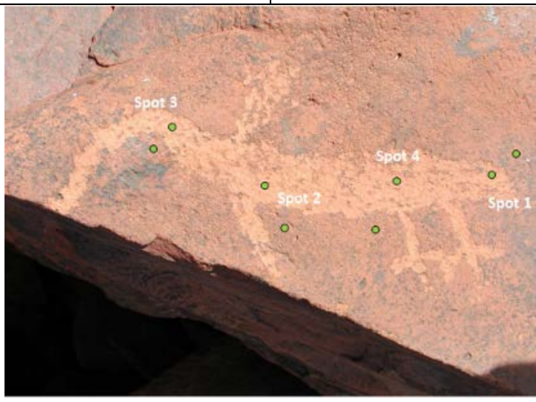
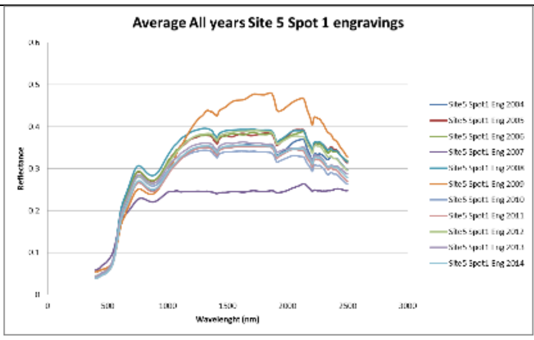
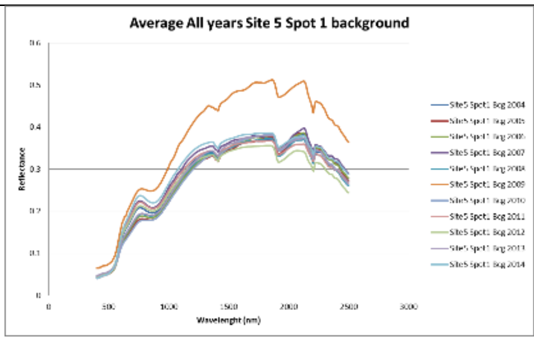
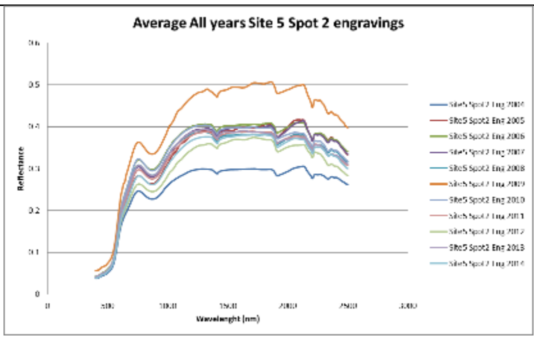
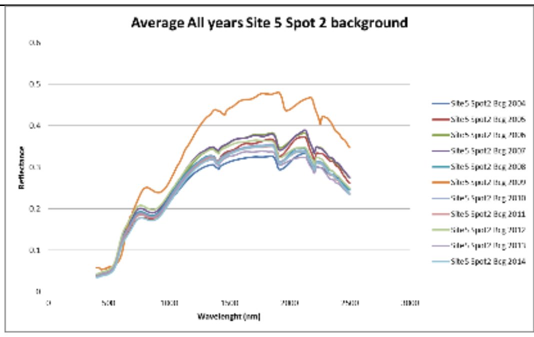
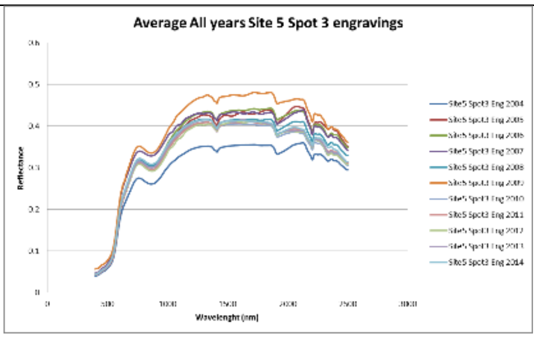
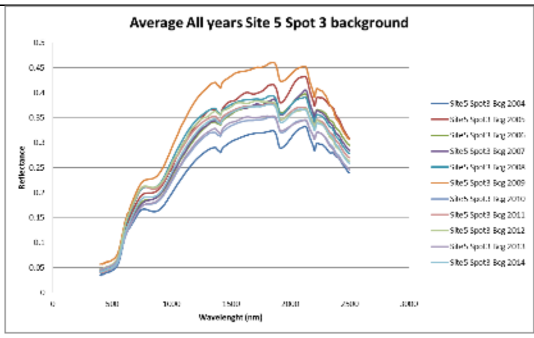
5.2 Spectral Results for 2013-2014

