Senate Environment and Communications References Committee
Inquiry into the protection of Aboriginal rock art of the Burrup Peninsula
17 November 2017 Hearing

CHAIR: Were changes made to the *Burrup Peninsula Aboriginal petroglyphs: colour change & spectral mineralogy 2004-2016* report that you released as a result of the findings of the 2017 DAA review?
Deborah Lau: The 2017 report from CSIRO supersedes all of the previous CSIRO reports, so that has been addressed.
CHAIR: So that 2016 report does include changes from the 2017 DAA review? Do you want me to put that on notice to you?
Deborah Lau: I think that would be beneficial, thank you.

Answer:

The June 2016 CSIRO Report "Burrup Peninsula Aboriginal Petroglyphs: Colour Change & Spectral Mineralogy 2004 – 2016" (EP161761, released 2017), which can be accessed at: https://www.der.wa.gov.au/images/documents/our-work/consultation/Burrup-Rock-Art/Burrup-Peninsula-Aboriginal-Petroglyphs-Colour-Change--Spectral-Miner.pdf and is provided as an attachment to these answers, incorporates responses to DAA's review as summarised in **Table 1**.

Some changes in measured colour were observed and these include the following:

- Data from the KM spectrophotometer shows a trend over time in the L* measurements. The lightness (L) decreasing at a modelled average rate of 0.31 units per year (a total decrease of about 2 units on this scale is just noticeable to the human eye). However no trend is indicated in either a* (degree of red/green) or b* (degree of yellow/blue).
- Data from the ASD spectrophotometer shows trends indicated in L* (degree of lightness) and a* (degree of red/green) but not on b* (degree of yellow/blue), though the evidence is not as strong as with the KM instrument.
  In the statistical analyses, the analysis for the ASD spectrophotometer includes the colour range, so that a comparison can be made between the BYK photo spectrometer and the ASD spectrometer.
- It should also be noted that the trends in BYK data from southern sites near industry do not differ significantly from the trends recorded at northern control sites further from industry. The BYK data from northern site 1 shows as much change as the southern sites, and more than several (compare for example the BYK data from site 6, plotted in Figure 35 to Figure 37) of the sites next to industries. The BYK data thus does not demonstrate any difference in colour change between southern sites close to industry and northern control sites.)

It should be noted that the report provides the colour measurements and hence changes in colour. The reasons for the colour changes are not addressed explicitly in this report. However, possible reasons for such small changes could include the results of natural weathering effect. The CSIRO report does not provide a basis to confirm or to exclude an attribution to the industrial development, other than to note that the measured changes are not statistically significantly different at sites near to or far from industry.

Table 1. Summary of CSIRO's response to the DAA[1] Recommendations, as presented in the June 2016 CSIRO Report, released in 2017

DAA Recommendation	**DAA review of draft CSIRO report and CSIRO assessment at time of the final June 2016 Report release:**	**CSIRO's analyses are available in the June 2016 Report entitled "Burrup Peninsula Aboriginal Petroglyphs: Colour Change & Spectral Mineralogy 2004 – 2016" released 2017** Please note that the results in the June 2016 report supersedes all results published previously
1. The historical data collected by the CSIRO should be systematically archived and held by DER.	DAA review of draft: Largely met in draft **CSIRO assessment at time of the final June 2016 Report: Fully Complete**	June 2016 report notes: "All the historical data collected for the all the spectrometers have been systematically archived and were sent to DER with consistent naming conventions, in a data format that is easily read by standard statistical software".
2. The CSIRO should be asked to revisit the cross calibration issues with the BYK and KM spectrophotometers	DAA review of draft: Not addressed in draft **CSIRO assessment at time of the final June 2016 Report: No longer relevant, in the light of analysis of the data**	June 2016 report notes: "It should be noted that data from the BYK spectrophotometer appears unreliable for drawing conclusions on colour change in the rock art and, as such the cross calibration issues with the BYK portable photo spectrometer and the KM photo spectrometer will no longer be undertaken." This approach is consistent with DAA observations (first dot point, pg 2 of Exec Summary)

[1] Data Analysis Australia Pty Ltd

DAA Recommendation	DAA review of draft CSIRO report and CSIRO assessment at time of the final June 2016 Report release:	CSIRO's analyses are available in the June 2016 Report entitled "Burrup Peninsula Aboriginal Petroglyphs: Colour Change & Spectral Mineralogy 2004 – 2016" released 2017 Please note that the results in the June 2016 report supersedes all results published previously
3. An analysis similar to that of Black and Diffey should be conducted using verified ASD estimates of L*, a*, b*	DAA review of draft 2016 Partially met in draft **CSIRO assessment at time of the final June 2016 Report: Complete**	June 2016 report notes: "For this report, combining the last two years of measurements (2015 and 2016), a complete statistical analyses of all the data (each individual measurement for the three instruments, a total of 24,000 colour measurements from 2004 to 2016) has been undertaken. … An examination of the colour measurements as a function of time, as well as a comparison of the two measurement techniques, has been conducted. … For both the KM and the ASD instruments, three-dimensional L*a*b* colour space (L* - degree of lightness, a* - degree of red/green, b* - degree of yellow/blue), identifying a tristimulus value (L*a*b*) for each sample point have been calculated." June 2016 report includes the other models recommended by DAA (such as those testing for the three-way interaction of trends over time on background and engraving at northern and southern sites), with full R code for the random effects in all models tested (the fixed effects, which differ in each model tested, are clearly defined also in the report). The change in measurement practice for the ASD spectrometer (replacing it for each measurement from 2015 onwards) was documented and included in the analyses.

DAA Recommendation	DAA review of draft CSIRO report and CSIRO assessment at time of the final June 2016 Report release:	CSIRO's analyses are available in the June 2016 Report entitled "Burrup Peninsula Aboriginal Petroglyphs: Colour Change & Spectral Mineralogy 2004 – 2016" released 2017 Please note that the results in the June 2016 report supersedes all results published previously
4. Future work by the CSIRO should be based upon an agreed analysis plan certified by a competent statistician	DAA review of draft: Not met in draft. **CSIRO assessment at time of the final June 2016 Report: Recommendation for future work noted and agreed**	CSIRO agrees that statistical analysis is a key part of planning for future analysis work (whether to be conducted by CSIRO or other organisations) – noting, it is only one of a number of technical issues that need to be included in the plan for analysis and that a number of technical practicalities need to be taken into account. The June 2016 report notes that "For future work CSIRO recommended that: • A complete statistical analysis is done on the full spectrum of each individual ASD spectrum (not just the visible part i.e. L*, a* and b*) …". The June 2016 report also notes that "A balance should be found between statistical endeavour and petroglyph protection." Turning to current analysis data, the June 2016 report includes comprehensive statistical analysis (see row above).

DAA Recommendation	DAA review of draft CSIRO report and CSIRO assessment at time of the final June 2016 Report release:	CSIRO's analyses are available in the June 2016 Report entitled "Burrup Peninsula Aboriginal Petroglyphs: Colour Change & Spectral Mineralogy 2004 – 2016" released 2017 Please note that the results in the June 2016 report supersedes all results published previously
5. Consideration should be given to expanding the number of measured sites and in doing so, improving the balance of the design to include more effective controls.	DAA review of draft: Not met in draft **CSIRO assessment at time of the June final 2016 Report: Recommendation for future work noted and agreed**	The June 2016 report notes that "For future work CSIRO recommends that: • A study be conducted to assess how many new sites and how many new engravings and backgrounds should be added to the current locations to increase the quality of the monitoring in the Burrup Peninsula. In particular, new control sites with similar rock types should be added to the current ones (for instance Depuch Island). It should also be noted that by increasing the number of independent measurement on each spot (in doing so improving statistical analysis) *could also have an adverse effect* on the petroglyphs and it was demonstrated in 2015 and 2016 by coloured spectrometers heads, signs that instruments measurements might be affecting the measured spots. A balance should be found between statistical endeavour and petroglyph protection." (emphasis added)
6. To maintain scientific rigour, future data collection should follow a fully documented and detailed protocol	DAA review of draft 2017: Not met. **CSIRO assessment at time of the final June 2016 Report: Recommendation noted and agreed**	CSIRO notes that detailed protocols for data collection will continue to be important, including for future analysis work (whether to be conducted by CSIRO or other organisations). The June 2016 Report provides commentary on the protocols used to collect the data in the report, including the sensitivities concerning alignment of photo spectrometers during data collection.

2017 DAA Recommendations:

DAA Recommendation	DAA review of draft CSIRO report and CSIRO assessment at time of the final June 2016 Report release:	CSIRO's analyses are available in the June 2016 Report entitled "Burrup Peninsula Aboriginal Petroglyphs: Colour Change & Spectral Mineralogy 2004 – 2016" released 2017 Please note that the results in the June 2016 report supersedes all results published previously
Recommendation 1. The Draft Report should include a succinct description of the measurement framework similar to that given above (with corrections as appropriate).	**CSIRO assessment at time of the final June 2016 Report: Recommendation Completed**	In addition to the detailed descriptions of the measurement framework for the study in the Introduction and Sections 1-2, and detailed instrument information in Subsections 4.2 (BYK and KM spectrophotometers) and 5.1 (ASD spectrometer), a new subsection 6.1 has been incorporated to provide a succinct description of aspects of the study relevant to the statistical analysis. A dedicated subsection, 6.3.1 'Factors Affecting Colour Measurements', has also been added.
Recommendation 2. Chapter 4 of the Draft Report should more directly address the poor quality of the BYK data. We recommend that the BYK data not be used, particularly not as a reference for changes since 2004, and that it be recommended to the readers not to rely on this data, unless cogent arguments can be presented to the contrary. Introducing the ASD colour measurements is appropriate in this Chapter.	**CSIRO assessment at time of the final June 2016 Report: Recommendation addressed on other chapters**	In accordance with DAA's recommendations in both 2016 and 2017 reports, CSIRO has directly addressed the quality of BYK data in the updated report, for example including in both the Executive Study and in the Conclusion the following recommendation to the reader not to rely on BYK data to draw conclusions concerning colour change: *"It should be noted that data from the BYK spectrophotometer appears unreliable for drawing conclusions on colour change in the rock art and, as such the cross calibration issues with the BYK portable photo spectrometer and the KM photospectrometer will no longer be undertaken."* Agreeing with DAA's Recommendation, BYK data is not used in the analysis of trends. Photospectrometer data from BYK and KM instruments is presented in Chapter 4 and ASD spectral data (from

DAA Recommendation	DAA review of draft CSIRO report and CSIRO assessment at time of the final June 2016 Report release:	CSIRO's analyses are available in the June 2016 Report entitled "Burrup Peninsula Aboriginal Petroglyphs: Colour Change & Spectral Mineralogy 2004 – 2016" released 2017 Please note that the results in the June 2016 report supersedes all results published previously
		which colour measurements are calculated) is presented in Chapter 5, with statistical analysis of all data sets provided in Chapter 6.
Recommendation 3. In Chapter 4 and other parts of the Draft Report less reliance should be placed on the ΔE measure.	**CSIRO assessment at time of the final June 2016 Report: Recommendation Completed**	Chapter 4 reports measured year-on-year change, both in terms of individual measures L*, a* and b* and the combined metric ΔE, but the report's conclusions are based not on the ΔE metric but on statistical analysis of individual colour components, agreeing with the Recommendation of DAA. The entire dataset has been provided to the WA government and each of the 24,000 L*, a* and b* observations made is plotted in Figures 19-58 of the report.
Recommendation 4. The Draft Report should include a proper statistical analysis of the spectral parameters in Chapter 5 to determine whether or not there have been significant changes.	**CSIRO assessment at time of the final June 2016 Report: Recommendation Completed**	The update to Section 6.3 extends statistical analysis from the KM spectrophotometer data to exactly analogous statistical models of equivalent colour measurements calculated from the ASD spectra shown in Chapter 5, in order to test whether there have been changes in colour over time, and whether these changes are at different rates at sites near to or far from industry, and whether the difference applies equally to background and engraving, in accordance with the models recommended by DAA.
Recommendation 5. The findings given in Section 6.2 of the Draft Report should be given greater prominence overall in the Draft Report, with the clear message that the BYK data has limited if any value.	**CSIRO assessment at time of the final June 2016 Report: Recommendation Completed**	The findings of Section 6.2, that '*BYK data is of doubtful value in understanding colour change in the rocks…conclusions on the changes in the rocks cannot reliably be based on the BYK data*',

DAA Recommendation	DAA review of draft CSIRO report and CSIRO assessment at time of the final June 2016 Report release:	CSIRO's analyses are available in the June 2016 Report entitled "Burrup Peninsula Aboriginal Petroglyphs: Colour Change & Spectral Mineralogy 2004 – 2016" released 2017 Please note that the results in the June 2016 report supersedes all results published previously
		are now highlighted in both the Executive Summary and Conclusion of the report. The repeated statement is clear that conclusions concerning colour change on the rocks cannot be based on BYK data: *It should be noted that data from the BYK spectrophotometer appears unreliable for drawing conclusions on colour change in the rock art*
Recommendation 6. The comments that the BYK data does not indicate change should be deleted or have strong caveats placed on it.	**CSIRO assessment at time of the final June 2016 Report: Recommendation Completed**	The text of DAA's Recommendation 6 is in error where it claims that the CSIRO report commented 'BYK data does not indicate change'. The report's comment is that the BYK data does not indicate a different rate of change at northern and southern sites. Even stronger caveats are now added, and repeated, fully meeting the intent of the DAA Recommendation: *While it is important to be clear that the recorded BYK data do show significant directional colour change over time, at differing rates on background and engraving of each spot at each site, the doubts over this BYK data make it impossible to conclude that it proves colour change actually occurred.* *(Ignoring for a moment these reservations, it is noteworthy that the trends in BYK data from southern sites near industry do not differ significantly from the trends recorded at northern control sites further from industry. The BYK data from northern site 1, plotted in Figures 19-21, shows as much change as the southern sites, and more than several (compare for example the BYK data*

DAA Recommendation	DAA review of draft CSIRO report and CSIRO assessment at time of the final June 2016 Report release:	CSIRO's analyses are available in the June 2016 Report entitled "Burrup Peninsula Aboriginal Petroglyphs: Colour Change & Spectral Mineralogy 2004 – 2016" released 2017 Please note that the results in the June 2016 report supersedes all results published previously
		from site 6, plotted in Figure 35 to Figure 37). The BYK data thus does not demonstrate any difference in colour change between southern sites close to industry and northern control sites.) *However, for the reasons given above, conclusions on the changes in the rocks cannot reliably be based on the BYK data. Rather, analysis should be conducted of data both from the KM spectrophotometer since its introduction and from the ASD spectrophotometer (the only instrument used for all years of the study), before overall conclusions are drawn.*
Recommendation 7. The Draft Report needs to provide substantially more information on the mixed models considered to demonstrate reasonable support for the conclusion that there is no evidence of impact of industry on the rock art.	**CSIRO assessment at time of the final June 2016 Report: Recommendation Completed**	As a slight clarification of the wording in DAA's 2017 Recommendation 7, the conclusion of these models is that there is no statistically significant evidence that the rate of colour change in rock art differed at sites near to or far from industry. The complete R code for the random effects in all models tested is now quoted in Subsection 6.3.3 of the report. The other component of each mixed model, the fixed effects, differs in each model tested, but these are also clearly defined for each model in Subsection 6.3.3, so that the models can be fully replicated by anyone with the data, completely demonstrating the statistical support for the conclusions reached. (R is open source and very widely used, highly reputable statistical software.)

DAA Recommendation	DAA review of draft CSIRO report and CSIRO assessment at time of the final June 2016 Report release:	CSIRO's analyses are available in the June 2016 Report entitled "Burrup Peninsula Aboriginal Petroglyphs: Colour Change & Spectral Mineralogy 2004 – 2016" released 2017 Please note that the results in the June 2016 report supersedes all results published previously
Recommendation 8. The Draft Report needs to properly document *all* changes in measurement practices and, where appropriate, incorporate these into the analyses.	**CSIRO assessment at time of the final June 2016 Report: Recommendation Completed**	Changes in measurement practices are fully documented as summarised in response to DAA's 2017 Recommendation 1 above; these are incorporated in analyses in Subsection 6.3.3 (for example, taking into account the repositioning of the ASD spectrometer for every measurement since 2015).
Recommendation 9. A formal design document should be produced before the next period of data collection, based upon established principles of the design of experiments. This document should fully explain any departures from the ideal, including the need to maintain a certain level of consistency with the existing data that, despite all its limitations, must remain part of future analysis.	**CSIRO assessment at time of the final June 2016 Report: Recommendation for future work noted but relevant to that future work**	This Recommendation relates to the **next period of data collection** rather than to the current report.
Recommendation 10. A formal analysis document should be produced in parallel to the design document before the next period of data collection.	**CSIRO assessment at time of the final June 2016 Report: Recommendation for future work noted but relevant to that future work**	This Recommendation relates to the **next period of data collection** rather than to the current report.

Senator Dean Smith:

1. The issue that this committee is really interested in understanding is whether industrial development has had any impact on the Burrup rock art. What does CSIRO's data conclude? Can I confirm that CSIRO says there is no difference between the control and the test sites?

CSIRO reaffirms the evidence given at the Hearing that CSIRO's primary role in conducting the spectrophotometer colour measurements was to measure the colour characteristics of the rock surfaces which can then be used as an indirect indicator of possible industry impact (refer page 16 of the Hansard dated 17 November 2017).

The June 2016 CSIRO Report "Burrup Peninsula Aboriginal Petroglyphs: Colour Change & Spectral Mineralogy 2004 – 2016" (EP161761, released 2017) reports measurements taken up to and including 2016 and analysis of these measurements, including the models recommended by the independent reviewer of the prior draft of the Report for testing for the three-way interaction of trends over time on background and engraving at northern and southern sites. The statistical analysis presented in the report at Table 18 (page 139 of the 146 page report) indicates varying degrees of evidence for change over time in the colour parameters L*, a* and b* measured with KM and ASD spectrometers, but presents no evidence that this change over time differs between northern and southern sites.

Section 7 of that Report (page 142 of the 146 page report) provides a summary of the CSIRO analysis which includes, in part, the following:

> "The petroglyphs at seven sites in the Burrup Peninsula were measured annually from 2004 to 2016. Three new sites close to the new Yara construction plant were also added from 2013 bringing the total to 10 sites. The same engravings and background rocks were measured *in situ*. Measurement of the annual colour changes utilised three instruments, the ASD and the BYK and KM. An examination of the colour measurements as a function of time, as well as a comparison of the two measurement techniques, has been conducted.
>
> For both the KM and the ASD instruments, three-dimensional L*a*b* colour space (L* - degree of lightness, a* - degree of red/green, b* - degree of yellow/blue), identifying a tristimulus value (L*a*b*) for each sample point have been calculated.
>
> Data from the KM spectrophotometer shows a trend over time in the L* measurements. The lightness (L) decreasing at a modelled average rate of 0.31 units per year (a total decrease of about 2 units on this scale is just noticeable to the human eye). However no trend is indicated in either a* (degree of red/green) or b* (degree of yellow/blue).
>
> Data from the ASD spectrometer shows trends indicated in L* (degree of lightness) and a* (degree of red/green) but not on b* (degree of yellow/blue), though the evidence is not as strong as seen with the KM instrument."

It should be noted that these small changes could be the results of natural weathering, or perhaps other causes; while the indication of colour change is important, and warrants closer attention, it cannot be automatically assumed that it represents the impact of pollution from industrial plants. Sites further from the industrial development, included in the study in order to test whether change is more rapid at sites more prone to pollution effects, in fact showed no statistically significant difference from the other sites. Again, quoting the previously cited section of the report:

> "*None of the instruments demonstrates a difference in the rate of change between the northern control sites and the southern sites closer to industry*." (italics added).

Table A below shows the trend analysis from the June 2016 CSIRO Report. Most p values are unremarkable, but a few are less than 0.05 (marked in *green italics* to stand out), and one is less than a sixth of 0.05 (marked in ***bold red italics*** to stand out even more), which is low enough to be significant even with a Bonferroni correction over the first row in the table. There is a statistically significant trend across the years, but no evidence of any difference between southern sites and northern control sites; or between the background/engraving contrast at southern and northern sites.

Table A omits BYK data, which gave strong evidence of a trend over time but contradicted the other instruments (both KM and ASD, as detailed in Subsection 6.2 of the June 2016 CSIRO report – since spectra recorded with the ASD spectrometer include the visible spectrum, comparison can be made between the BYK spectrophotometer and the ASD spectrometer) and is considered unreliable.

The following provides more information in relation to the statistical analysis of the findings.

As Tables B - F below show, 2016 was the first time that both KM and ASD data indicated a significant change in the same variable (though only the KM data gives evidence strong enough to meet the 0.05 level of significance after applying a Bonferroni correction).