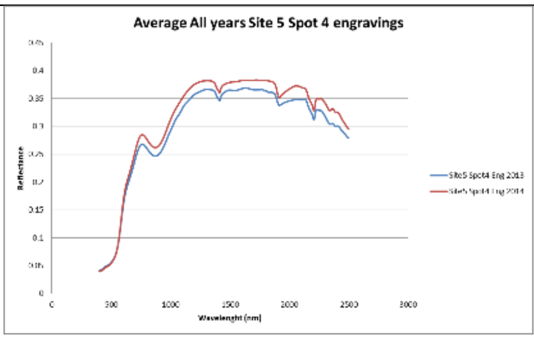
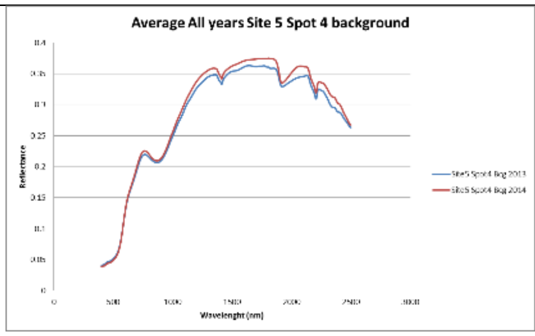
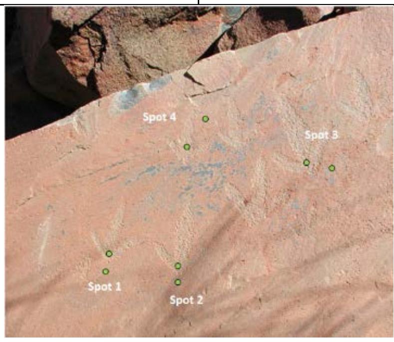
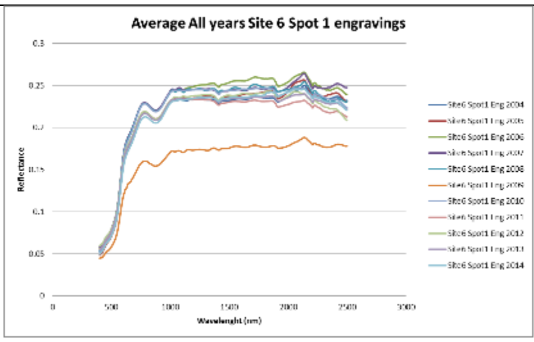
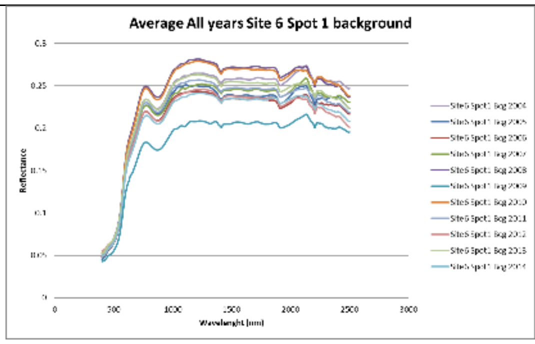
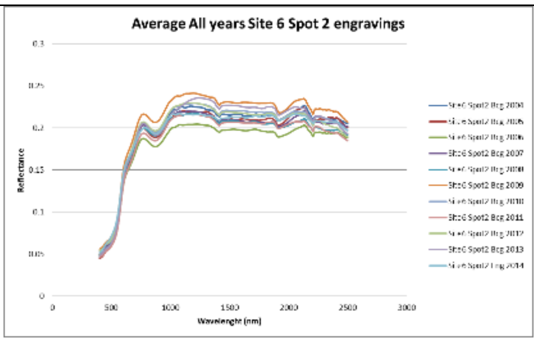
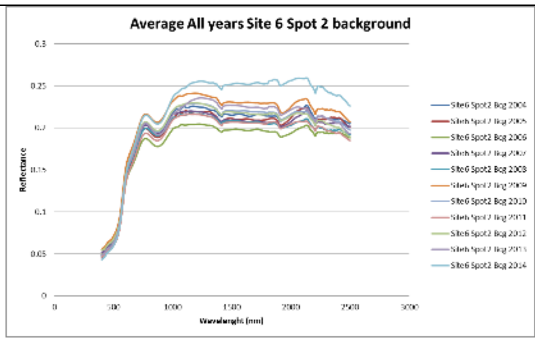
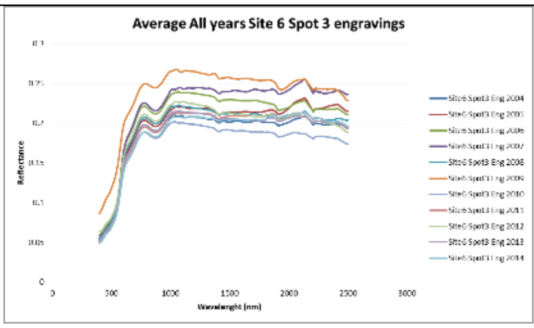
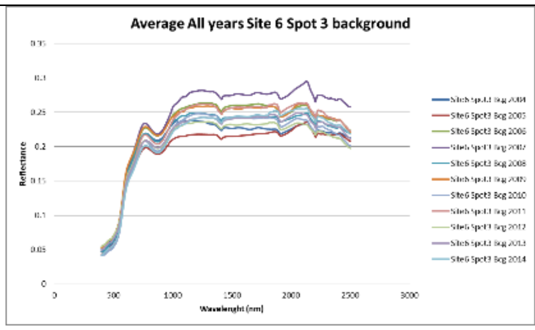
5.2.1 PICTURES AND SPECTRA