	KM			ASD		
	L*	**a***	**b***	**L***	**a***	**b***
year	***0.004***	0.28	0.60	*0.029*	*0.012*	0.46
control * year	0.33	0.45	0.89	0.94	1.00	0.93
control * year * type	0.71	0.84	0.84	0.77	0.13	0.94

Table A*. p values for successively adding to models for L*, a* and b* measured with KM and ASD spectrometers: a trend over time (first row); different trends on northern and southern sites (second row); and different trends also on background and engraving (third row). Data up to and including 2016.*

Tables B - F repeat the analysis of Table A for every year back to 2010. There was already statistically significant evidence of change over time in 2014, which should have been reported then, but prior to this, no trends satisfy the 0.05 level of significance after applying a Bonferroni correction. Some individual trends had p values less than 0.05 one year but not the next, suggesting it would have been premature in these cases to draw conclusions from p values only slightly less than 0.05. The Bonferroni correction is designed to guard against reaching such mistaken conclusions based on random fluctuations in the data; without this correction, mistaken conclusions would likely be drawn, given that multiple tests, each with a 0.05 probability of error, are being performed. The Bonferroni correction ensures there is only a 0.05 probability of error taken across *all six* tests in the first row of each table.

	KM			ASD		
	L*	a*	b*	L*	a*	b*
year	***0.008***	0.06	0.07	0.09	*0.04*	0.32
control * year	0.26	0.22	0.41	0.97	0.19	0.84
control * year * type	0.22	0.70	0.33	0.98	0.83	0.91

Table B*. p values as in Table 1. Data up to and including 2014.*

	KM			ASD		
	L*	a*	b*	L*	a*	b*
year	*0.02*	*0.04*	0.38	0.34	*0.045*	1.00
control * year	1.00	0.38	0.86	0.90	0.09	*0.04*
control * year * type	0.31	0.87	0.56	0.89	0.77	0.83

Table C*. p values as in Table 1. Data up to and including 2013.*

	KM			ASD		
	L*	a*	b*	L*	a*	b*
year	0.06	*0.046*	0.39	0.57	0.29	0.98
control * year	0.93	0.60	0.85	0.43	0.07	0.35
control * year * type	0.41	0.96	0.98	0.64	0.69	0.59

Table D*. p values as in Table 1. Data up to and including 2012.*

	KM			ASD		
	L*	a*	b*	L*	a*	b*
year	0.59	0.52	0.80	0.09	0.83	0.43
control * year	0.72	0.64	0.93	0.60	0.42	0.97
control * year * type	0.41	0.61	0.73	0.92	0.88	0.89

Table E*. p values as in Table 1. Data up to and including 2011.*

	KM			ASD		
	L*	a*	b*	L*	a*	b*
year	0.58	0.95	0.65	0.33	0.79	0.42
control * year	0.97	0.72	0.90	0.48	0.22	0.58
control * year * type	0.70	0.88	0.50	0.80	0.93	0.99

Table F*. p values as in Table 1. Data up to and including 2010.*

In summary, the CSIRO colour measurements made during 2004 – 2016 (inclusive), when analysed using a model that includes a time trend, shows varying degrees of evidence for change over time in the colour parameters L*, a* and b* over the different photospectrometers , but no evidence that this change over time differs between northern and southern sites.

2. The analysis conducted by CSIRO leads to a different conclusion to the analysis of Professor Black. Why do you say this committee should rely on CSIRO's analysis: what are the characteristics of the CSIRO report that makes it more reliable?

The June 2016 CSIRO Report (released during 2017) includes the last two years of measurements (2015 and 2016) and a complete statistical analysis of all the data for both the KM and the ASD photospectrometers instruments. This also includes data for three new sites that were incorporated into the BRATWG monitoring program in 2014 and so the June 2016 CSIRO Report also includes three years of data for these sites. In line with the recommendation of the independent reviewer (Data Analysis Australia Pty Ltd) the BYK spectrophotometer data, which has been concluded to be unreliable for drawing conclusions on colour change in the rock art, has been excluded from the statistical analysis as the measurements taken with the BYK spectrophotometer contradicts data from the other spectrophotometers. The June 2016 CSIRO Report provides statistical testing for the three-way interaction of trends over time on background and engraving at northern and southern sites (and see above detailed answer).

The analysis provided previously by Black & Diffey (14 May 2016) was of the results from 2004 to 2014 but not the data from measurements in 2015 and 2016.

The principle difference between the analysis of Professor Black and the recent CSIRO report is *not* in the analysis itself, but in the data underlying it: Professor Black used BYK data and CSIRO's analysis does not, for reasons described earlier. Even here, though, there is in fact some broad agreement between the analyses; the document 'REANALYSIS OF THE COLOUR CHANGES FROM 2004 TO 2014 ON BURRUP PENINSULA ROCK ART SITES', by Professor Black and Dr Simon Diffey, dated 2 May 2016, says

> 'There was no significant difference in colour change at the two northern sites compared to the five southern sites closer to industry.'

This actually agrees with CSIRO's conclusion that the data do not show sites closer to industry to be changing colour at a rate statistically significantly different to control sites further from industry. For example, the BYK data from northern Site 1, plotted in Figures 19-21 of the recent CSIRO report, shows as much change as the southern sites nearer to industry, and more than several (compare for example the BYK data from site 6, plotted in Figures 35-37). Thus even the BYK data - if one is to examine that notwithstanding reservations about that instrument - does not demonstrate any difference in colour change between southern sites close to industry and northern control sites. Differences in analysis thus should not be overstated.

3. Do you say that CSIRO is uniquely and best placed to assess the experiment? What is the value of being on the ground where an experiment is taking place, when it comes to assessing the effectiveness of that experiment?

Being on the ground when observations were made is *not* necessary in order to analyse a given dataset; however, methodological questions about the method of data acquisition are clearly better answered by those who were involved at the time.

The team involved in conducting the measurements (or being present when measurements are made) on the ground will inevitably have the opportunity to make operational observations that are relevant to understanding the results. These observations can include anything out of the ordinary; for example, white bird droppings were observed on a measurement spot one year, which wa reported at the time. Observations such as these are used during the data cleaning process to mitigate the problem of spurious data in the analysis.

Another example that illustrates the importance of this, outlined in the June 2016 CSIRO Report, is in relation to the potential pros and cons of increasing the number of measurements taken.

Prior to undertaking the first field trips, experimental planning and rehearsal indicated that 7 measurements per spot was the maximum number that could be taken in the planned timeframe scheduled for each site. Some sites are remote and require a long trek for access. Return on the boat is time-bound since the boat can be stranded when the tide goes out which is a safety consideration. As the team became more familiar with the process and faster at taking measurements, it allowed time for increased collection within the same timeframe.

A decision was taken in 2015 to increase to 21 the number of measurements to be taken on background and on engraving at each spot on each site, in the expectation that added measurements would reduce any sample variance introduced by surface heterogeneity or roughness of the rock surface and the increased sampling therefore might improve the statistical analysis of the data.

However, the experimental observation was that this change in measurement protocol could also potentially damage the sample spot of measurement, as this is repeated 21 times for KM spectrophotometer and 21 times for the ASD reflectance spectrometer. Repeatedly placing the head of each instrument on the rock may induce its own slight effect on rock colour. The Report notes the observation that:

> *"In 2015 and 2016, it was observed that the heads of both the Konica Minolta (KM) and ASD spectrometers were showing colouring, signs that instruments measurements might be affecting the measured spots".*

This example illustrates well that although the design of experimentation on an arms-length theoretical basis can be important, a very direct understanding of the measurement technique as implemented is also required in order to understand the limitations of the experimental process.

4. The May 2017 Review by Data Analysis Australia (DAA), which assessed CSIRO's draft report, identified a number of opportunities for improvement – not with regard to the accuracy of the results, but in relation to the way the results were presented. CSIRO has since completed its final report. Can you explain how CSIRO, in this final report, has responded to each of the opportunities identified by DAA?

Table 1 above summarises CSIRO's response to the DAA Recommendations arising from the DAA review of the draft version of the CSIRO Report; as presented in the June 2016 Report titled "Burrup Peninsula Aboriginal Petroglyphs: Colour Change & Spectral Mineralogy 2004 – 2016" (EP161761, released 2017).

Senator Siewert:

Written Question

- Has the CSIRO sought legal advice on the vulnerability of being sued as a consequence of acknowledging flaws in their previous reports on the Burrup Peninsula?

Answer: Any legal advice that CSIRO may have sought, including in relation to this or other topics, is not disclosed.

MINERAL RESOURCES
www.csiro.au

Burrup Peninsula Aboriginal Petroglyphs: Colour Change & Spectral Mineralogy 2004–2016

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Copyright and disclaimer

Important disclaimer

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Acknowledgments

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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). It was named after Mount Burrup, the highest topographic point. The Burrup Peninsula 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. The term petroglyph is derived from the Greek words 'petros' meaning rock or stone and 'glyphein' meaning to carve. Petroglyphs are human artefacts produced by partly removing a rock surface by pecking or pounding using a chisel.The petroglyphs have been carved in two rock types, namely granophyre and gabbro. These rocks have been subjected to weathering and display a core of fresh rock surrounded by a cm-thick "leached" zone in turn covered by a thin iron oxide rich skin. The petroglyphs were engraved in the rocks by removing the outermost skin to expose the leached zone providing a strong contrast between the "engraving" and the "background". The leached zone is characterised by an augmentation of the porosity as a result of the dissolution of primary minerals as well as an increase of both kaolinite and goethite. As the amount of primary minerals decreases, the amount of secondary minerals increases, but some of the most weathering resistant primary minerals such as quartz and chlorite are still partially present. An increase in phosphorus (mainly as apatite microcrystals) has been characterised in both the leached and surface zones for all samples. The addition of apatite can only be explained by an external source namely bird droppings (or guano) a natural fertilizer. Guano typically contains 8 to 16% percent nitrogen, 8 to 12% equivalent phosphoric acid, and 2 to 3% equivalent potash. Hence, the bird dropping will not only add phosphorus to the rocks but also nitrogen.

Alongside the petroglyphs, the Burrup Peninsula hosts 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 former 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 former Burrup Rock Art Technical Working Group (BRATWG) 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. The site selection for sites close to industry and for distant "control" sites was based predominantly on predicted gas concentrations derived from modelling by SKM. In addition geology was important to ensure that both of the major rock types that supported the petroglyphs, granophyre and gabbro, were included.

For 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. Three spots on each engraving and three spots on each background rock were measured *in situ* using a portable photospectrometer for colour measurement and a reflectance spectrometer for visible and near infrared analysis. In 2014, the rock art monitoring project expanded at the request of Yara Pilbara

Nitrates Pty Ltd (YPNPL). The company was building a Technical Ammonium Nitrate Production Facility Project (or TAN) on the Burrup Peninsula, and to adhere to the requirements of the Environment Protection and Biodiversity Conservation Act 1999, YPNPL needed 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 "the Department of Environment Regulation (DER)" 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. After initial monitoring in February 2014, the three new sites have become part of the BRATWG monitoring program. As well as the three new sites, an extra spot (both engraving and background) was added on each monitored petroglyph panel, bringing the total to eight sampling spots (four areas classified as 'engraving' and four areas classified as 'background') to increase the accuracy of future statistical analysis of measurements.

As the project was entering its 10th year, it was appropriate to review the approach to data analysis that was implemented at the outset and has remained in place without significant modification since 2004.

Previously, the following analyses for the photospectrometer colour measurements were as follows:

- 21 independent measurements of each spot
- Replicate sample data was collected in L*a*b* numerical format. (L* is a measure of lightness, from 0 (black) to 100 (white); a* and b* can take positive or negative values. Higher a* values correspond to increasing red colour and lower values to increasing green colour; b* similarly records the contrast between yellow (high values) and blue (low values). Data has been calculated relative to the D65 standard illuminant, intended to represent average daylight.)
- Measurements at a single spot were averaged and reported.
- Colour difference between background and engraving was calculated and reported year to year and from the current year to the beginning of the study.
- Annual measurements of the colour difference between background and engraving were plotted and a trend line reported.

The analyses for the Analytical Spectral Device (ASD) Reflectance spectrometer were as follows:

- 10 measurements of each spot. In 2015, the number of measurements was increased to 21 to match the photospectrometer and also the head of the spectrometer was removed and replaced after each measurement.
- Measurements at a single spot were averaged and reported.
- Spectral parameters were extracted and plotted.

It should be added that the 21 measurements for each instrument reduce sample variance introduced by surface heterogeneity or roughness. It should be also noted that this might improve the statistical analysis of the data but can also potentially damage the spot at this is repeated 21 times for the photospectrometer and 21 times for the ASD reflectance spectrometer. In 2015 and 2016, it was observed that the heads of both the Konica Minolta (KM) and ASD spectrometers were showing colouring, signs that instruments measurements might be affecting the measured spots.

The initial measurements (2004 to 2008) were acquired using only the ASD spectrometer and a Gardner (BYK) photospectrometer. These instruments are described in the experimental section of this report. In 2009, some of the automated memory retention functions of the BYK spectrophotometer started failing, requiring laborious manual data saving. Calibration and instrument performance were unaffected. It was decided to pair the BYK instrument with a more modern KM spectrophotometer (also described in this report) 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.

The spectral parameters were extracted from the ASD reflectance spectrometer and include (1) the depth (D900) and minimum wavelength (W900) of the large 900nm centred absorption providing information on the iron oxides; (2) the depth of the chlorite absorption at 2250 nm after local Hull removal - DChlorite (residual mineral from the fresh rocks) and (3) the depth of the kaolinite at 2206 nm after local Hull removal (DKaolinite) and, when present, gibbsite (DGibbsite) absorptions (secondary minerals resulting from the weathering of the primary minerals). The plot of these spectral parameters shows variations from year to year.

For this report, combining the last two years of measurements (2015 and 2016), a complete statistical analyses of all the data (each individual measurement for the three instruments, a total of 24,000 colour measurements from 2004 to 2016) has been undertaken.

Measurement of the annual colour changes used two spectrophotometer techniques, the ASD and the BYK and KM. An examination of the colour measurements as a function of time, as well as a comparison of the two measurement techniques, has been conducted.

For both the KM and the ASD instruments, three-dimensional L*a*b* colour space (L* - degree of lightness, a* - degree of red/green, b* - degree of yellow/blue), identifying a tristimulus value (L*a*b*) for each sample point have been calculated.

Data from the KM spectrophotometer shows a trend over time in the L* measurements. The lightness (L) decreasing at a modelled average rate of 0.31 units per year (a total decrease of about 2 units on this scale is just noticeable to the human eye). However no trend is indicated in either a* (degree of red/green) or b* (degree of yellow/blue).

Data from the ASD spectrometer shows trends indicated in L* (degree of lightness) and a* (degree of red/green) but not on b* (degree of yellow/blue), though the evidence is not as strong as with the KM instrument.

The conclusion of colour change would be clearer if it was detected across all dimensions of colour (it would be natural for colour change to be evident in all dimensions, L*, a* and b*, not only in one or two of them). The results are not fully conclusive and if the measurements do reflect real colour change, as the data suggest, then continued observations would continue to mark out the trend more clearly; and if not, observations will likely continue to fluctuate over time, making the randomness of the recorded variation more apparent. Sites 21-23 have currently only three years of observations; additional observations will be particularly helpful at these sites. Nonetheless, the indication of significant colour change is important, and warrants closer attention. None of the instruments demonstrates a difference in the rate of change between the northern control sites and the southern sites closer to industry.

It should be noted that data from the BYK spectrophotometer appears unreliable for drawing conclusions on colour change in the rock art and, as such the cross calibration issues with the BYK portable photospectrometer and the KM photospectrometer will no longer be undertaken.

All the photospectrometer data (KM, BYK and ASD) have been provided in an easily readable format to WA DER for safekeeping.

It should be noted that the results of this report supersede all results previously published.

For future work, it is recommended that:

- A complete statistical analyses is done on the full spectrum of each individual ASD spectrum (not just the visible part i.e. L*, a* and b*).
- A study be conducted to assess how many new sites and how many new engravings and backgrounds should be added to the current locations to increase the quality of the monitoring in the Burrup Peninsula. In particular, new control sites with similar rock types should be added to the current ones (for instance Depuch Island). It should also be noted that by increasing the number of independent measurement on each spot (in doing so improving statistical analysis) could also have an adverse effect on the petroglyphs. There were signs in 2015 and 2016 that instruments measurements might be affecting the measured spots. A balance should be found between statistical endeavour and petroglyph protection.
- One (1) rock sample be collected at each site (old and new), a total of 10 rocks based on current monitoring, and brought to CSIRO in Perth to be stored in a container where humidity is 0% (no water) and in an argon atmosphere (no oxygen and no oxidation) and placed in a dark area. This will allow a comparison between the control sites, where natural weathering occurs and these reference samples.

It is also recommended that the colour and mineralogical monitoring be complemented in the future with atmospheric and microbiological monitoring similar to those conducted in the past.

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 Environmental Regulation (DER), CSIRO has measured the colour of selected petroglyphs on the Burrup Peninsula over a period of thirteen 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 13 years, the petroglyphs at 7 specially selected sites in the Burrup Peninsula (Western Australia) were measured using reflectance spectroscopy and colour spectrophotometry (2004 to 2016 - 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; Markley et al., 2014; Markley et al., 2015). In 2014, three additional sites located within a 2 km radius of the Yara Pilbara Nitrates Pty Ltd (YPNPL) Technical Ammonium Nitrate Production Facility Project (or TAN) were added to the monitoring program. From 2004 to 2012, three spots on each engraving and 3 spots on each background rock were measured *in situ* using an ASD spectrometer and a spectrophotometer, with a 4th engraving and background spot added in 2013. The spectral measurements were co-located with the colour measurements. Initially, at each engraving and background spot seven spectra were acquired and averaged, with this increasing to 21 repeat measurements at each spot in 2005 to improve the statistical robustness of the data. The spectral variation for each spot (both engraving and background) was also assessed. The colour values were crosschecked to the colour value calculated by the ASD spectrometer.

The 2004 spectral study (Ramanaidou and Caccetta, 2005) is the baseline dataset that has been used to monitor potential variation that occurred in the last 13 years. The thirteen-year study (2004-2016) has assessed the ability of the mineralogy to monitor and explain the mineralogical changes (if any) of seven rock art sites in the Burrup Peninsula, and an additional three sites in 2014, along with analysing any colour differences or changes.

2. Location and sampling of the petroglyphs

The sites for monitoring (Table 1 and Figure 1) were determined by the Burrup 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 aspects such as distance from the sea, elevation, direction of exposure and importantly cultural acceptability.

For the record, the site selection for sites close to industry and for distant "control" sites were based predominantly on predicted gas concentrations derived from modelling by SKM (modelling is available on the WA DER website). In addition geology was important to ensure that both of the major rock types that supported the petroglyphs, granophyre and gabbro, were included.

Initially, 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.

Initially, for spectral mineralogy, measurements based on the average of a minimum of seven readings were recorded at each sampling point and 10 replicate measurements were made for colour analysis. In order to reduce to a minimum the impact of the measurements, a paramount parameter for such a cultural sensitive study, the head of the ASD spectrometer (albeit in rubber) was not moved, that is the measurements were all collected with the head/detector not removed and then replaced on the spot after each measurement.

In 2013, it was decided to increase the accuracy of the statistical analysis of measurements by adding (1) a fourth engraving and background spot on each petroglyph, (2) more spectral measurements from ten (10) to twenty one (21) readings recorded at each sampling point and (3) that the instruments (both spectrometers) head/detector in contact with the spot was removed and then replaced on the spot after each measurement so that 21 independent measurements were taken at each sample point to reduce sample variance introduced by surface heterogeneity or roughness, and by systematic error. It should be noted that this might improve the statistical analysis of the data but can also potentially damage the spot at this is repeated 21 times for the photospectrometer and 21 times for the ASD reflectance spectrometer. In 2015 and 2016, it was observed that the heads of both the KM and ASD spectrometers were showing colouring, signs that instruments measurements might be affecting the measured spots.