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 and 4 for both engraving and background for the six sites; 5, 6, 7, 21, 22 and 23.
- Comparison of the average spectra for the engravings and background for each of the four spots between 2013 and 2014. For sites 5, 6 and 7, all the spectra from the 2004 to 2012 year (from the 11 years monitoring study in the Burrup (Murujuga) Peninsula are plotted to show the variability of the measurements.
- 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 (Table 10. 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 (Table 10).

Table 10. 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

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

Site 5 Spot 4		
Location	Spectra Engraving	Spectra Background
		
Site 6 Spot 1		
Site 6 Spot 2		
Site 6 Spot 3		

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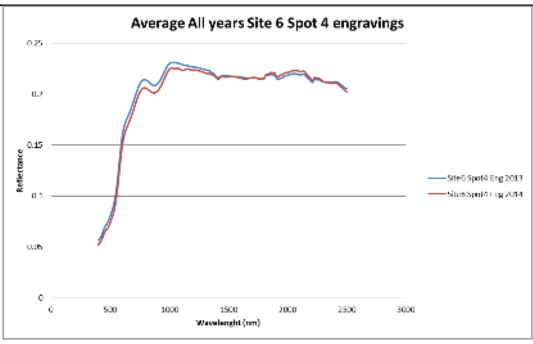