A sampling area was chosen on the criteria that it had relatively uniform colour over a minimum area of 20mm, 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

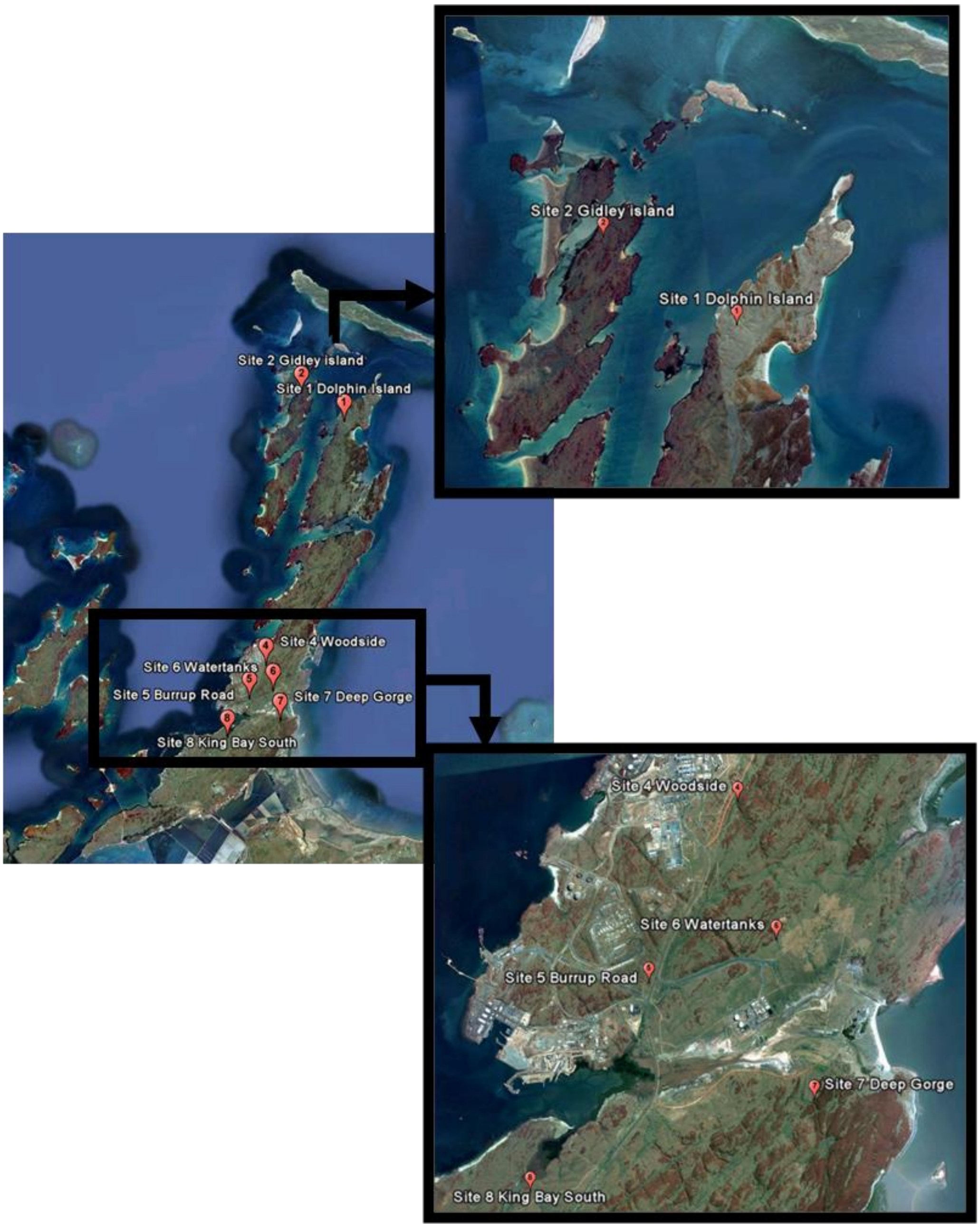


Figure 1: Google Earth® maps of the Burrup Peninsula with the location of the petroglyphs.

For the three additional sites included as part of this study for the Yara Pilbara Nitrates Pty Ltd (YPNPL) Technical Ammonium Nitrate Production Facility Project, a similar approach was adopted where consideration was given to the location of the plant site and its 2 km radius relative to the wind main directions through the year (Figure 2). The Elders of the Murujuga Aboriginal Corporation made the ultimate decision. 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 2) from the (BRATWG) monitoring program and three additional monitoring sites within 2 km of plant site labelled 21 or Yara West, 22 or Yara North East and 23 or Yara East (Figure 2). In July 2014, the three additional sites (21, 22 and 23) became part of the BRATWG monitoring program with a new 10 monitoring sites.

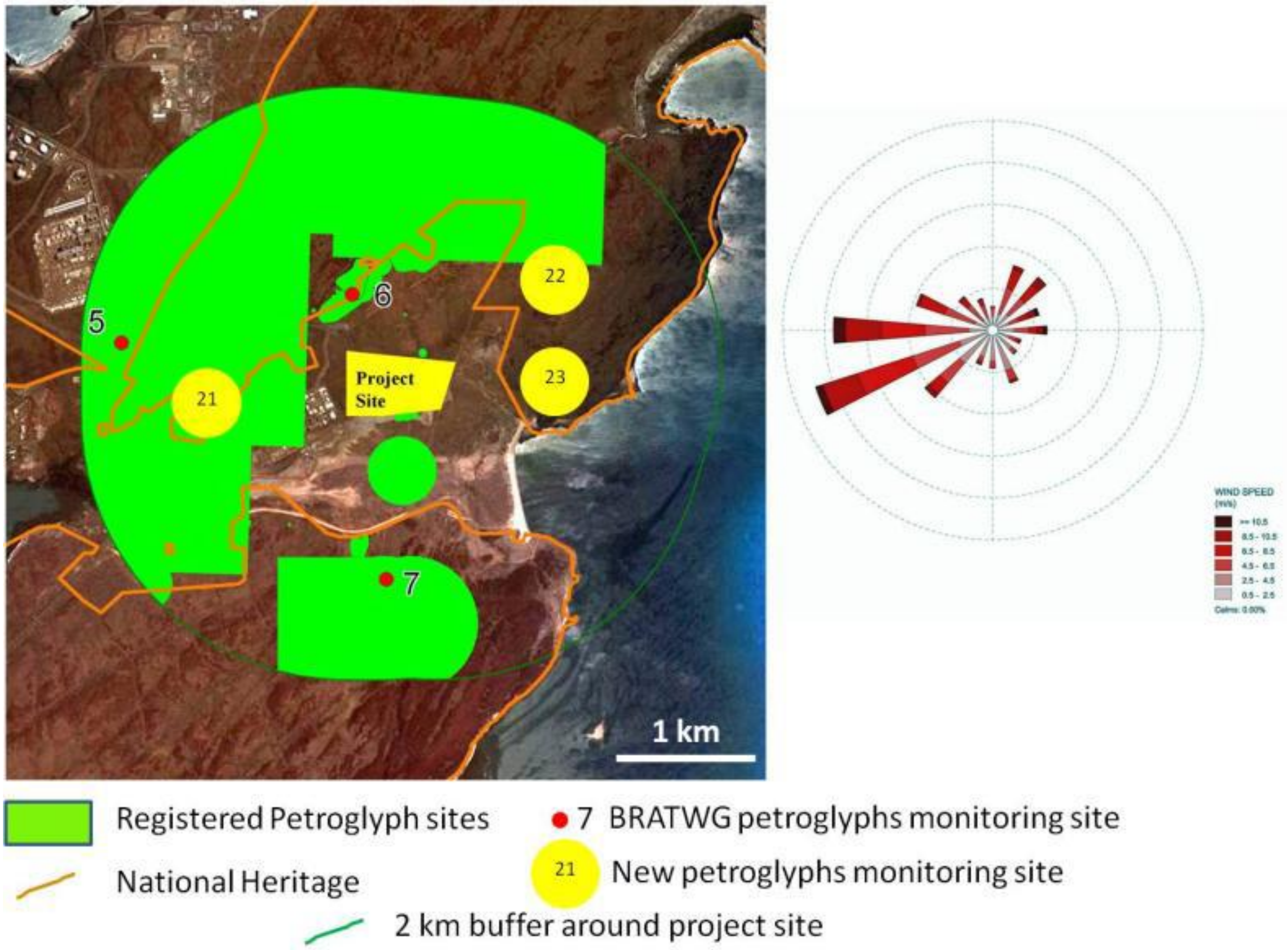


Figure 2: New sites (Yellow numbers) with dominant wind directions and speed.

Table 2: 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. Petroglyphs (This section is from Ramanaidou and Fonteneau, 2015 and 2017)

The term petroglyph is derived from the Greek words ‘petros’ meaning rock or stone and ‘glyphein’ meaning to carve. Petroglyphs are human artefacts produced by partly removing a rock surface by engraving, pecking, pounding or carving using a chisel. In Australia and, in particular in the Burrup Peninsula, it has been demonstrated that the petroglyphs were created mainly by pounding and pecking (Maynard, 1977; Bednarik, 1998, 2007). The Burrup Peninsula is home to the world’s largest collection of Aboriginal petroglyphs.

The primary lithology of the Burrup Peninsula is dominated by granophyre and gabbro dated at around 2.7 billion years old. These rocks have been subjected to weathering and display a core of fresh rock surrounded by a cm-thick “leached” zone (a black line outlines the leached zone in Figure 3) in turn covered by a thin iron oxide rich skin (Figure 3). The petroglyphs were carved by removing the few top millimetres of the iron oxide-rich layer to expose the lighter leached zone. The contrast between the original reddish background and the lighter coloured etching makes it obvious to the naked eye. The leached zone is characterised by an augmentation of the porosity because of the dissolution of primary minerals as well as an increase of both kaolinite and goethite. Partial goethitisation of the Fe-bearing minerals such as chlorite, magnetite, hematite and actinolite in granophyre and chlorite, actinolite, augite in gabbro has occurred. The Al-rich minerals such as feldspar, chlorite, epidote and muscovite are partially replaced by kaolinite. As the amount of primary minerals decreases, the amount of secondary minerals (resulting from weathering) increases. The red-orange mm-thick outer surface coating (Figure 3) is characterised by a further increase in kaolinite, hematite and goethite. Some of the most weathering resistant primary minerals such as quartz and chlorite are still present.

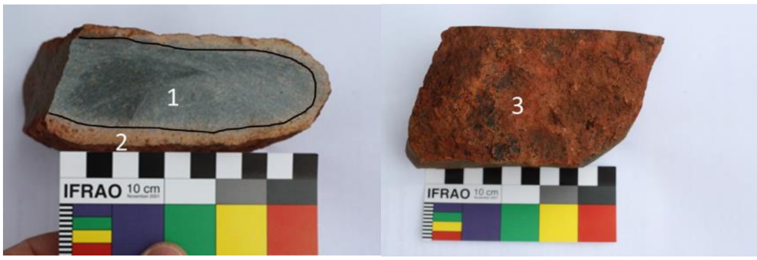


Figure 3. Weathered granophyre with Munsell colour including (1) fresh rock (7.5B 5/2), (2) leached zone (7.5YR 4/2) and (3) surface coating (2.5YR 4/4).

An increase in phosphorus (P) in both the leached and surface zones has been observed for all samples with a maximum measured in the leached zone (2 in Figure 3). This increase in P_2O_5 in the leached and surface zones is respectively 12 times and 6 times more compared to the fresh rock. This addition of phosphorus can only be explained by an external source of P namely guano (bird droppings) a natural fertilizer. The composition of seabird guano mainly includes ammonium oxalate ($C_2H_8N_2O_4$) and urate ($C_5H_7N_5O_3$), phosphates $(NH4)_3PO_4$. Guano typically contains 8 to 16% percent nitrogen (mainly uric acid), 8 to 12% equivalent phosphoric acid, and 2 to 3% equivalent potash. Hence, the bird dropping will not only add phosphorus to the rocks but also nitrogen (N). Bird droppings from seagulls are frequently found on the surfaces of the gabbros and granophyres including the petroglyphs (Figure 4).

Figure 4. Bird droppings on Murujuga rocks

4. Colour Measurement

4.1 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 (L* - degree of lightness, a* - degree of red/green, b* - degree of yellow/blue), 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 at 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.

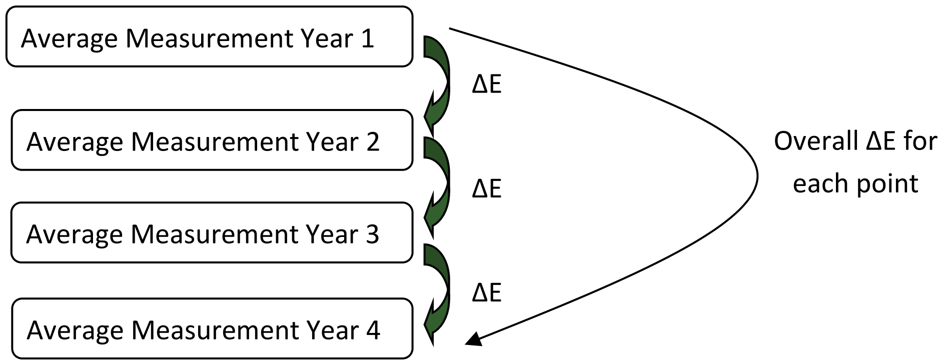
4.2 Experimental Methodology

The difference between two colours measured instrumentally is ΔE. It derives from the German word – *Empfindung* – that 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:

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

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



In 2009, a Konica Minolta CM-700d spectrophotometer was used during the field data collection trips to evaluate its suitability and practical handling features, and was found to be reliable and well suited to the purpose. The spectrophotometer has a flat conical head configuration that provided an improved repeatability on the rougher rock surfaces (Figure 5). The measurement head has a diameter of 10 mm, which is half of the instrument used in parallel for spectral mineralogy measurements (ASD FieldSpec Pro head diameter is 20 mm). The increased measurement field diameter reduces the effect of surface heterogeneity on the overall averaged colour measurement. The instrument specifications are given in Table 3.

In SCE mode, the specular reflectance is excluded from the measurement and only the diffuse reflectance is measured. This produces a colour evaluation that correlates to the way the observer sees the colour of an object. When using the SCI mode, the specular reflectance is included with the diffuse reflectance during the measurement process. This type of colour evaluation measures total appearance independent of surface conditions.

Figure 5: Konica Minolta CM-700d spectrophotometer.

Table 3: Instrument Specifications for the Konica Minolta CM-700d spectrophotometer.

Colour Space	Observer	Illuminant	Measurement/ illumination area
L*a*b*	10^{o}	D65 –simulated daylight	SAV: Φ3 mm/Φ6 mm
Light source	**Measurement time**	**Repeatability**	
Pulsed xenon lamp (with UV cut filter)	Approx. 1 second	Spectral reflectance: Standard deviation within 0.1%	

All measurements from 2013 were collected using the Konica Minolta (KM) spectrophotometer. For the results presented in this report, years 2009 - 2016 were collected using the KM spectrophotometer, while 2004 -2008 were BYK spectrophotometer data (see the 2014 report for further details on their comparison of the two spectrophotometers).

4.3 Results and Discussion

4.3.1 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 fourth engraving and background analysis spots, new in 2013, are indicated in these photos.

The original data collection in 2004 consisted of 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 evaluate statistically the variability of 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 heterogeneity or roughness, and by systematic error. For clarity, the raw data have not been included here, but averages of the data are presented with the colour difference measurements calculated with the standard CIE methods.

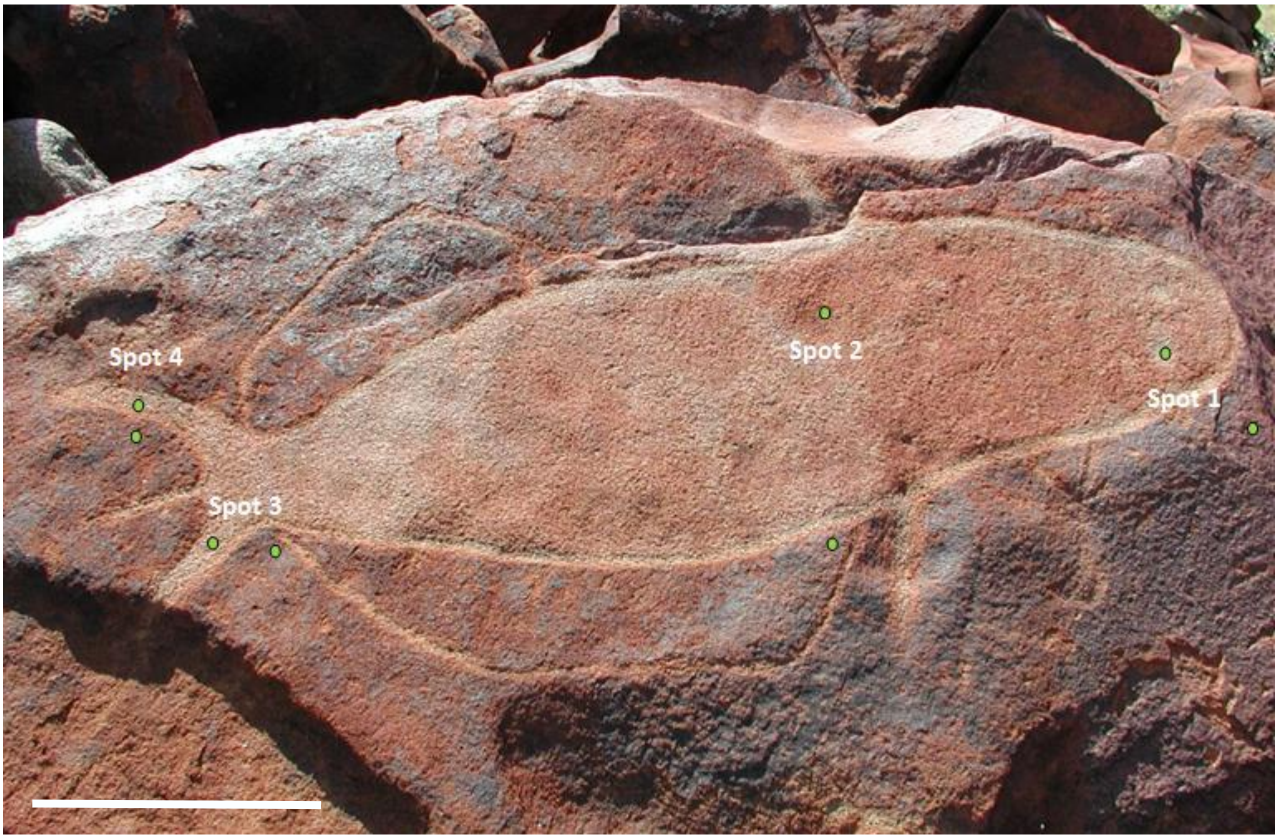


Figure 6: Site 1- Dolphin Island (White scale bar is 50 cm).

Table 4: Average Colour Measurements for Site 1 – Dolphin Island (2004 – 2016).
Note: KM measurements are in red. No comparison calculated for 2008-09 due to change of instrument.

Sample	Colour scale L*	Colour scale a*	Colour scale b*	Colour difference* ΔE (change from previous year)
Site 1 Spot 1 Engraving				
Average 2016	40.72	9.59	16.86	2.67
Average 2015	43.35	9.16	16.74	1.77
Average 2014	41.80	8.78	15.97	1.34
Average 2013	42.93	9.35	16.41	0.88
Average 2012	42.76	9.79	17.15	0.38
Average 2011	42.42	9.83	17.32	0.48
Average 2010	42.85	9.74	17.13	1.48
Average 2009	41.76	9.22	16.28	
Average 2008	19.10	4.54	12.45	2.34
Average 2007	17.16	5.71	13.03	2.39
Average 2006	16.79	3.83	11.59	3.04
Average 2005	14.97	6.08	12.53	2.16
Average 2004	14.32	8.08	13.00	0.00
Site 1 Spot 1 Background				
Average 2016	33.19	11.11	9.69	0.82
Average 2015	32.66	10.48	9.72	0.88
Average 2014	33.42	10.66	9.32	1.15
Average 2013	32.55	11.17	9.87	0.45
Average 2012	33.00	11.21	9.81	0.89
Average 2011	32.82	10.34	9.75	1.47
Average 2010	33.78	11.18	10.48	0.60
Average 2009	33.44	10.87	10.08	
Average 2008	29.91	11.10	11.22	1.72
Average 2007	28.24	10.69	11.14	1.16
Average 2006	28.97	10.29	10.33	1.84
Average 2005	27.66	11.26	11.20	2.24
Average 2004	29.87	11.20	10.79	0.00
Site 1 Spot 2 Engraving				
Average 2016	32.58	16.92	18.44	1.36
Average 2015	32.10	16.46	17.25	1.61
Average 2014	33.26	16.88	18.28	2.55
Average 2013	32.26	15.71	16.24	1.37
Average 2012	33.14	16.23	17.16	1.20
Average 2010	33.81	16.77	17.99	2.39
Average 2010	32.28	15.91	16.37	1.58
Average 2009	33.24	16.54	17.46	
Average 2008	14.96	11.17	13.53	3.52
Average 2007	12.13	9.76	11.98	4.89
Average 2006	8.37	8.22	9.26	1.84
Average 2005	7.91	9.84	9.99	0.69
Average 2004	8.43	9.62	9.59	0.00
Site 1 Spot 2 Background				
Average 2016	31.01	11.51	11.62	2.87
Average 2015	31.37	9.57	9.54	0.62
Average 2014	31.65	9.11	9.24	1.58
Average 2013	30.34	8.39	8.72	4.85
Average 2012	32.41	11.62	11.68	3.84