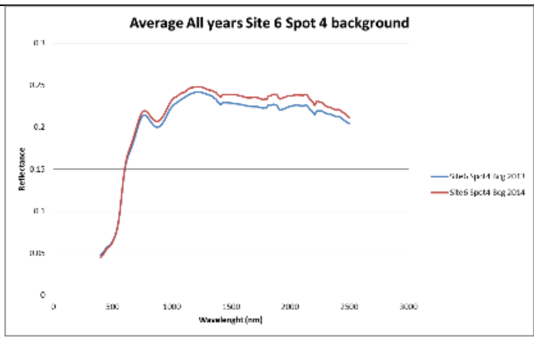
Spot 4</td><td>
</td><td>
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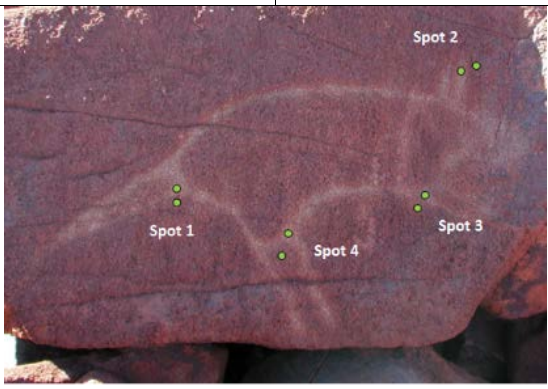
<tr><td>Location</td><td>Spectra Engraving</td><td>Spectra Background</td></tr>
<tr><td></td><td colspan="2">
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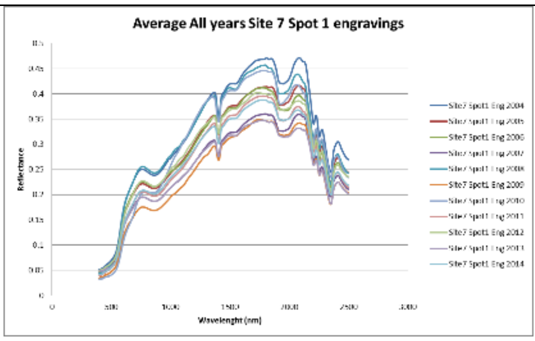
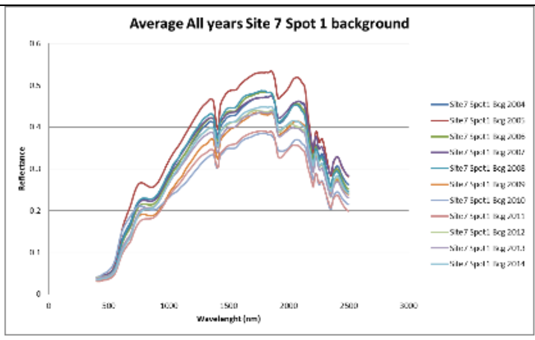
<tr><td>Site 7
Spot 1</td><td>
</td><td>
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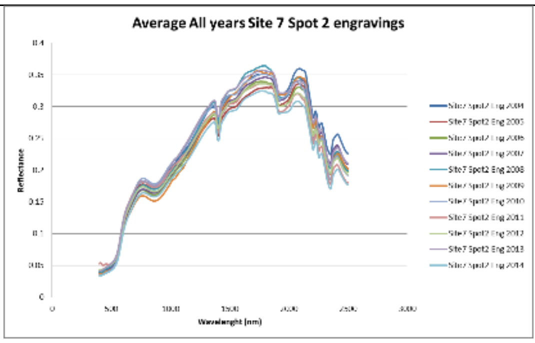
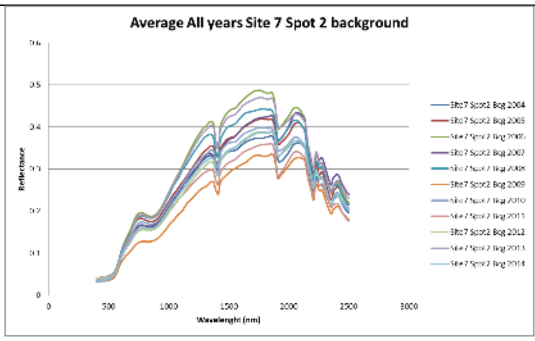
Spot 2</td><td>
</td><td>
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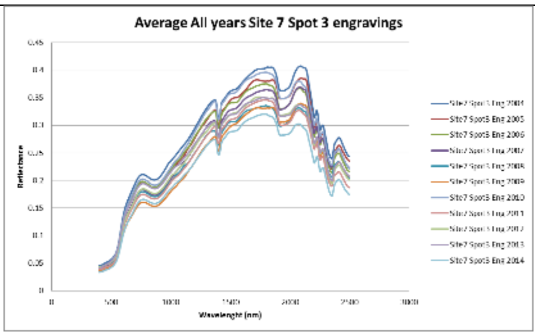
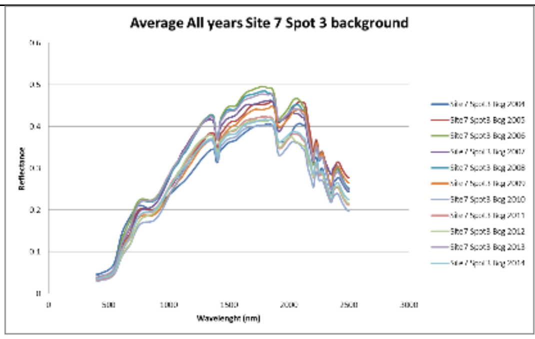
Spot 3</td><td>
</td><td>
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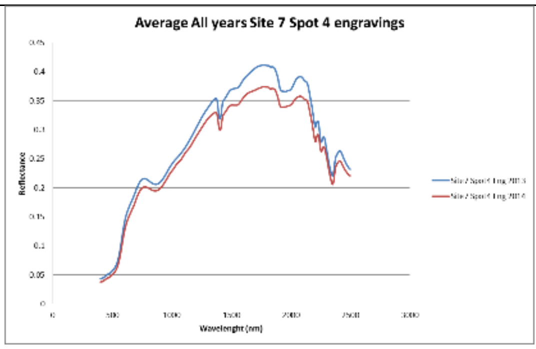
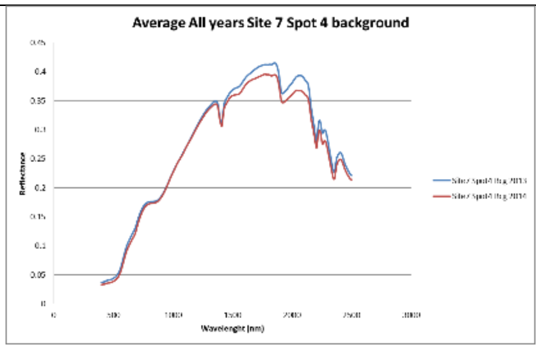
Site7 Spot 4		