Average 2011	30.37	8.97	9.79	2.59
Average 2010	32.05	10.65	10.83	1.72
Average 2009	31.76	9.64	9.47	
Average 2008	26.35	9.51	11.43	6.11
Average 2007	20.96	7.06	9.92	8.54
Average 2006	28.82	10.21	11.06	7.88
Average 2005	20.98	9.46	11.46	6.74
Average 2004	27.66	10.35	11.87	0.00
Site 1 Spot 3 Engraving				
Average 2016	39.63	14.31	18.82	0.70
Average 2015	39.06	14.70	18.96	0.51
Average 2014	38.66	14.47	19.18	1.21
Average 2013	38.87	13.83	18.18	1.15
Average 2012	37.79	13.99	17.81	1.51
Average 2011	39.11	14.08	18.54	0.79
Average 2010	38.53	14.36	19.00	1.29
Average 2009	39.81	14.52	19.06	
Average 2008	32.98	11.15	17.56	6.37
Average 2007	26.72	10.16	16.94	3.60
Average 2006	23.22	10.68	16.27	3.16
Average 2005	25.67	12.25	17.51	3.02
Average 2004	28.67	12.12	17.18	0.00
Site 1 Spot 3 Background				
Average 2016	29.27	12.16	12.2	3.27
Average 2015	29.69	9.89	9.88	4.02
Average 2014	29.49	12.47	12.96	0.72
Average 2013	29.17	12.25	12.36	4.22
Average 2012	30.21	9.47	9.36	1.77
Average 2011	30.14	10.67	10.67	0.52
Average 2010	29.75	10.44	10.40	0.26
Average 2009	29.97	10.57	10.42	
Average 2008	15.14	7.48	10.02	4.29
Average 2007	19.09	8.97	10.76	6.43
Average 2006	13.07	7.30	9.25	2.43
Average 2005	11.45	8.75	10.33	2.44
Average 2004	13.42	7.98	9.11	0.00
Site 1 Spot 4 Engraving				
Average 2016	38.02	13.46	18.19	3.36
Average 2015	41.25	13.79	19.07	6.87
Average 2014	35.08	12.09	16.57	4.28
Average 2013	38.39	13.95	18.56	
Site 1 Spot 4 Background				
Average 2016	29.27	12.16	12.20	0.79
Average 2015	28.65	12.54	12.51	0.18
Average 2014	28.73	12.41	12.42	2.10
Average 2013	29.49	11.17	10.91	

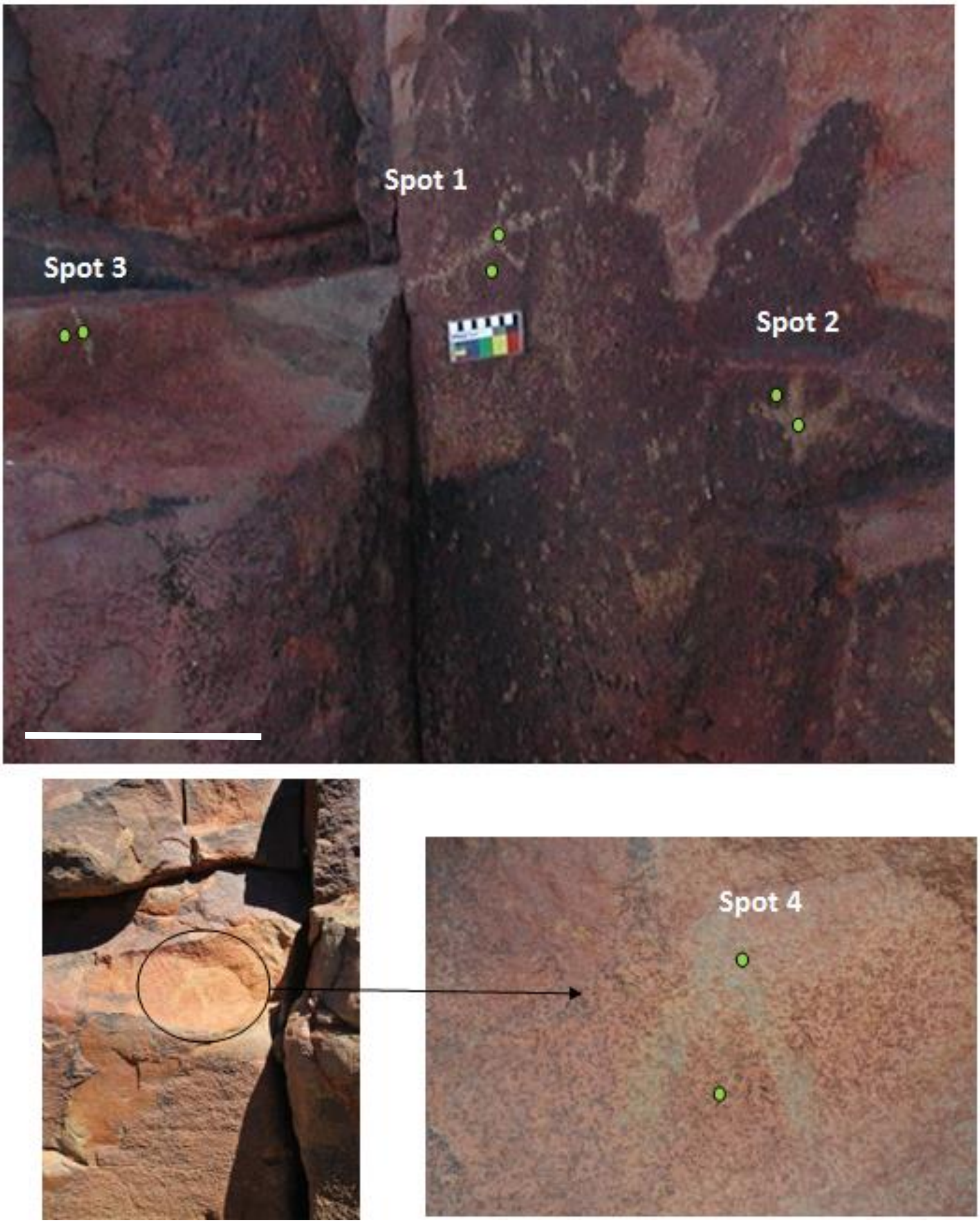


Figure 7: Site 2 – Gidley Island (white scale bar is 10 cm).

Table 5: Average Colour Measurements for Site 2 – Gidley Island (2004 – 2016).
Note: KM measurements are in red. No comparison calculated for 2008-09 due to change of instrument.

Sample	Colour scale L*	a*	b*	Colour difference* ΔE (change from previous year)
Site 2 Spot 1 Engraving				
Average 2016	44.42	9.40	18.60	3.36
Average 2015	43.45	9.36	18.52	5.59
Average 2014	38.34	8.70	16.34	1.97
Average 2013	40.17	9.06	16.98	0.40
Average 2012	39.83	9.22	16.83	3.25
Average 2011	42.78	9.31	18.20	0.35
Average 2010	43.06	9.44	18.37	4.54
Average 2009	38.80	9.33	16.81	
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	0.00
Site 2 Spot 1 Background				
Average 2016	29.85	9.31	10.23	3.38
Average 2015	32.12	9.76	12.69	1.46
Average 2014	32.63	10.43	13.88	2.36
Average 2013	31.68	10.04	11.76	1.30
Average 2012	30.53	9.96	11.16	1.23
Average 2011	31.65	10.36	11.47	1.68
Average 2010	32.33	10.41	13.01	1.76
Average 2009	31.44	9.88	11.58	
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	0.00
Site 2 Spot 2 Engraving				
Average 2016	44.43	10.46	20.25	0.22
Average 2015	44.44	10.66	20.34	0.82
Average 2014	45.08	11.00	20.72	1.53
Average 2013	43.89	11.96	20.80	0.85
Average 2012	44.14	11.19	20.52	0.43
Average 2011	44.44	10.99	20.76	0.79
Average 2010	44.68	11.58	21.24	1.27
Average 2009	45.12	12.68	21.68	
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	0.00
Site 2 Spot 2 Background				
Average 2016	27.77	9.80	9.36	1.86
Average 2015	28.63	10.81	10.66	0.28
Average 2014	28.80	11.02	10.57	1.07
Average 2013	28.72	10.14	9.96	1.34
Average 2012	29.60	10.55	10.89	1.03

Average 2011	28.86	11.27	10.88	0.53
Average 2010	29.37	11.26	11.01	1.40
Average 2009	29.80	12.46	11.60	
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	0.00
Site 2 Spot 3 Engraving				
Average 2016	42.50	10.53	19.69	0.11
Average 2015	42.42	10.50	19.62	4.21
Average 2014	39.24	13.20	20.18	1.81
Average 2013	39.50	11.63	19.31	1.69
Average 2012	41.07	12.02	19.81	2.19
Average 2011	42.79	10.67	19.83	3.25
Average 2010	40.16	12.56	20.13	3.62
Average 2009	43.29	10.74	19.94	
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	0.00
Site 2 Spot 3 Background				
Average 2016	31.83	13.18	17.07	0.83
Average 2015	31.12	12.81	16.85	0.80
Average 2014	30.96	13.58	16.97	1.43
Average 2013	30.21	12.54	16.33	0.58
Average 2012	29.67	12.63	16.16	1.38
Average 2011	30.88	12.85	16.79	1.26
Average 2010	31.72	13.52	17.46	1.19
Average 2009	30.85	13.06	16.78	
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	0.00
Site 2 Spot 4 Engraving				
Average 2016	42.53	14.74	21.78	0.71
Average 2015	42.06	14.26	21.58	2.08
Average 2014	41.88	16.17	22.38	1.73
Average 2013	41.73	14.62	21.63	
Site 2 Spot 4 Background				
Average 2016	38.42	20.97	22.88	3.26
Average 2015	35.69	19.52	21.86	0.39
Average 2014	36.00	19.32	21.73	2.67
Average 2013	38.12	20.61	22.72	

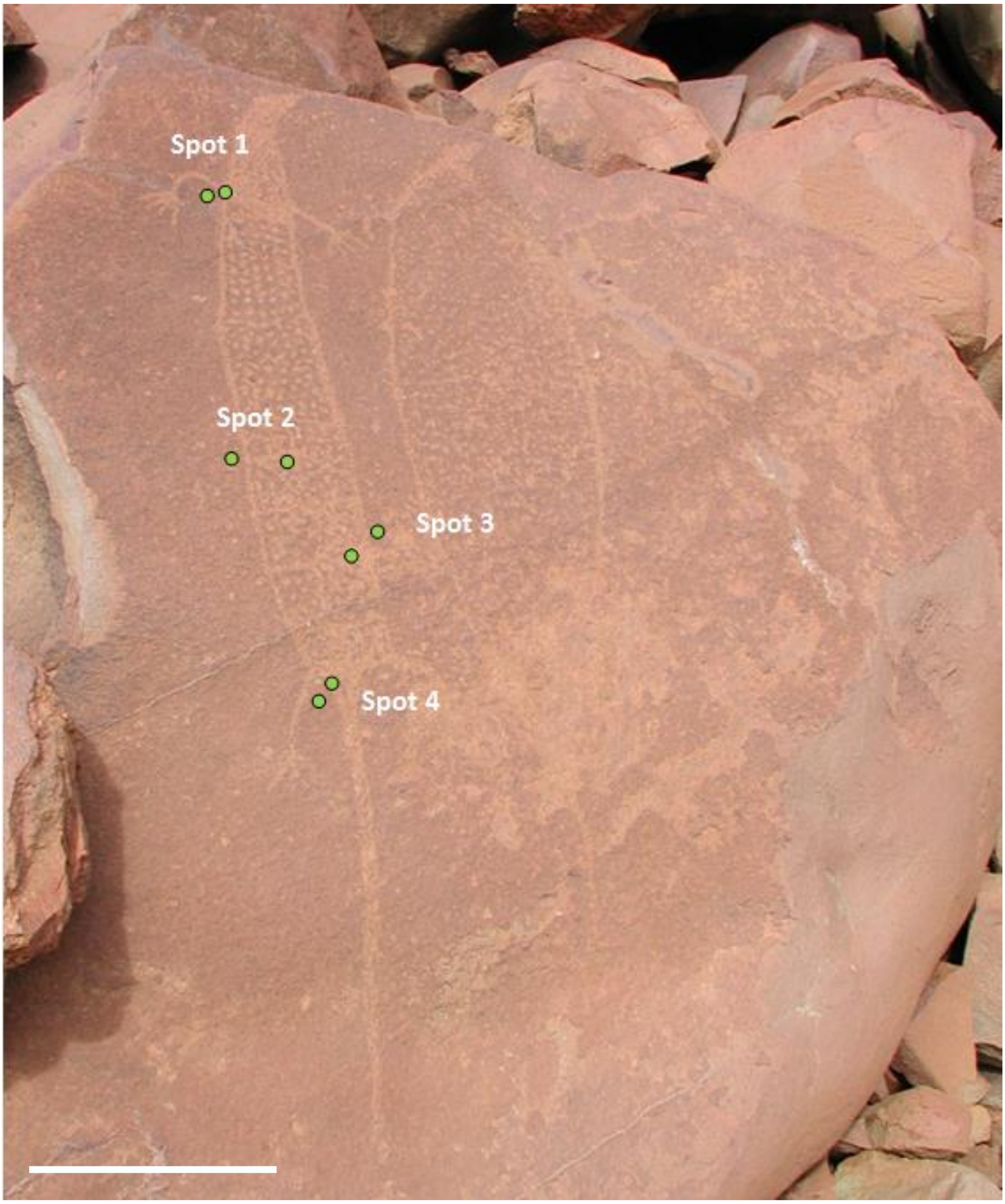


Figure 8: Site 4 – Woodside (White scale bar is 10 cm).

Table 6: Average Colour Measurements for Site 4 – Woodside (2004 – 2016).
Note: KM measurements are in red. No comparison calculated for 2008-09 due to change of instrument.

Sample	Colour scale L*	a*	b*	Colour difference* ΔE (change from previous year)
Site 4 Spot 1 Engraving				
Average 2016	34.20	15.65	18.38	0.97
Average 2015	34.00	16.41	18.95	0.81
Average 2014	33.85	16.02	18.26	0.90
Average 2013	34.34	16.21	18.99	0.74
Average 2012	34.10	15.89	18.37	0.84
Average 2011	34.20	16.31	19.09	0.28
Average 2010	34.33	16.12	18.93	4.10
Average 2009	38.09	16.75	20.46	
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	0.00
Site 4 Spot 1 Background				
Average 2016	29.51	13.38	13.91	0.55
Average 2015	29.88	13.68	14.19	0.86
Average 2014	29.15	13.48	13.77	0.92
Average 2013	30.01	13.52	14.11	0.65
Average 2012	30.57	13.68	14.39	0.30
Average 2011	30.37	13.89	14.48	0.43
Average 2010	30.77	13.81	14.60	3.03
Average 2009	33.53	14.64	15.53	
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	0.00
Site 4 Spot 2 Engraving				
Average 2016	33.50	15.71	18.55	0.86
Average 2015	32.98	15.75	17.86	0.97
Average 2014	32.09	15.96	18.20	1.47
Average 2013	33.33	15.16	18.23	0.64
Average 2012	32.69	15.25	18.31	1.40
Average 2011	33.94	15.89	18.34	0.57
Average 2010	33.90	15.66	17.83	0.66
Average 2009	34.55	15.74	17.82	
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	0.00
Site 4 Spot 2 Background				
Average 2016	30.60	13.48	14.34	1.81
Average 2015	31.64	14.52	15.39	0.77
Average 2014	31.92	14.07	14.84	0.80
Average 2013	32.69	14.17	15.05	0.65
Average 2012	32.39	14.58	15.47	0.77

Average 2011	31.68	14.39	15.24	1.88
Average 2010	33.19	14.90	16.24	1.65
Average 2009	32.34	14.33	14.95	
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	0.00
Site 4 Spot 3 Engraving				
Average 2016	33.25	15.68	18.56	3.84
Average 2015	36.68	16.66	19.99	0.98
Average 2014	35.86	16.36	19.54	1.86
Average 2013	37.39	16.75	20.51	0.67
Average 2012	36.93	16.42	20.17	0.51
Average 2011	37.11	16.78	20.49	0.56
Average 2010	36.89	16.57	20.02	2.75
Average 2009	34.67	15.84	18.57	
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	0.00
Site 4 Spot 3 Background				
Average 2016	32.18	14.48	15.55	1.84
Average 2015	33.46	15.11	16.71	1.60
Average 2014	32.29	14.60	15.74	0.86
Average 2013	33.14	14.63	15.78	1.40
Average 2012	32.10	13.99	15.10	5.15
Average 2011	31.55	13.41	10.01	7.04
Average 2010	33.53	14.97	16.58	3.98
Average 2009	30.84	13.47	14.06	
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	0.00
Site 4 Spot 4 Engraving				
Average 2016	34.20	15.65	18.38	1.67
Average 2015	35.41	16.49	19.17	1.01
Average 2014	35.80	16.64	20.09	0.77
Average 2013	36.32	16.23	19.70	
Site 4 Spot 4 Background				
Average 2016	31.72	13.74	14.93	2.51
Average 2015	33.36	14.86	16.46	1.58
Average 2014	32.60	14.41	15.13	0.83
Average 2013	31.86	14.28	15.49	

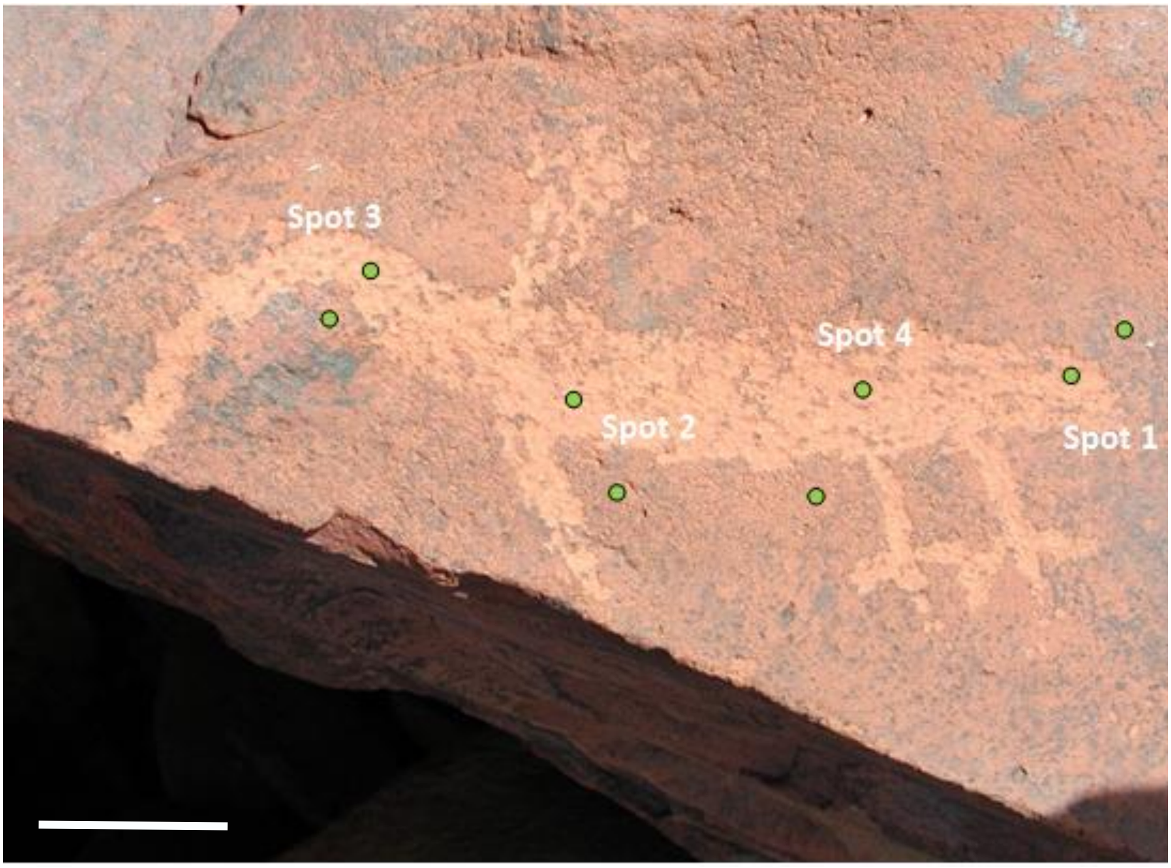


Figure 9: Site 5 – Burrup Road (White scalar is 10 cm).

Table 7: Average Colour Measurements for Site 5 – Burrup Road (2004 – 2016).
Note: KM measurements are in red. No comparison calculated for 2008-09 due to change of instrument.