Location	Spectra Engraving	Spectra Background
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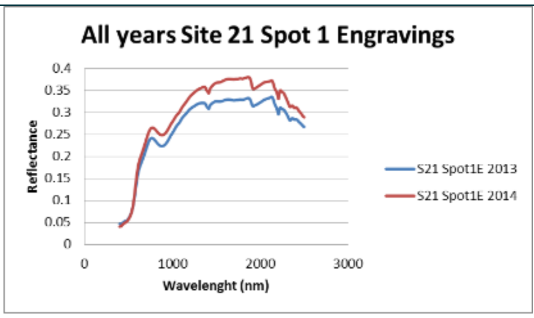
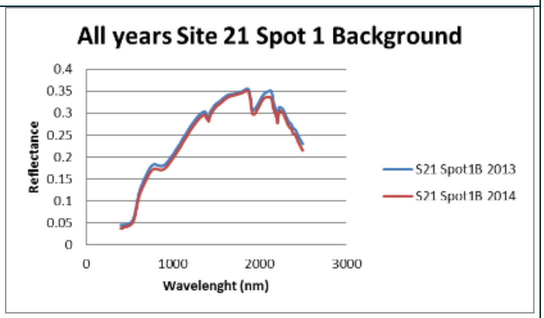
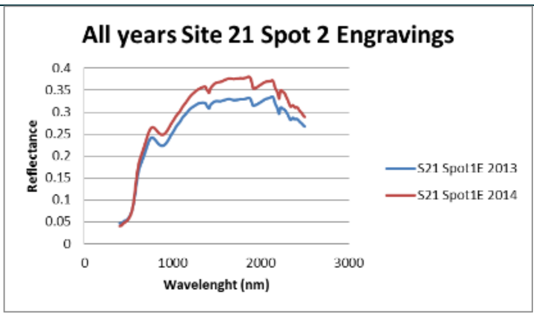
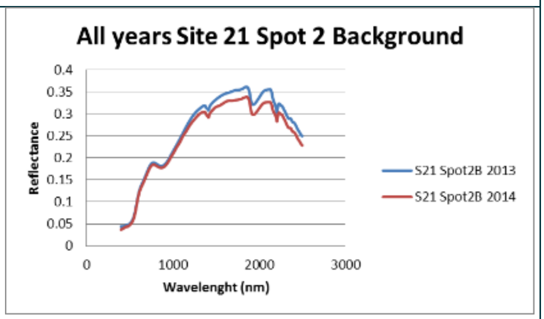
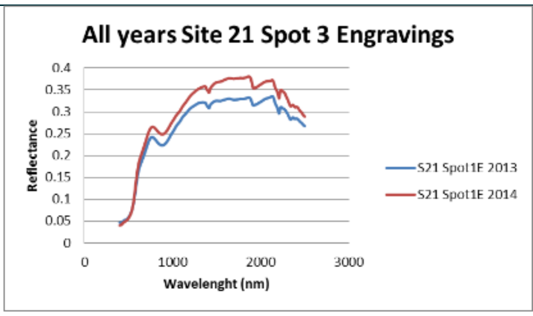
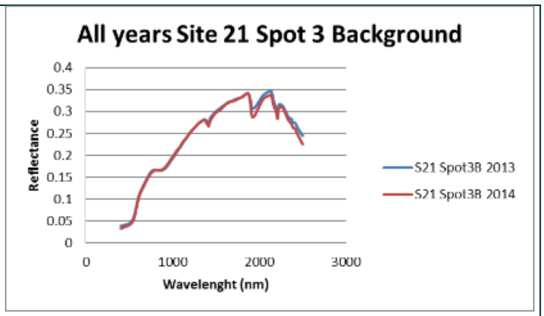
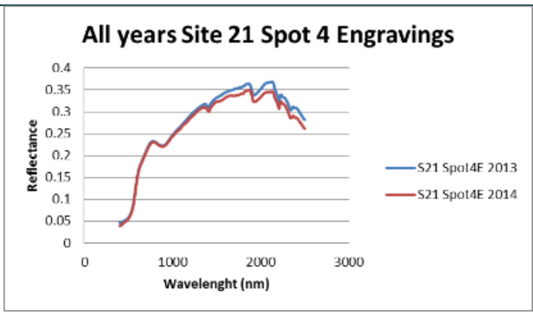
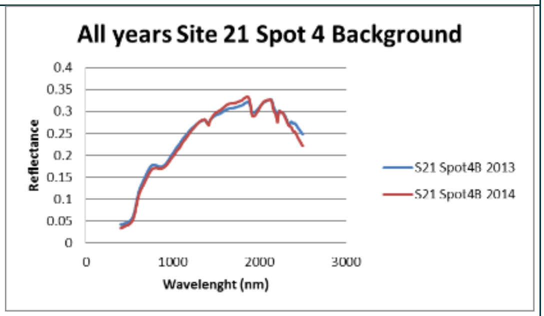