Sample	Colour scale L*	a*	b*	Colour difference* ΔE (change from previous year)
Site 5 Spot 1 Engraving				
Average 2016	37.71	18.95	22.80	1.08
Average 2015	38.77	19.15	22.81	4.73
Average 2014	36.69	16.83	19.25	0.80
Average 2013	35.93	16.78	19.48	2.83
Average 2012	38.07	17.80	21.02	1.66
Average 2011	38.06	18.67	22.44	0.81
Average 2010	38.74	18.47	22.04	2.52
Average 2009	39.87	19.89	23.79	
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	0.00
Site 5 Spot 1 Background				
Average 2016	35.71	16.58	17.79	2.53
Average 2015	35.17	14.96	15.92	0.72
Average 2014	34.88	14.65	15.33	2.65
Average 2013	35.78	15.77	17.56	3.63
Average 2012	35.08	13.69	14.67	0.52
Average 2011	34.58	13.60	14.52	1.10
Average 2010	35.20	14.08	15.30	3.83
Average 2009	31.40	14.32	14.89	
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	0.00
Site 5 Spot 2 Engraving				
Average 2016	39.07	21.10	24.59	2.50
Average 2015	37.88	19.67	22.92	1.09
Average 2014	38.59	20.21	23.54	3.98
Average 2013	35.15	18.61	22.35	1.96
Average 2012	37.07	18.97	22.30	2.17
Average 2011	38.17	20.31	23.60	1.09
Average 2010	38.26	19.53	22.85	0.68
Average 2009	37.99	19.53	22.22	
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	0.00
Site 5 Spot 2 Background				
Average 2016	29.98	14.55	15.20	0.67
Average 2015	30.65	14.57	15.14	0.42
Average 2014	30.28	14.76	15.20	0.94
Average 2013	31.09	14.44	14.87	0.22
Average 2012	31.16	14.58	15.02	0.24
Average 2011	31.20	14.36	15.11	1.14

Average 2010	32.05	14.77	15.75	0.33
Average 2009	32.16	14.78	15.44	
Average 2008	29.94	13.70	15.58	1.53
Average 2007	29.02	14.63	16.37	2.32
Average 2006	27.19	13.76	15.23	3.61
Average 2005	29.53	15.28	17.53	
Average 2004	No measurements			
Site 5 Spot 3 Engraving				
Average 2016	39.59	19.94	23.68	0.59
Average 2015	39.58	19.36	23.79	1.14
Average 2014	39.00	18.68	23.08	0.86
Average 2013	38.21	18.94	22.85	1.46
Average 2012	39.26	19.66	23.57	0.35
Average 2011	39.26	19.46	23.86	0.75
Average 2010	40.00	19.48	23.94	2.77
Average 2009	39.13	18.51	21.50	
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	0.00
Site 5 Spot 3 Background				
Average 2016	34.70	15.86	17.40	2.55
Average 2015	35.50	14.52	15.38	5.17
Average 2014	32.62	11.61	12.22	1.01
Average 2013	32.53	12.21	13.02	2.61
Average 2012	34.07	13.66	14.55	2.41
Average 2011	34.46	12.52	12.47	5.16
Average 2010	36.45	15.67	16.04	1.50
Average 2009	35.74	14.52	15.39	
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	0.00
Site 5 Spot 4 Engraving				
Average 2016	37.75	19.71	22.83	1.16
Average 2015	37.30	19.09	21.96	0.22
Average 2014	37.27	19.30	22.02	0.49
Average 2013	37.69	19.24	22.26	
Site 5 Spot 4 Background				
Average 2016	33.27	16.71	17.88	1.85
Average 2015	32.51	15.50	16.71	0.53
Average 2014	32.93	15.58	16.40	1.13
Average 2013	32.44	14.87	15.68	

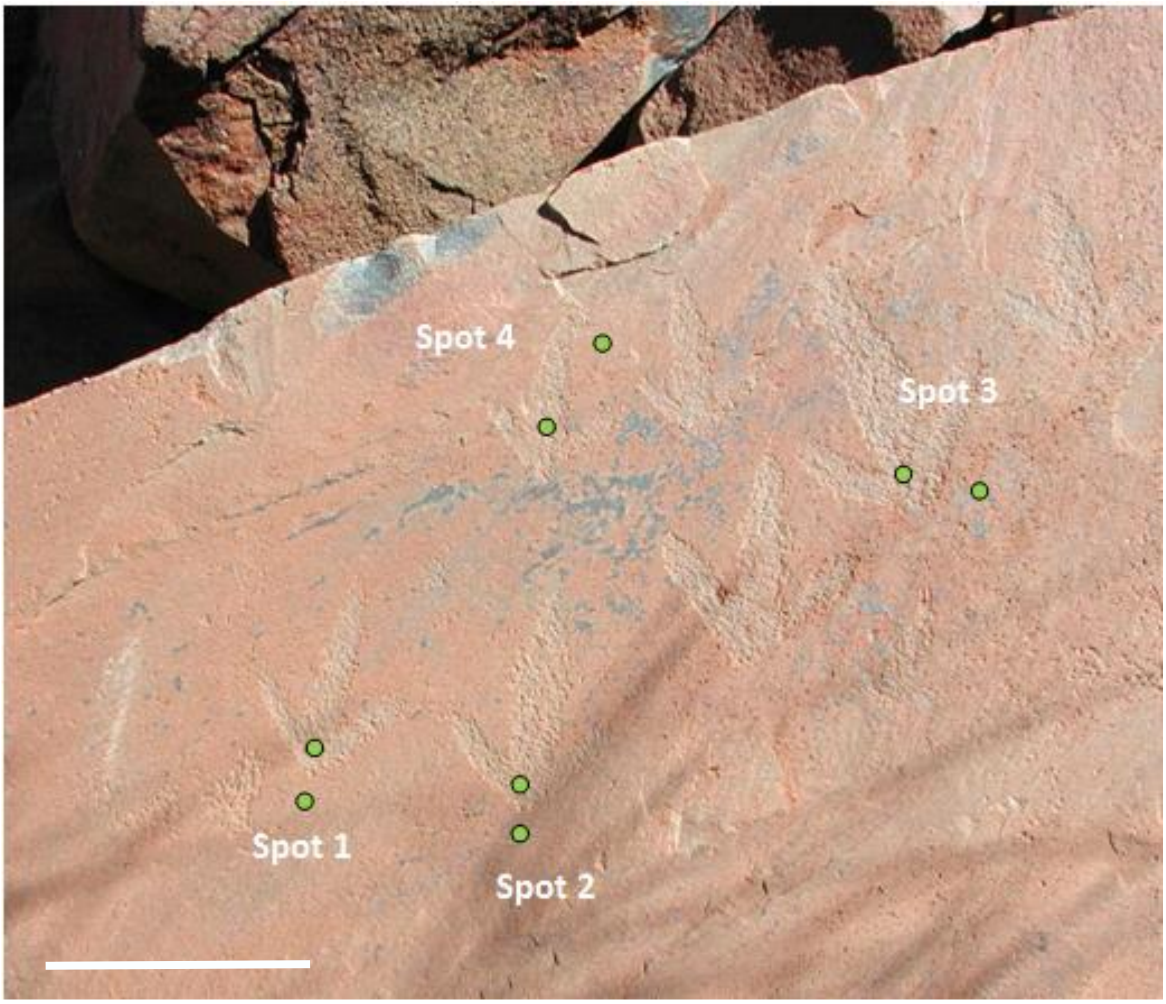


Figure 10: Site 6 – Water Tanks (White scale bar is 10 cm).

Table 8: Average Colour Measurements for Site 6 – Water Tanks (2004 – 2016).
Note: KM measurements are in red. No comparison calculated for 2008-09 due to change of instrument.

Sample	Colour scale L*	Colour scale a*	Colour scale b*	Colour difference* ΔE (change from previous year)
Site 6 Spot 1 Engraving				
Average 2016	40.31	12.23	17.96	1.87
Average 2015	40.76	10.87	16.76	0.48
Average 2014	40.29	10.89	16.68	1.47
Average 2013	40.92	11.80	17.65	0.97
Average 2012	40.64	11.19	16.96	0.28
Average 2011	40.74	11.34	17.17	0.49
Average 2010	40.31	11.51	17.34	0.72
Average 2009	41.00	11.56	17.13	
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	0.00
Site 6 Spot 1 Background				
Average 2016	39.07	13.16	17.50	0.83
Average 2015	39.50	13.66	18.00	1.29
Average 2014	39.47	12.75	17.08	0.25
Average 2013	39.24	12.65	17.11	0.81
Average 2012	39.45	13.27	17.60	0.60
Average 2011	38.87	13.17	17.45	0.73
Average 2010	39.46	13.51	17.72	0.28
Average 2009	39.61	13.34	17.57	
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	0.00
Site 6 Spot 2 Engraving				
Average 2016	39.25	11.57	16.85	0.91
Average 2015	39.87	10.99	16.53	1.29
Average 2014	39.24	11.96	17.10	0.90
Average 2013	39.86	11.36	16.85	1.09
Average 2012	38.83	11.70	16.91	1.19
Average 2011	39.97	11.39	16.79	0.40
Average 2010	39.64	11.48	16.99	0.64
Average 2009	40.09	11.47	16.54	
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	0.00
Site 6 Spot 2 Background				
Average 2016	37.83	13.38	16.88	1.14
Average 2015	37.79	12.57	16.08	1.73
Average 2014	37.08	12.16	15.21	2.14
Average 2013	38.52	12.80	16.66	1.39
Average 2012	37.91	12.14	15.61	1.93
Average 2011	38.33	13.45	16.96	0.55

Average 2010	38.01	13.23	16.57	1.37
Average 2009	38.49	12.33	15.64	
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	0.00
Site 6 Spot 3 Engraving				
Average 2016	39.08	11.95	16.95	2.05
Average 2015	39.48	10.53	15.52	1.60
Average 2014	38.18	11.36	15.93	0.86
Average 2013	38.92	11.68	16.22	0.76
Average 2012	39.31	11.02	16.17	0.74
Average 2011	38.72	11.45	16.03	0.36
Average 2010	38.53	11.62	16.29	11.46
Average 2009 (bird droppings on spot)*	48.77	7.27	13.53	
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	0.00
Site 6 Spot 3 Background				
Average 2016	38.26	13.06	16.63	2.34
Average 2015	37.32	14.62	18.10	3.89
Average 2014	38.72	11.79	15.83	1.62
Average 2013	38.48	13.00	16.88	0.33
Average 2012	38.55	13.33	16.93	1.48
Average 2011	38.91	12.00	16.39	0.63
Average 2010	38.65	12.30	15.90	1.20
Average 2009	38.57	13.30	16.55	
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	0.00
Site 6 Spot 4 Engraving				
Average 2016	40.48	11.45	16.89	1.29
Average 2015	40.26	10.58	15.97	1.13
Average 2014	39.47	11.26	16.42	1.68
Average 2013	41.12	10.97	16.58	
Site 6 Spot 4 Background				
Average 2016	39.41	13.24	16.77	2.11
Average 2015	39.95	14.24	18.55	2.41
Average 2014	38.94	13.10	16.68	0.68
Average 2013	39.43	13.37	17.05	

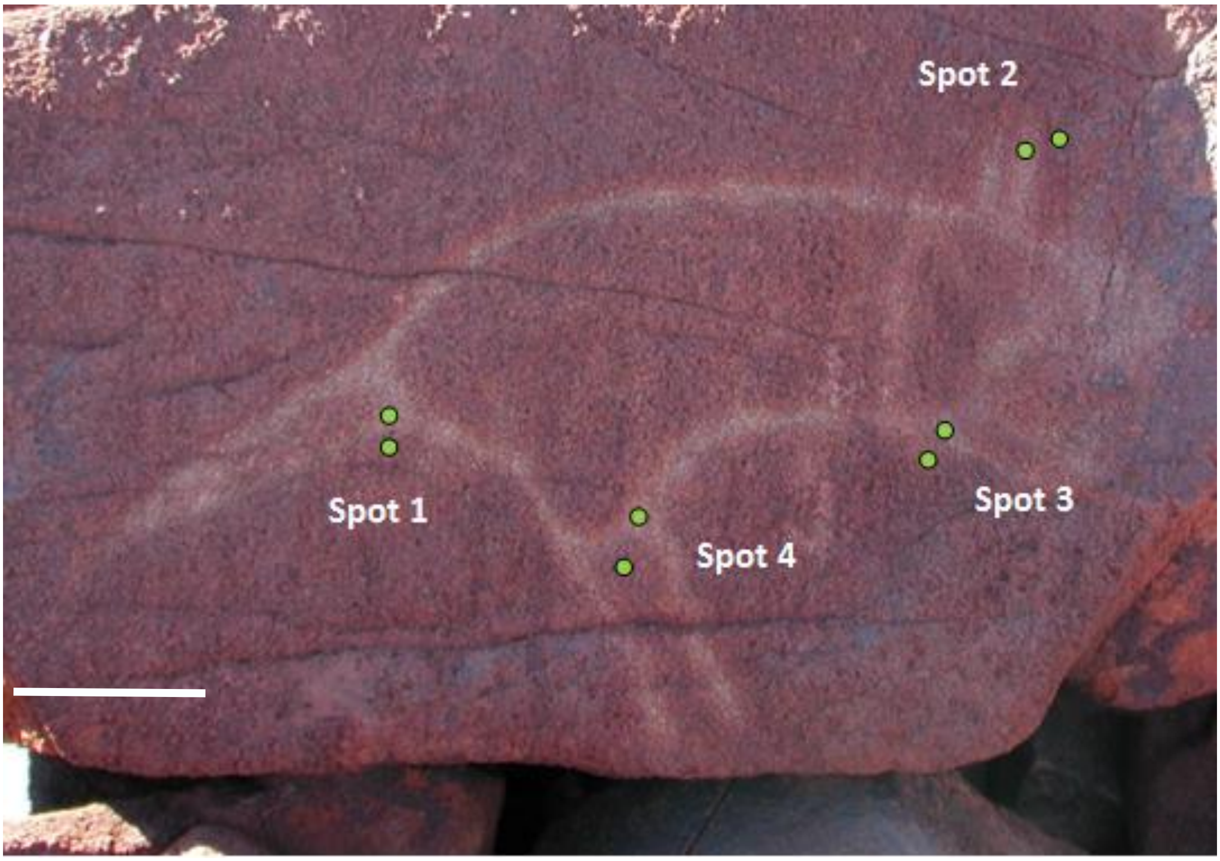


Figure 11: Site 7 – Deep Gorge (White scale bar is 25 cm).

Table 9: Average Colour Measurements for Site 7 – Deep Gorge (2004 – 2016).
Note: KM measurements are in red. No comparison calculated for 2008-09 due to change of instrument.

Sample	Colour scale L*	a*	b*	Colour difference* ΔE (change from previous year)
Site 7 Spot 1 Engraving				
Average 2016	38.23	14.54	19.07	1.29
Average 2015	37.24	14.11	18.36	0.29
Average 2014	37.24	14.40	18.37	3.10
Average 2013	34.24	13.87	17.79	0.95
Average 2012	35.06	14.19	18.15	2.77
Average 2011	37.71	14.56	18.85	1.40
Average 2010	39.05	14.76	19.20	2.54
Average 2009	36.54	14.77	18.82	
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	0.00
Site 7 Spot 1 Background				
Average 2016	28.18	13.19	13.99	3.54
Average 2015	25.67	11.61	12.06	7.88
Average 2014	31.05	15.58	16.21	3.14
Average 2013	29.54	13.15	14.93	0.75
Average 2012	29.18	13.81	14.96	1.42
Average 2011	27.90	13.79	14.34	1.04
Average 2010	28.73	14.07	14.89	1.14
Average 2009	29.81	13.97	15.25	
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	0.00
Site 7 Spot 2 Engraving				
Average 2016	34.34	14.28	17.14	0.99
Average 2015	33.98	13.78	16.37	3.12
Average 2014	31.22	15.24	16.45	1.95
Average 2013	32.87	14.21	16.49	1.73
Average 2012	33.76	12.98	15.66	2.57
Average 2011	33.90	15.17	17.00	0.29
Average 2010	33.84	14.90	17.10	0.94
Average 2009	34.65	15.29	17.38	
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	0.00
Site 7 Spot 2 Background				
Average 2016	26.31	12.23	12.36	2.33
Average 2015	28.62	12.48	12.53	1.29
Average 2014	27.38	12.73	12.27	0.91
Average 2013	27.39	12.91	13.16	4.30
Average 2012	31.50	13.70	14.17	2.90
Average 2011	28.99	14.85	15.06	1.80

Average 2010	30.76	14.52	14.98	1.96
Average 2009	30.27	16.07	16.09	
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	0.00
Site 7 Spot 3 Engraving				
Average 2016	31.90	14.18	16.29	2.38
Average 2015	33.77	12.88	15.59	1.76
Average 2014	32.53	14.04	16.07	1.60
Average 2013	34.09	14.02	16.40	1.02
Average 2012	34.29	13.18	15.84	1.72
Average 2011	35.02	14.46	16.72	0.84
Average 2010	35.67	13.94	16.56	2.13
Average 2009	33.55	13.80	16.35	
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	
Average 2004	No measurements			
Site 7 Spot 3 Background				
Average 2016	30.69	14.81	15.91	6.20
Average 2015	26.65	11.74	12.34	5.46
Average 2014	30.38	14.52	15.19	0.95
Average 2013	30.87	14.55	16.01	2.03
Average 2012	29.65	13.66	14.65	3.37
Average 2011	26.88	12.44	13.19	0.89
Average 2010	27.76	12.45	13.09	1.88
Average 2009	26.11	11.90	12.37	
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	0.00
Site 7 Spot 4 Engraving				
Average 2016	36.03	14.82	18.44	0.91
Average 2015	35.68	14.05	18.11	0.79
Average 2014	35.81	14.81	18.28	2.47
Average 2013	38.03	15.29	19.25	
Site 7 Spot 4 Background				
Average 2016	28.48	11.53	12.47	2.93
Average 2015	29.52	13.65	14.20	3.07
Average 2014	27.38	12.07	12.65	3.27
Average 2013	30.26	12.88	13.97	

Figure 12: Site 8 – King Bay South (Colour chart on rock is 10 cm).

Table 10: Average Colour Measurements for Site 8 – King Bay South (2004 – 2016).
Note: KM measurements are in red. No comparison calculated for 2008-09 due to change of instrument.

Sample	Colour scale			Colour difference* ΔE (change from previous year)
	L*	a*	b*	
Site 8 Spot 1 Engraving				
Average 2016	38.28	16.20	18.10	6.20
Average 2015	33.97	13.41	14.62	1.39
Average 2014	35.05	14.20	14.99	1.01
Average 2013	35.76	14.25	15.70	1.41
Average 2012	34.52	14.22	16.37	1.92
Average 2011	34.93	13.37	14.69	3.22
Average 2010	36.47	15.05	16.96	4.45
Average 2009	36.47	16.58	21.14	
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	0.00
Site 8 Spot 1 Background				
Average 2016	34.20	12.78	13.41	1.55
Average 2015	33.31	12.23	12.26	0.64
Average 2014	32.91	12.17	11.76	0.62
Average 2013	32.75	11.93	12.31	0.73
Average 2012	32.26	11.79	12.84	0.95
Average 2011	32.82	11.97	12.09	0.20
Average 2010	32.78	11.99	12.29	5.66
Average 2009	32.57	15.21	16.94	
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	0.00
Site 8 Spot 2 Engraved				
Average 2016	36.46	14.41	16.07	1.80
Average 2015	35.70	13.93	14.51	0.73
Average 2014	35.99	14.51	14.84	1.26
Average 2013	36.38	14.88	15.98	1.04
Average 2012	35.57	14.32	15.64	0.62
Average 2011	35.87	14.32	15.10	1.20
Average 2010	34.79	13.88	14.82	0.71
Average 2009	35.43	13.82	14.52	
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	0.00
Site 8 Spot 2 Background				
Average 2016	33.74	12.30	12.75	2.78
Average 2015	31.52	11.33	11.39	0.27
Average 2014	31.63	11.39	11.14	1.25
Average 2013	32.42	11.72	12.05	0.57
Average 2012	32.54	11.19	11.87	0.87
Average 2011	32.17	11.93	12.17	0.31

Average 2010	32.33	12.02	12.42	0.80
Average 2009	33.08	11.91	12.16	
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	0.00
Site 8 Spot 3 Engraved				
Average 2016	34.16	15.81	19.79	1.30
Average 2015	35.23	16.24	20.38	1.61
Average 2014	34.09	15.74	19.36	0.79
Average 2013	33.35	15.46	19.45	0.55
Average 2012	32.85	15.23	19.44	2.13
Average 2011	34.80	16.06	19.64	2.23
Average 2010	32.95	15.46	18.54	4.19
Average 2009	34.73	13.81	15.14	
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	0.00
Site 8 Spot 3 Background				
Average 2016	30.93	13.52	15.05	0.66
Average 2015	30.32	13.63	14.85	0.31
Average 2014	30.14	13.48	14.64	0.60
Average 2013	30.73	13.52	14.69	0.98
Average 2012	31.32	13.62	15.47	2.75
Average 2011	32.51	15.12	17.45	0.62
Average 2010	32.11	14.65	17.36	5.78
Average 2009	33.28	12.07	12.32	
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	0.00
Site 8 Spot 4 Engraved				
Average 2016	34.50	15.60	18.49	0.84
Average 2015	33.70	15.66	18.73	0.20
Average 2014	33.65	15.66	18.53	1.08
Average 2013	34.11	15.20	17.67	
Site 8 Spot 4 Background				
Average 2016	30.50	12.83	14.16	0.32
Average 2015	30.48	12.64	13.90	0.80
Average 2014	30.89	13.15	14.35	0.29
Average 2013	30.68	12.94	14.32	

Figure 13: Site 21 – Yara West (Colour chart on rock is 10 cm).

Table 11: Average Colour Measurements for Site 21- Yara West (2014 Feb - 2016).