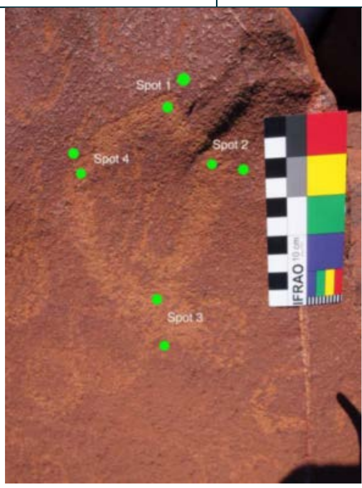
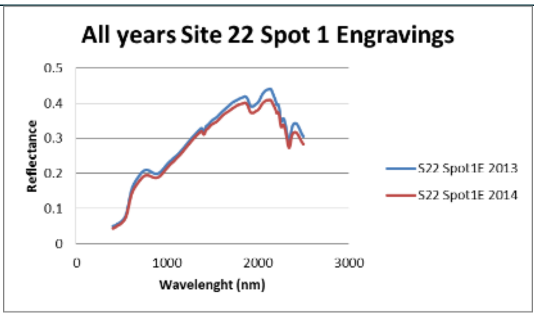
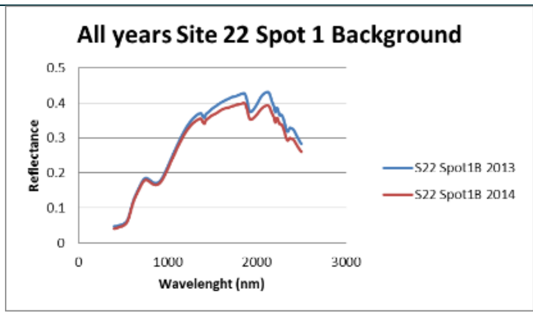
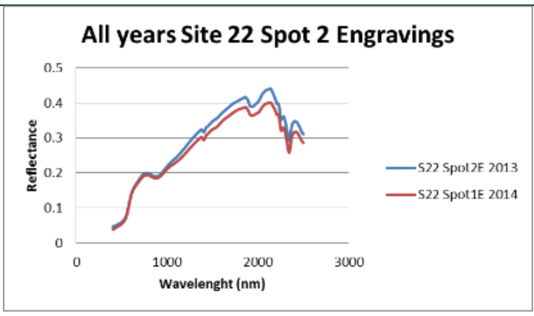
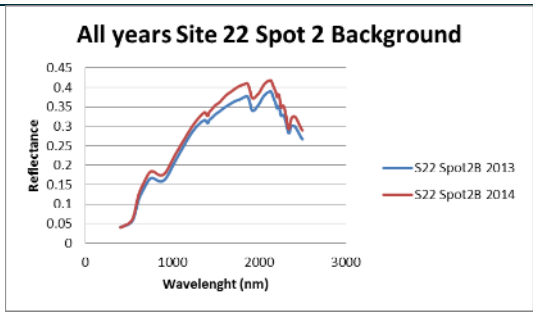
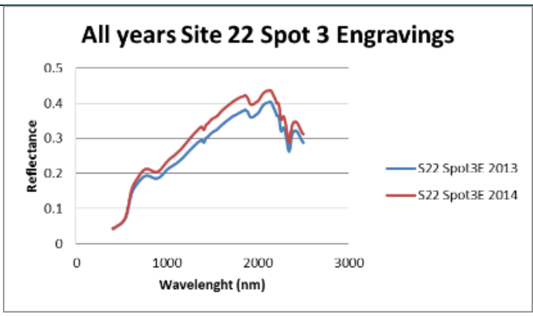
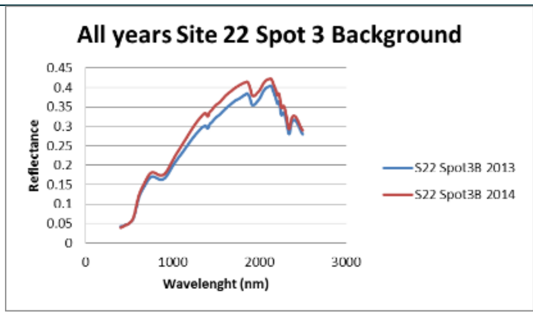
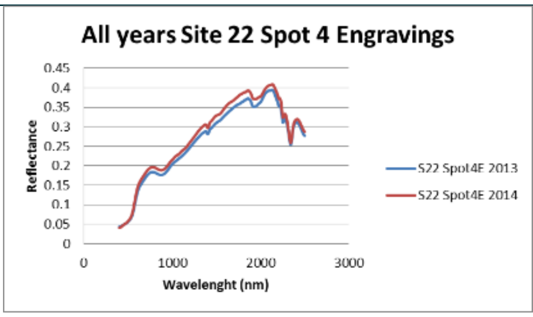
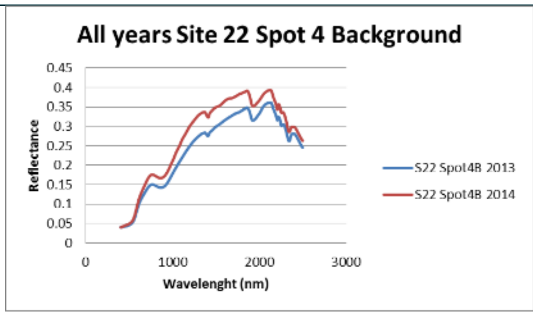
Site 21 Spot 1		
Site 21 Spot 2		