Sample	Colour scale L*	a*	b*	Colour difference* ΔE (change from previous year)
Site 21 Spot 1 Engraving				
Average 2016	38.99	17.45	22.80	1.10
Average 2015	39.99	17.03	22.59	1.05
Average 2014 (July)	39.07	17.29	22.14	1.59
Average 2014 (February)	38.04	16.35	21.38	0.00
Site 21 Spot 1 Background				
Average 2016	32.08	14.59	15.12	2.78
Average 2015	31.68	13.62	12.55	1.73
Average 2014 (July)	32.85	14.03	13.75	1.37
Average 2014 (February)	31.59	13.76	13.26	0.00
Site 21 Spot 2 Engraving				
Average 2016	36.93	15.31	20.73	2.09
Average 2015	38.94	15.70	21.17	1.61
Average 2014 (July)	37.55	15.55	20.36	1.52
Average 2014 (February)	36.08	15.33	20.04	0.00
Site 21 Spot 2 Background				
Average 2016	33.59	14.47	16.81	1.22
Average 2015	34.50	13.97	16.17	0.62
Average 2014 (July)	34.94	14.40	16.13	1.19
Average 2014 (February)	33.77	14.19	16.23	0.00
Site 21 Spot 3 Engraving				
Average 2016	38.01	17.71	22.49	0.74
Average 2015	38.67	17.47	22.71	0.52
Average 2014 (July)	38.54	17.96	22.82	2.56
Average 2014 (February)	38.57	16.01	21.17	0.00
Site 21 Spot 3 Background				
Average 2016	31.16	13.97	15.99	1.20
Average 2015	31.09	13.48	14.90	1.19
Average 2014 (July)	31.95	14.23	15.22	0.63
Average 2014 (February)	31.56	13.99	15.64	0.00
Site 21 Spot 4 Engraving				
Average 2016	37.42	15.69	20.44	1.41
Average 2015	38.83	15.60	20.47	0.29
Average 2014 (July)	38.71	15.71	20.23	2.80
Average 2014 (February)	37.41	17.28	22.16	0.00
Site 21 Spot 4 Background				
Average 2016	32.50	13.51	15.78	1.73
Average 2015	32.60	12.92	14.16	1.07
Average 2014 (July)	32.89	13.69	14.83	2.16
Average 2014 (February)	31.53	12.39	13.77	0.00

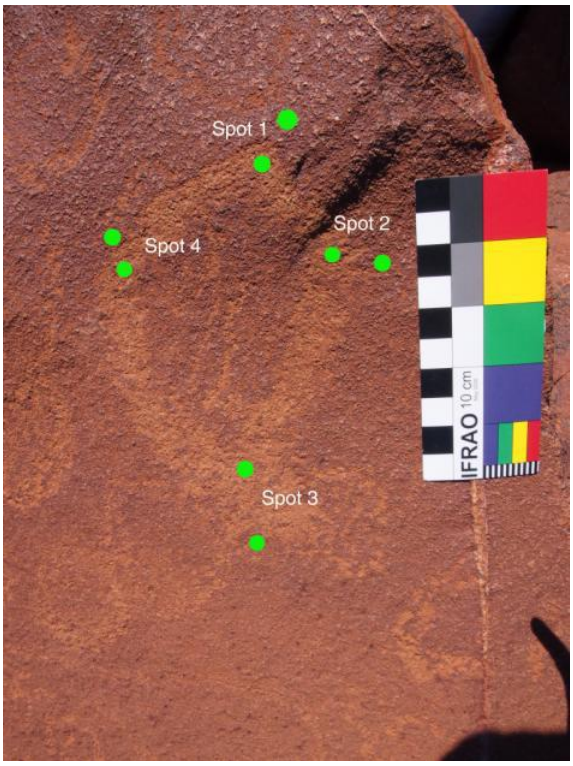


Figure 14: Site 22 – Yara North East (Colour chart on rock is 10 cm).

Table 12: Average Colour Measurements for Site 22 – Yara North East (2014 Feb - 2016).

Sample	Colour scale L*	a*	b*	Colour difference* ΔE (change from previous year)
Site 22 Spot 1 Engraving				
Average 2016	36.15	13.38	17.38	1.18
Average 2015	37.30	13.46	17.62	2.30
Average 2014 (July)	39.12	13.54	19.02	2.91
Average 2014 (February)	36.82	13.54	17.23	0.00
Site 22 Spot 1 Background				
Average 2016	33.15	12.05	12.53	0.48
Average 2015	32.76	12.10	12.26	1.38
Average 2014 (July)	34.08	12.21	12.63	0.39
Average 2014 (February)	33.80	12.11	12.37	0.00
Site 22 Spot 2 Engraving				
Average 2016	33.72	13.75	16.62	3.74
Average 2015	36.57	14.31	18.97	0.60
Average 2014 (July)	37.08	14.33	18.65	2.60
Average 2014 (February)	35.15	13.64	17.04	0.00
Site 22 Spot 2 Background				
Average 2016	29.70	12.18	13.41	3.51
Average 2015	33.12	12.54	14.10	0.78
Average 2014 (July)	33.85	12.72	13.90	1.54
Average 2014 (February)	32.32	12.52	14.00	0.00
Site 22 Spot 3 Engraving				
Average 2016	35.99	14.19	18.02	2.94
Average 2015	38.43	14.61	19.60	0.17
Average 2014 (July)	38.34	14.49	19.51	1.71
Average 2014 (February)	37.11	14.41	18.33	0.00
Site 22 Spot 3 Background				
Average 2016	32.77	12.93	14.71	2.09
Average 2015	34.66	13.37	15.48	2.08
Average 2014 (July)	33.71	12.53	13.82	0.53
Average 2014 (February)	34.06	12.75	14.15	0.00
Site 22 Spot 4 Engraving				
Average 2016	32.54	13.50	16.98	7.04
Average 2015	39.09	14.05	19.51	3.47
Average 2014 (July)	36.12	13.99	17.71	1.43
Average 2014 (February)	37.32	14.11	18.48	0.00
Site 22 Spot 4 Background				
Average 2016	31.22	11.54	12.13	2.61
Average 2015	33.71	12.05	12.71	0.74
Average 2014 (July)	33.96	12.41	13.31	1.07
Average 2014 (February)	33.63	11.92	12.42	0.00

Figure 15: Site 23 – Yara East (Colour chart on rock is 10 cm).

Table 13: Average Colour Measurements for Site 23 - Yara East (2014 Feb - 2016).

Sample	Colour scale L*	Colour scale a*	Colour scale b*	Colour difference* ΔE (change from previous year)
Site 23 Spot 1 Engraving				
Average 2016	38.74	10.21	17.49	0.26
Average 2015	38.69	10.26	17.74	2.66
Average 2014 (July)	36.71	9.61	16.09	1.72
Average 2014 (February)	38.39	9.59	16.49	0.00
Site 23 Spot 1 Background				
Average 2016	33.90	11.71	15.45	1.80
Average 2015	34.77	10.52	14.41	1.45
Average 2014 (July)	34.54	11.54	15.42	1.00
Average 2014 (February)	35.16	12.08	16.00	0.00
Site 23 Spot 2 Engraving				
Average 2016	35.40	13.19	19.56	1.23
Average 2015	34.49	12.78	18.84	2.10
Average 2014 (July)	32.86	11.53	18.35	2.93
Average 2014 (February)	35.36	12.90	19.05	0.00
Site 23 Spot 2 Background				
Average 2016	34.59	13.58	17.48	2.04
Average 2015	36.34	13.17	18.45	1.39
Average 2014 (July)	37.26	14.00	19.05	0.43
Average 2014 (February)	36.93	14.28	19.04	0.00
Site 23 Spot 3 Engraving				
Average 2016	37.54	10.56	16.75	0.36
Average 2015	37.84	10.76	16.71	0.59
Average 2014 (July)	37.71	10.69	17.28	0.48
Average 2014 (February)	38.17	10.72	17.42	0.00
Site 23 Spot 3 Background				
Average 2016	34.03	14.18	18.01	4.09
Average 2015	31.34	13.20	15.09	1.50
Average 2014 (July)	31.86	14.14	16.13	0.70
Average 2014 (February)	31.70	13.65	15.65	0.00
Site 23 Spot 4 Engraving				
Average 2016	38.45	9.91	16.94	1.03
Average 2015	37.48	10.24	16.80	0.78
Average 2014 (July)	37.82	10.65	17.36	1.47
Average 2014 (February)	36.39	10.94	17.20	0.00
Site 23 Spot 4 Background				
Average 2016	35.57	9.67	13.24	0.66
Average 2015	35.22	9.45	12.72	4.27
Average 2014 (July)	32.12	7.46	10.56	3.24
Average 2014 (February)	31.61	9.92	12.60	0.00

The averaged colour change for each site is presented in Table 14, which is an overall average for each of the six spots measured on a petroglyph, with data from the additional fourth engraving and background spot included in 2014, 2015 and 2016 results[1]. The colour change for both the Southern and Northern sites for the period are reasonably consistent over the measurement period. At any given time interval, the

[1] Spot 4 has not been included prior to 2014 as initial measurements were taken in 2013, therefore no colour change for previous years could be calculated.

average change at the Southern and Northern sites are comparable, indicating that accelerated weathering at Southern sites within close proximity to industrial complexes was not observed.

Table 14: Averaged colour change for each site.
Note: KM measurements are in red. No comparison calculated for 2008-09 due to change of instrument.
***Comparison of 2004 with 2016 used 2004 BYK data converted to be comparable with KM data.**

Site	Averaged site-specific colour change												
	ΔE 15-16	ΔE 14-15	ΔE 13–14	ΔE 12–13	ΔE 11–12	ΔE 10–11	ΔE 09–10	ΔE 08–09	ΔE 07–08	ΔE 06–07	ΔE 05–06	ΔE 04–05	ΔE 04–16*
4	**1.75**	**0.94**	**0.93**	0.79	1.50	1.79	2.70		2.90	2.42	2.34	1.29	11.10
5	**1.61**	**1.80**	**1.48**	2.12	1.23	1.68	1.94		3.22	6.95	4.98	4.29	13.88
6	**1.56**	**1.13**	**1.20**	0.89	1.04	0.53	2.61		1.42	1.58	2.23	2.61	13.78
7	**2.57**	**1.49**	**2.17**	1.80	2.46	1.04	1.76		3.78	7.58	9.00	10.58	9.34
8	**1.93**	**0.98**	**0.86**	0.88	1.54	1.30	3.60		2.30	2.94	4.09	3.99	11.76
21	**1.53**	**0.87**	**1.73**										
22	**2.92**	**1.64**	**1.35**										
23	**1.43**	**1.53**	**1.50**										
Overall southern sites average	1.91	1.30	1.40	1.30	1.55	1.27	2.51		2.72	4.30	4.53	4.55	11.97
1	**1.98**	**2.69**	**1.87**	2.15	1.60	1.37	1.16		4.06	4.50	3.43	2.88	13.54
2	**1.71**	**3.18**	**1.82**	1.03	1.59	1.31	2.30		4.01	2.38	2.88	3.56	14.06
Overall northern sites average	1.85	2.93	1.84	1.59	1.59	1.34	1.73		4.05	3.44	3.16	3.22	13.80

The thirteen 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; it has also allowed 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 2004–16, which indicates the colour change over the thirteen-year interval from 2004 to 2016, site 7 consistently displayed the greatest year-to-year colour change up to 2009. For sites 4, 6 and 8 (southern), the colour change values for the interval 2004–16 were comparable to or lower than those of the northern sites 1 and 2. With the northern sites as the control sites, and the southern sites as test sites, there were no indications that changes at both sites were 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. This is supported by the improvement in the consistency of the results at these sites from 2009 onwards, where the new Konica Minolta spectrophotometer, with an improved head configuration, was deployed for data collection. At site 5, spot 3 there is a large patch of black patina (see Figure 9) 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 10), however, did not consistently record the lowest colour change values so measurement repeatability is therefore dependent on more than just surface roughness.

The 2016 data for sites 21, 22 and 23 all show average colour change values that are similar to those of the northern control sites, and are comparable to Sites 5, 6 and 7, which form part of the monitoring for the Yara Pilbara Nitrates Pty Ltd (YPNPL) Technical Ammonium Nitrate Production Facility Project.

Table 15: Colour difference between background and petroglyph
Note: KM measurements are in red.

Spot 1	Site 1	Site 2	Site 4	Site 5	Site 6	Site 7	Site 8	Site 21	Site 22	Site 23
Average 2016	**10.5**	**16.8**	**7.0**	**5.9**	**1.6**	**11.3**	**7.1**	**10.7**	**5.9**	**5.5**
Average 2015	**12.8**	**12.7**	**6.9**	**8.8**	**3.3**	**13.4**	**2.7**	**13.4**	**7.2**	**5.1**
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
Average 2012	12.3	10.9	5.8	8.1	2.5	6.7	4.8			
Average 2011	12.2	13.1	6.5	10.0	2.6	10.8	3.6			
Average 2010	11.3	12.0	6.1	8.8	2.2	11.2	6.7			
Average 2009	10.5	9.0	7.0	13.5	2.3	7.7	5.9			
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 2016	**8.9**	**19.9**	**5.6**	**14.6**	**2.3**	**9.6**	**4.8**	**5.2**	**5.4**	**2.3**
Average 2015	**9.3**	**18.5**	**3.1**	**11.8**	**2.6**	**6.7**	**5.8**	**6.9**	**6.2**	**1.9**
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
Average 2012	7.2	17.5	2.9	10.4	1.7	2.8	5.8			
Average 2011	11.8	18.5	4.1	12.5	2.6	5.3	5.3			
Average 2010	7.6	18.4	1.9	10.6	2.4	3.8	3.9			
Average 2009	10.7	18.3	3.9	10.1	2.0	4.6	3.8			
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	0.0	2.6	23.4	5.5			
Spot 3										
Average 2016	**15.5**	**11.3**	**3.4**	**8.9**	**1.4**	**1.4**	**6.2**	**10.2**	**4.8**	**5.2**
Average 2015	**13.9**	**11.8**	**4.8**	**10.5**	**5.2**	**7.9**	**7.8**	**11.7**	**5.7**	**7.1**
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
Average 2012	12.2	12.0	7.4	12.0	2.5	4.8	4.5			
Average 2011	12.4	12.5	12.3	14.2	0.7	9.1	3.3			
Average 2010	12.9	8.9	5.1	9.5	0.8	8.8	1.7			
Average 2009	13.7	13.0	6.4	8.1	12.2	8.7	3.6			
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	0.0	6.3			
Spot 4										
Average 2016	**10.7**	**7.5**	**4.7**	**7.3**	**2.1**	**10.2**	**6.5**	**7.1**	**5.4**	**4.7**
Average 2015	**14.3**	**8.3**	**3.8**	**8.0**	**4.5**	**7.3**	**6.5**	**9.3**	**8.9**	**4.7**
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 spectrometer. These systems measure diagnostic mineral spectral features that are particularly suitable for qualitative analysis of many geological materials. Some of the advantages of the technique include little sample preparation (if any), and rapid measurement (1 to 5 seconds) 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; 2015 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 based on 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 ASD covers the spectral range 350-2500 nm with a spectral resolution of three nm at 700 nm using three detectors: a 512 element Si photodiode array for the 400-1000 nm range and two separate, thermo-electrically cooled, graded index InGaAs photodiodes for the 1000-2500 nm range. The input is through a 1.4 m fibre optic. The average scanning time to acquire a spectrum is 1 second. There are two ways of operating the ASD spectroradiometer, 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. The area measured by the ASD spectrometer is 3.14 cm^2.

5.2 Spectral Results for 2004-2016

5.2.1 PICTURES AND SPECTRA

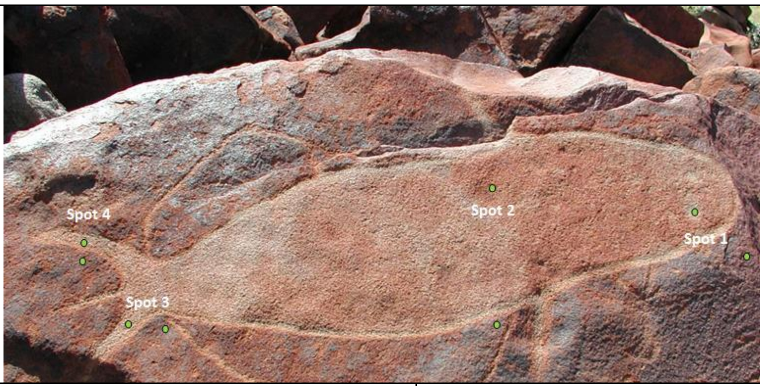
For each site, the description and interpretation include:

- A digital image of the engraving with the location of the measurements: spot 1, 2, and 3 and, from 2013 a new spot labelled 4 for both engraving and background. The new 4th engraving and background analysis spots have been added to the photographs.
- A comparison of the average spectra for the engravings and background for each of the three (or four) spots between 2004 and 2016.
- 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.

Figure 16: ASD FieldSpecPro and Konica Minolta CM-700dspectrophotometer operating on petroglyphs in the Burrup Peninsula (2013)

All the historical data collected for the all the spectrometers have been systematically archived and were sent to DER with consistent naming conventions, in a data format that is easily read by standard statistical software.

Site 1



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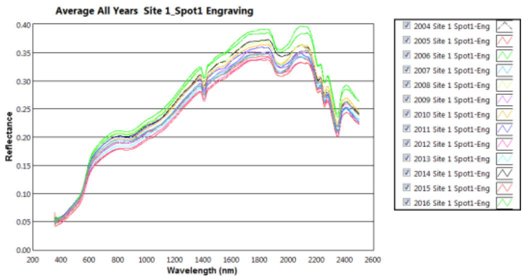
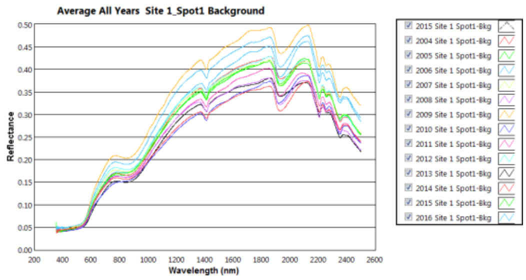
Spot 1





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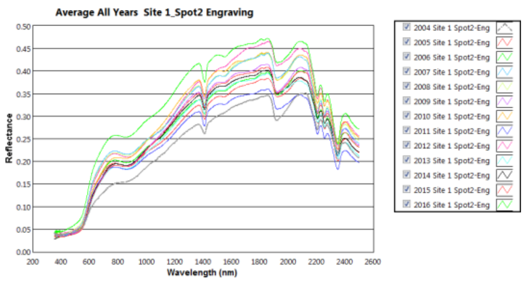
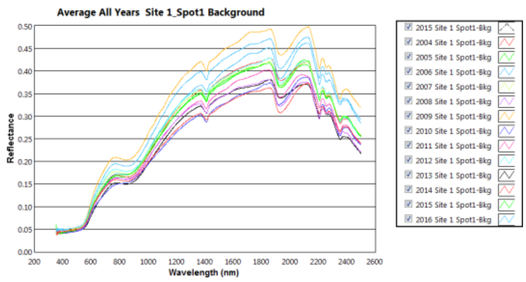
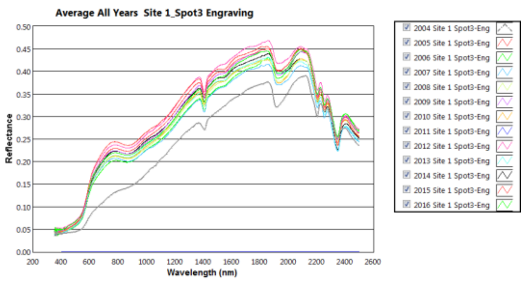
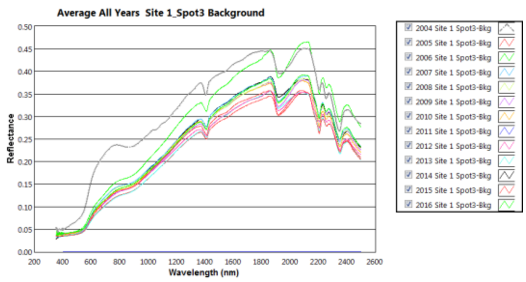
Spot 2





Site 1
Spot 3





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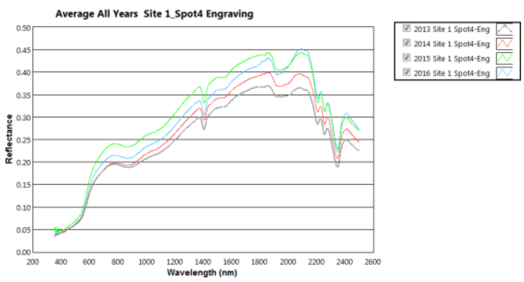
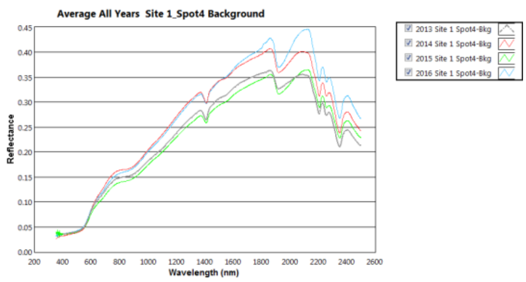
Spot 4





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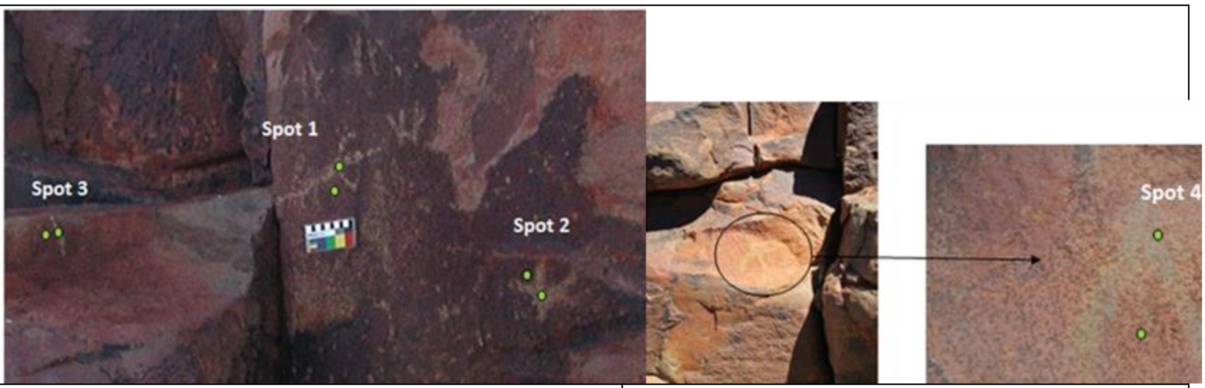