Site 21 Spot 3		
Site 21 Spot 4		
Location	Spectra Engraving	Spectra Background
Site 22		
Site 22 Spot 1		
Site 22 Spot 2		

Site 22 Spot 3		
Site 22 Spot 4		

Location	Spectra Engraving	Spectra Background
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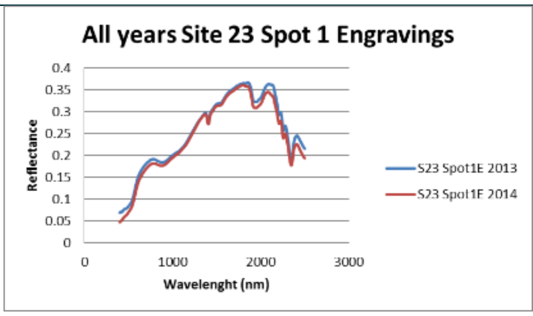
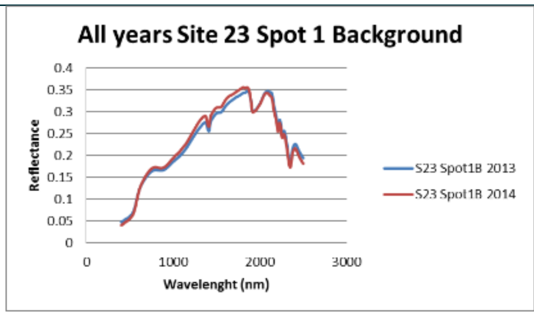
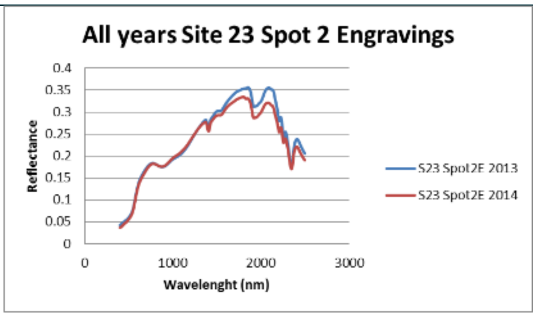
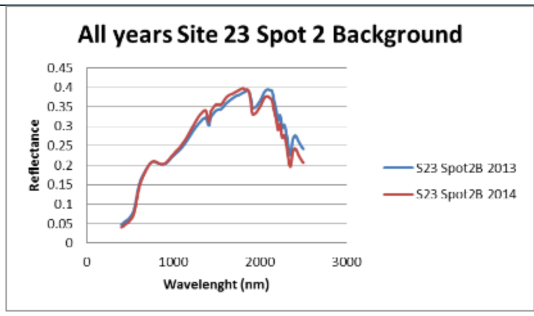
Site 23 Spot 1		
Site 23 Spot 2		

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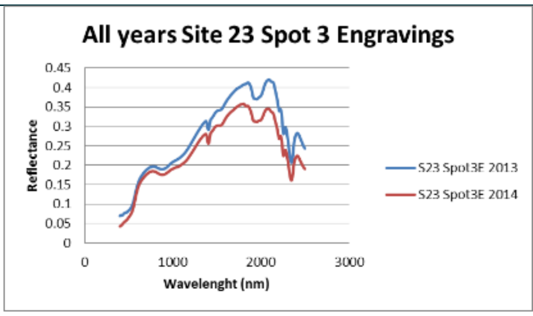
<td>
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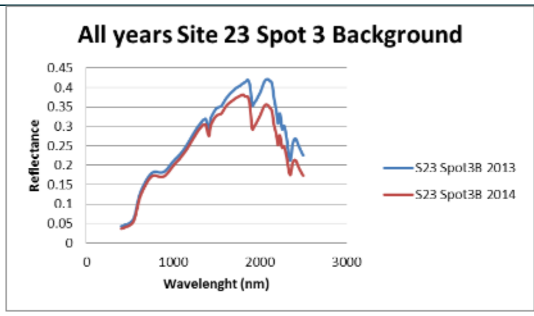
<td>
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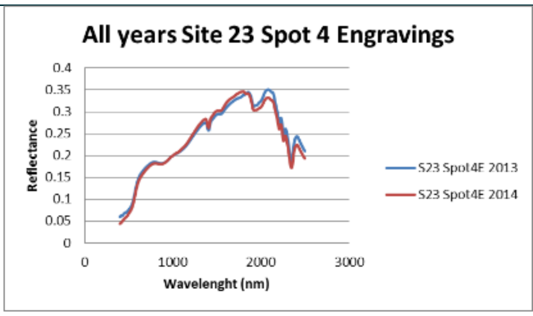
<td>
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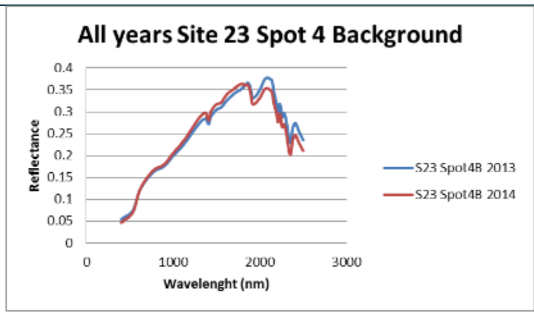
<td>
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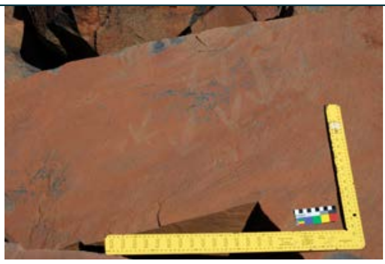
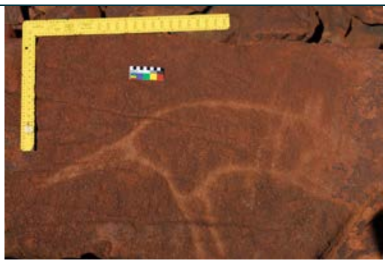
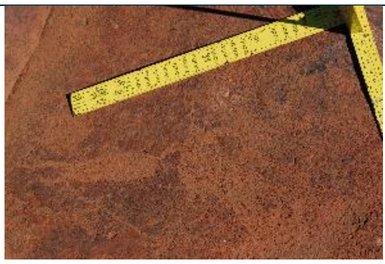
6. 3D Mapping

The 3D mapping provides an approach of assessing the change in the surface of the petroglyphs. As explained for the colour and spectra measurements, the 3D images acquired this year will be used as a baseline for the following years to establish if the surface of the petroglyphs shows variations or changes.

The first photograph of the petroglyph was acquired at a known distance (180 or 300 cm based on the size of the petroglyphs). The second photograph was taken at the same distance from the petroglyph but was moved laterally at 1/6 distance of the first photograph to generate a 3 D image (Table 10). Two rulers are used to provide scale and dimension. To observe the 3D images a dedicated software called sirovision™ is required.

Table 11 Photographs information for the generation of the 3D mapping

Site	Photographs
6	
7	
21	
22	

23	

7. Conclusion of 2013-2014 study

The Heritage Monitoring of 6 sites within 2 km of the Yara Pilbara Nitrates Pty Ltd plant site (Western Australia) in the Burrup Peninsula have been measured 2013 and 2014. The engravings and background rocks were measured *in situ*. Measurement of the annual colour and mineralogical 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 and no significant change was identified. The 3D pictures were acquired for both years and change was not detected.

8. References

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

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.