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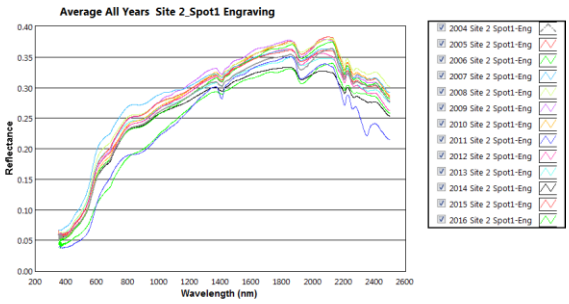

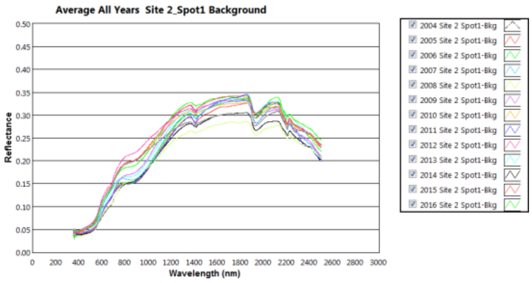

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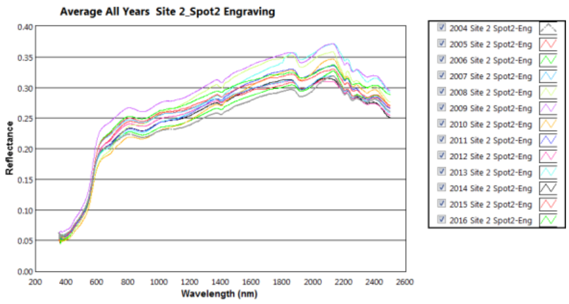
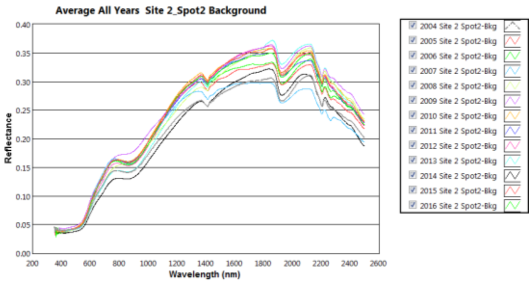
Spot 2





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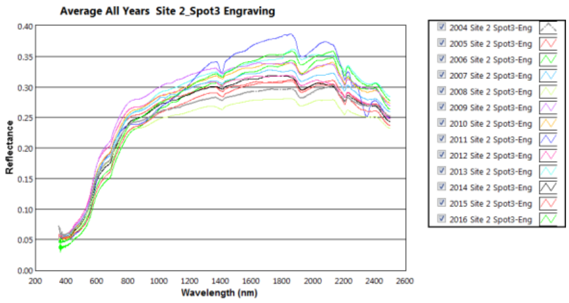
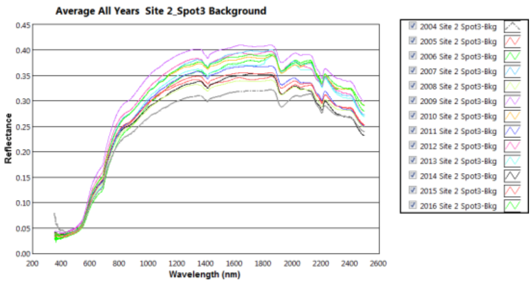
Spot 3





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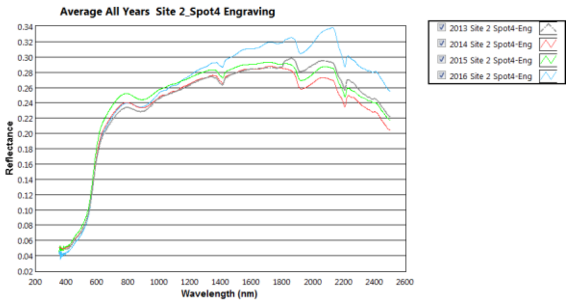
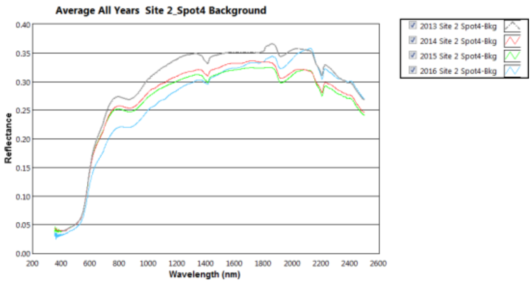
Spot 4





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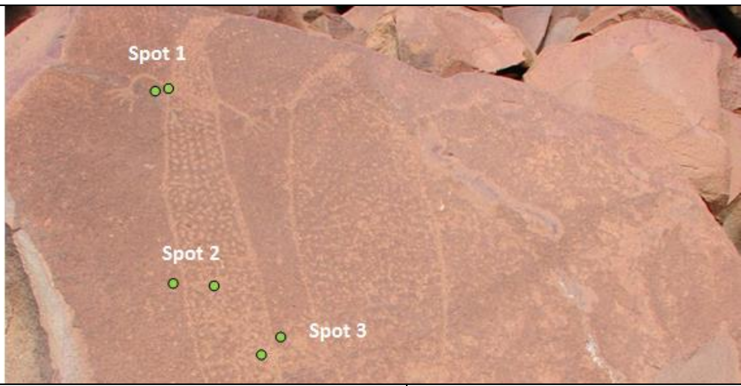
<tr><td>Site 4</td><td colspan="2">
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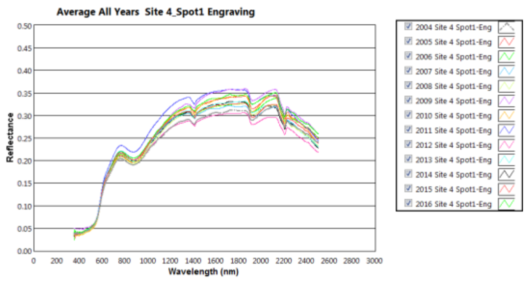
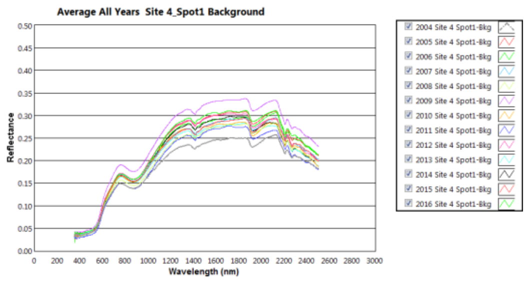
Spot 1</td><td>
</td><td>
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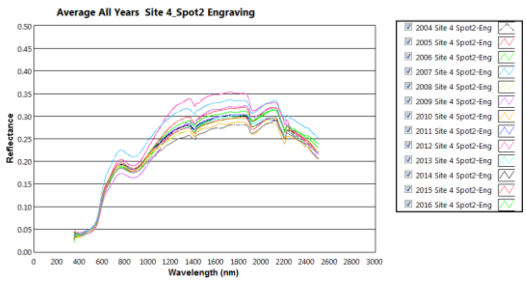
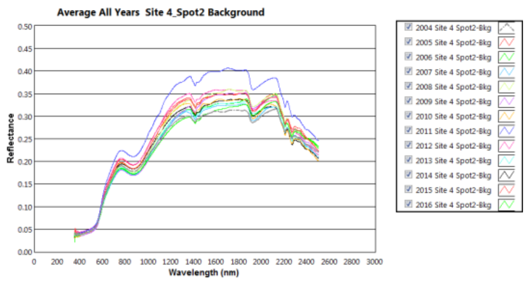
Spot 2</td><td>
</td><td>
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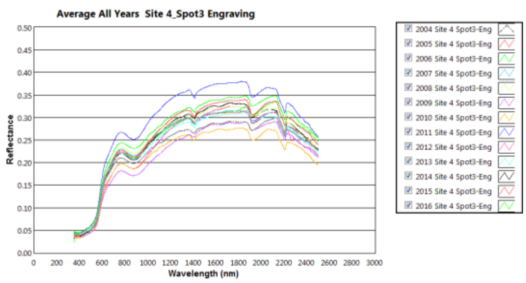
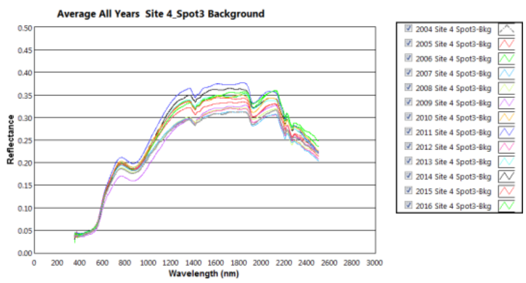
Spot 3</td><td>
</td><td>
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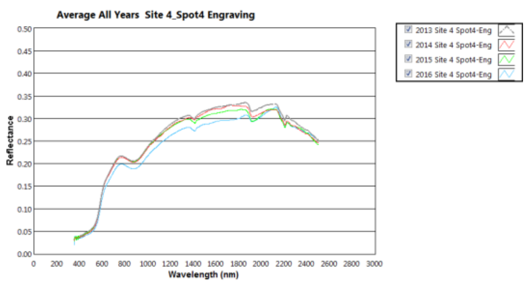
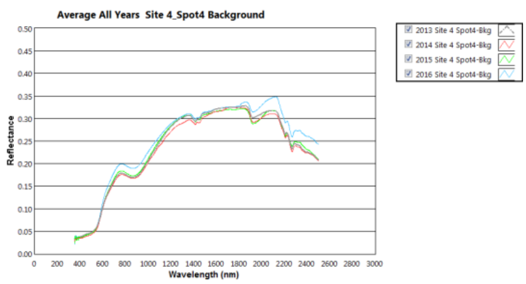
Spot 4</td><td>
</td><td>
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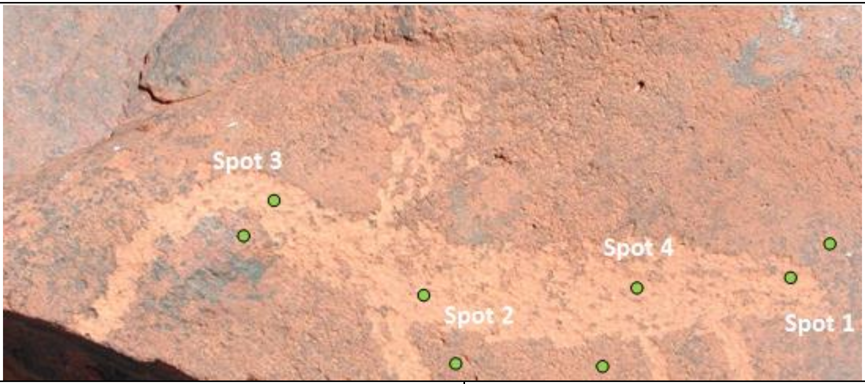

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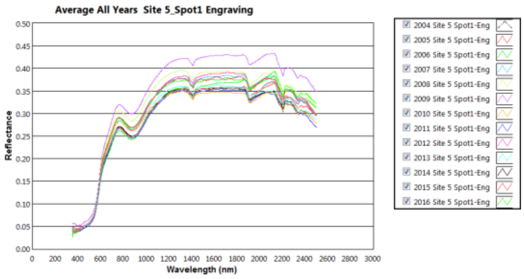

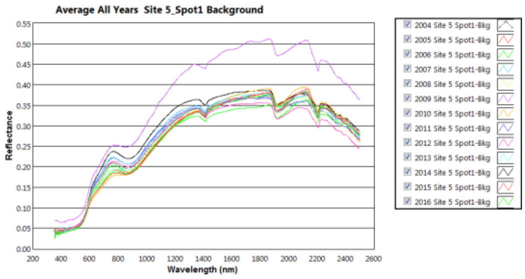

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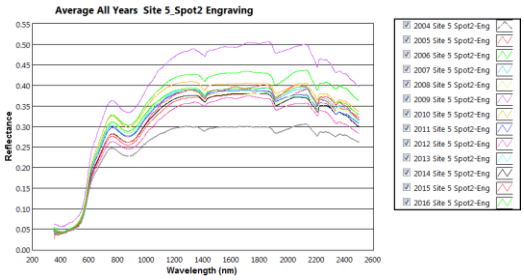

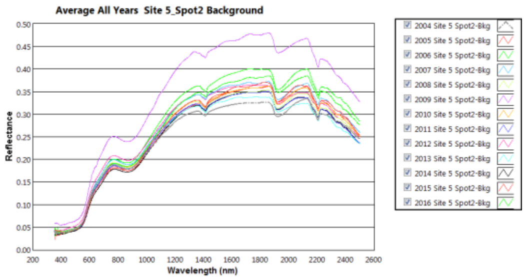

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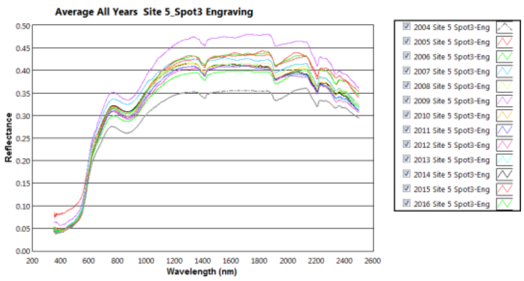

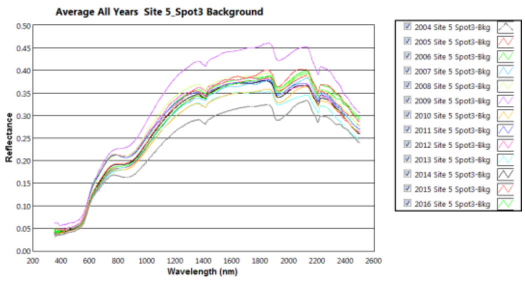

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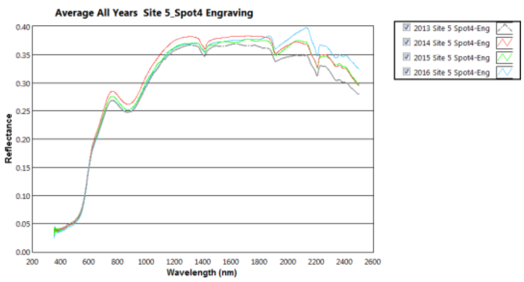
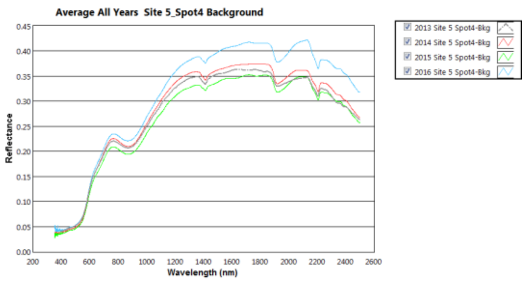
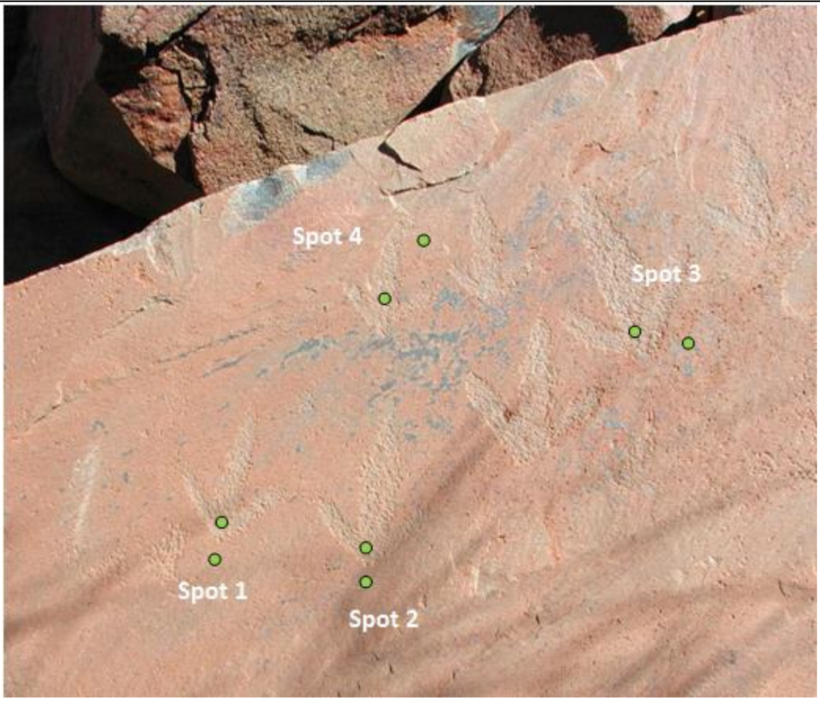
Spot 4







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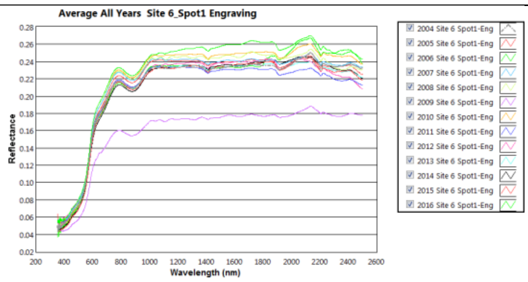
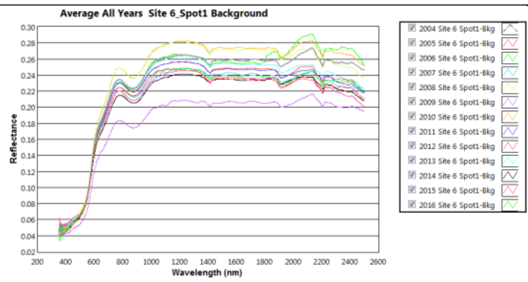
Spot 1





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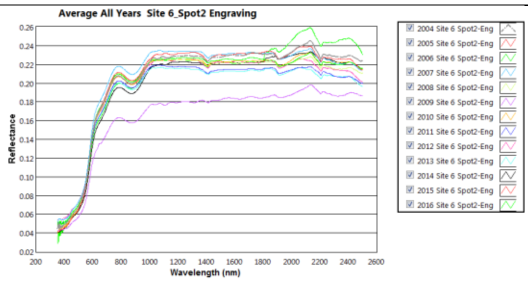
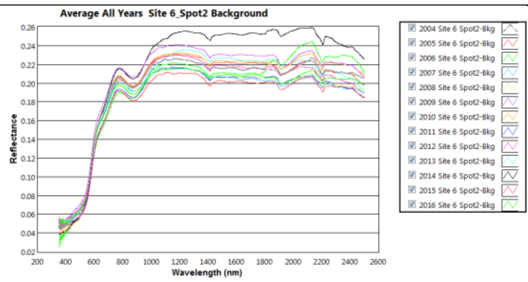
Spot 2





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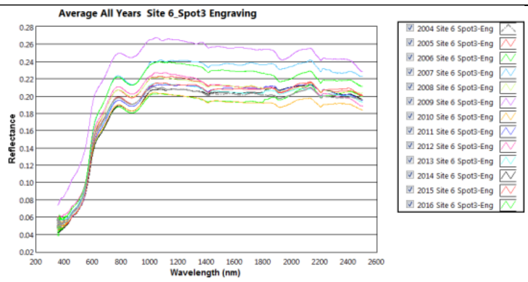

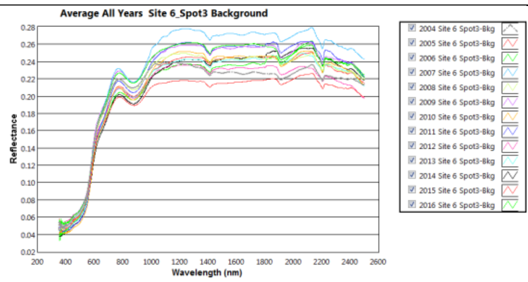

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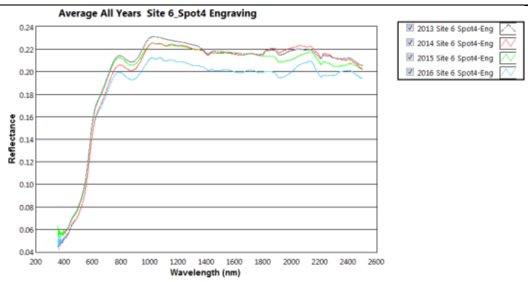
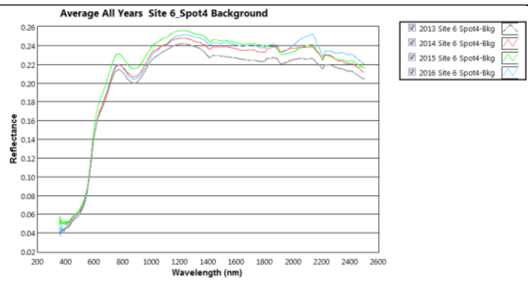
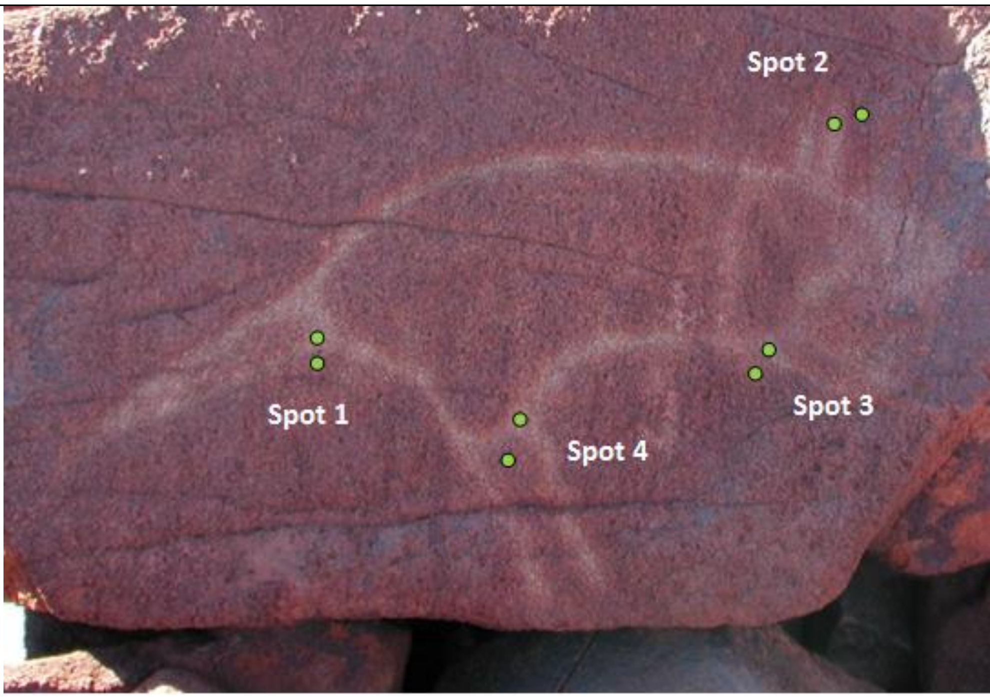
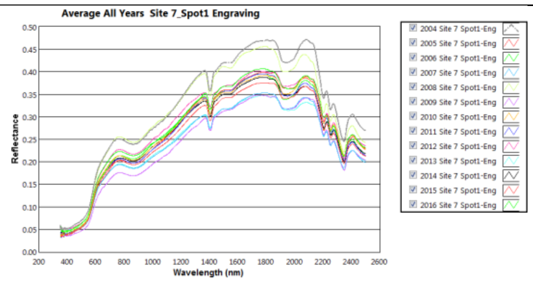
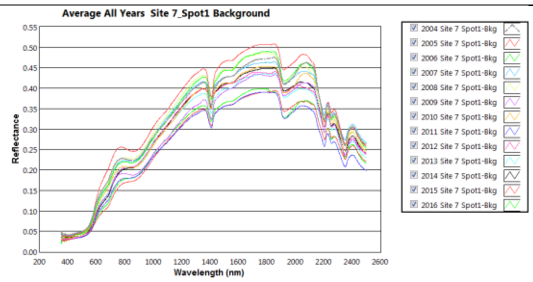
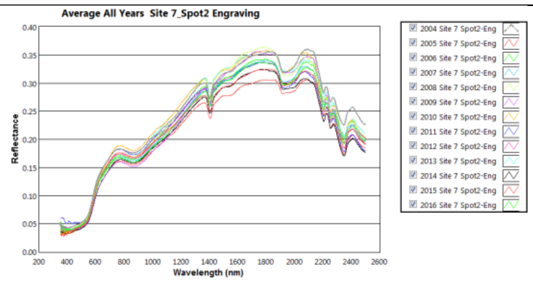
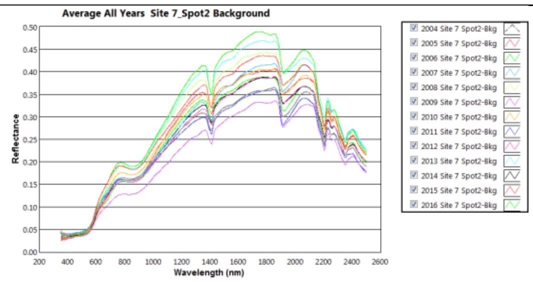
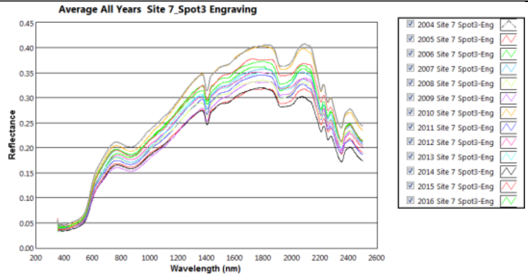
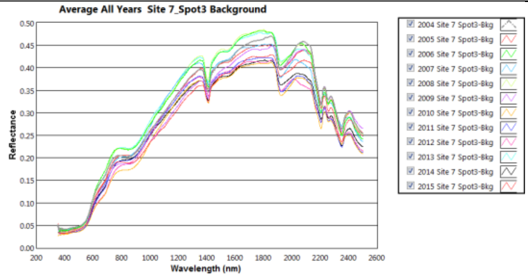
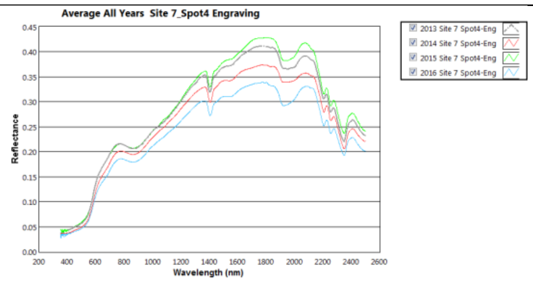
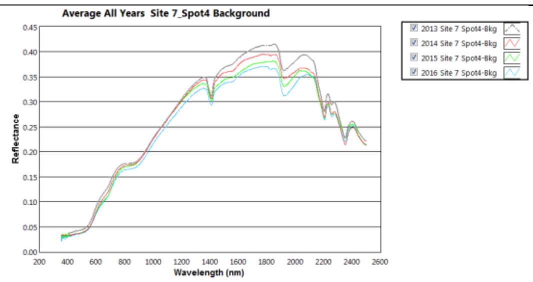
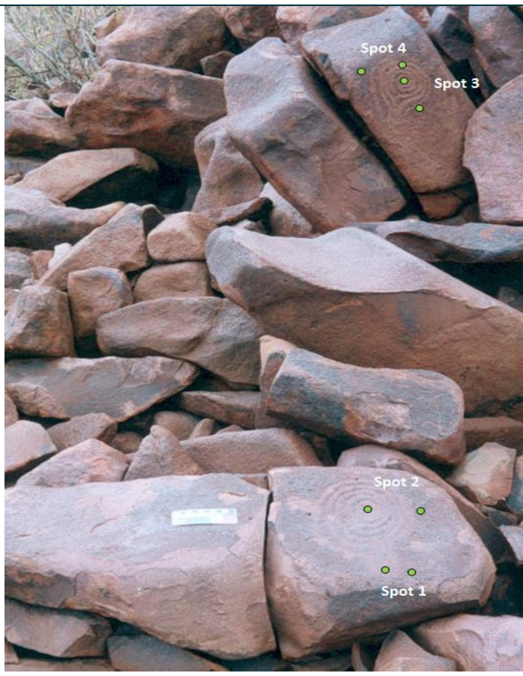
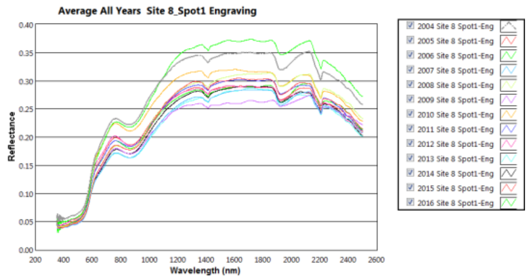
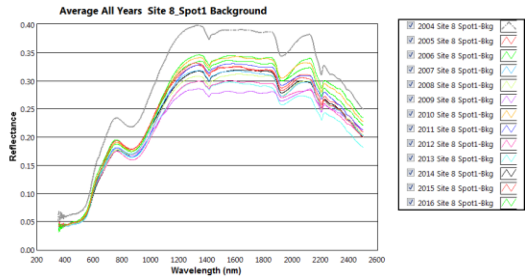
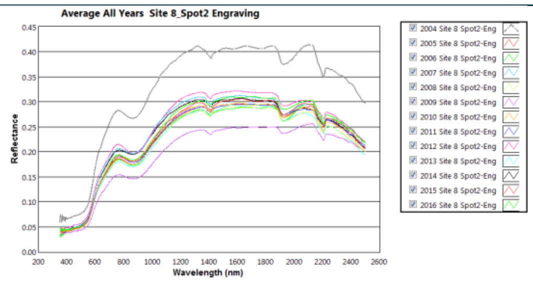
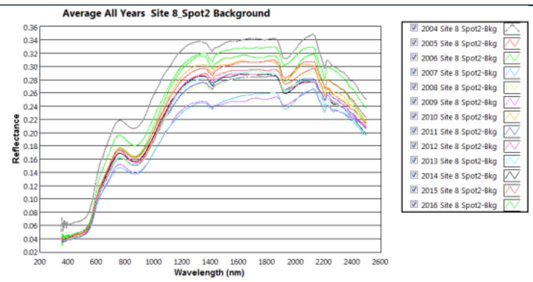
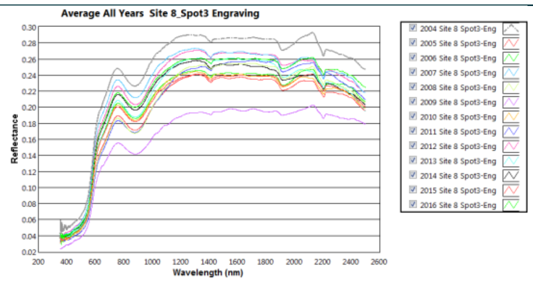
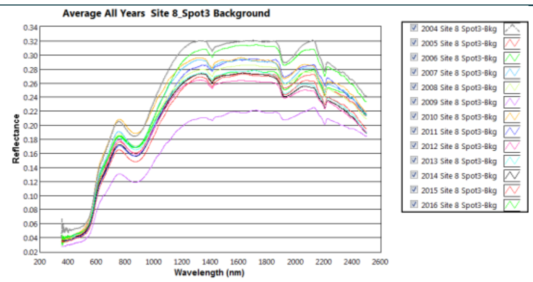
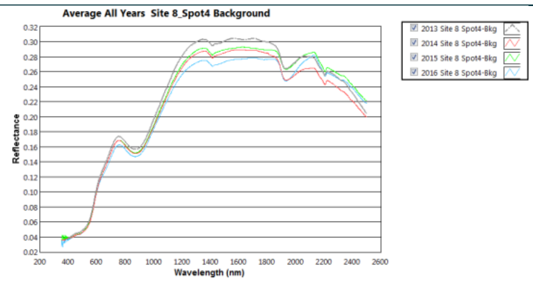
Spot 4





		
Site 7 Spot 1		
Site 7 Spot 2		
Site 7 Spot 3		
Site7 Spot 4		

Site 8		
Site 8 Spot 1		
Site 8 Spot 2		
Site 8 Spot 3		
Site 8 Spot 4		

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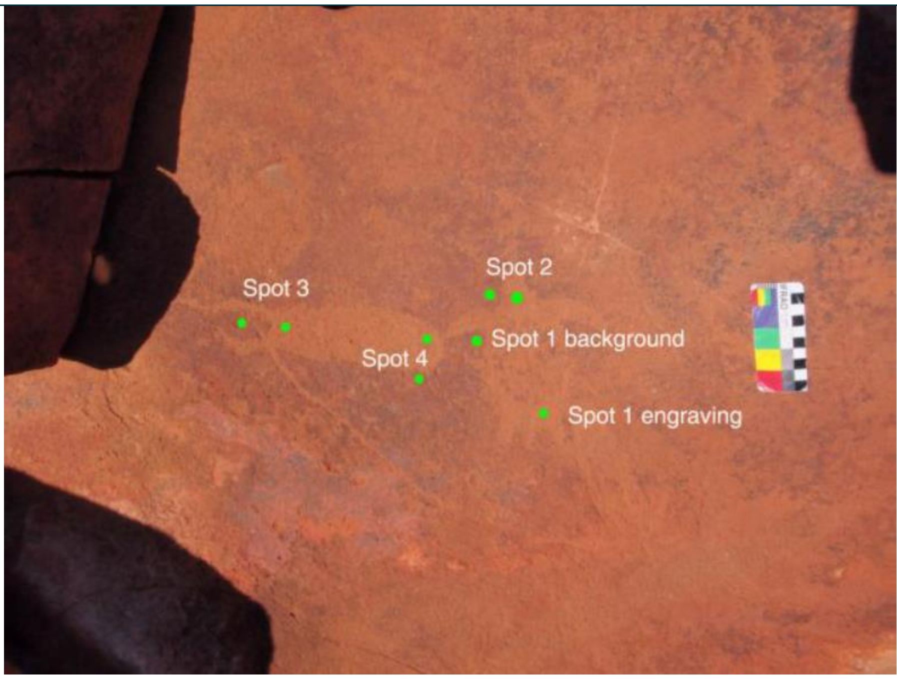
<tr><td>Site 21</td><td colspan="2">
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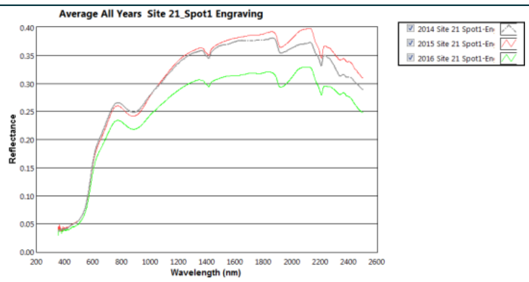
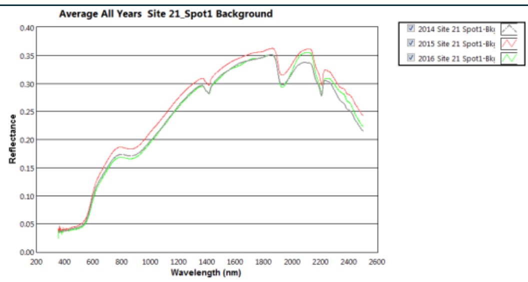
<tr><td>Site 21 Spot 1</td><td>
</td><td>
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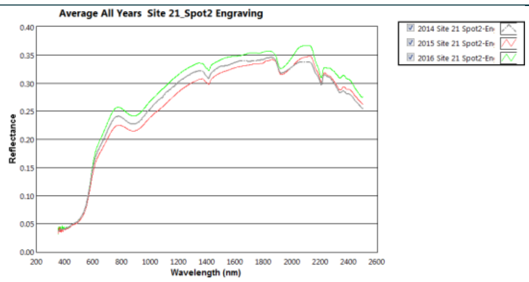
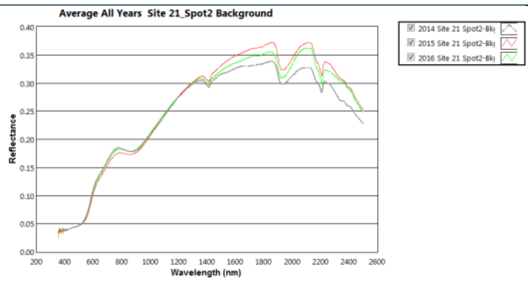
<tr><td>Site 21 Spot 2</td><td>
</td><td>
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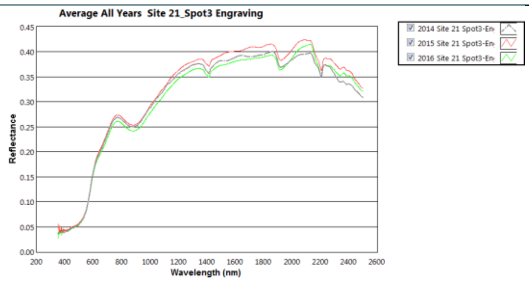
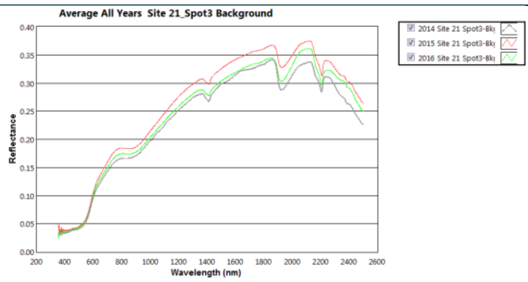
<tr><td>Site 21 Spot 3</td><td>
</td><td>
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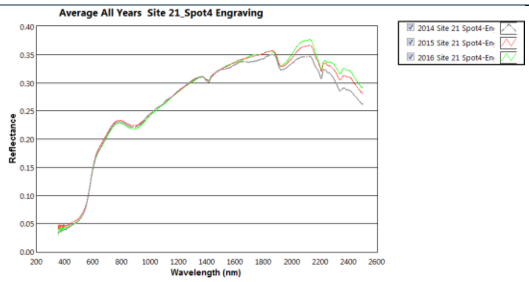
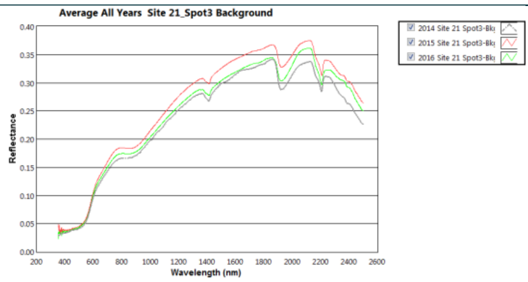
<tr><td>Site 21 Spot 4</td><td>
</td><td>
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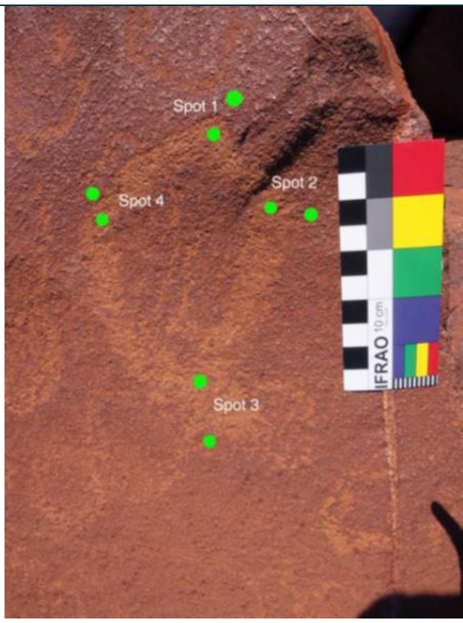
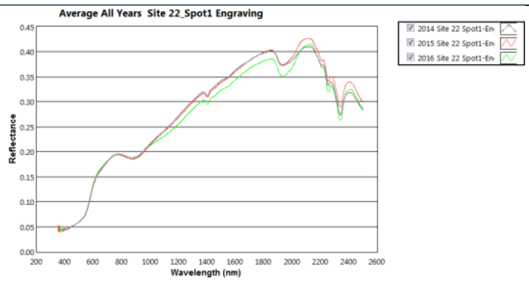
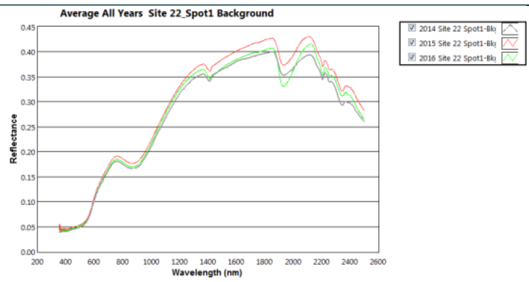
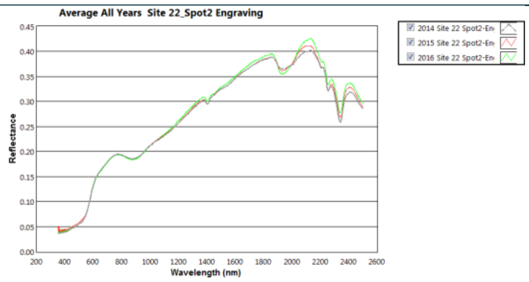
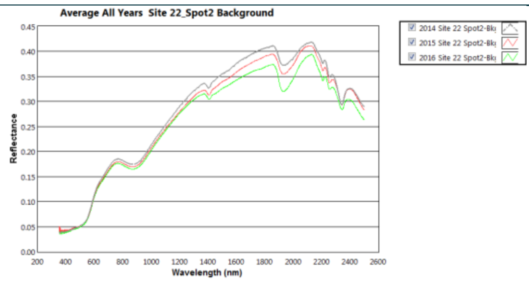
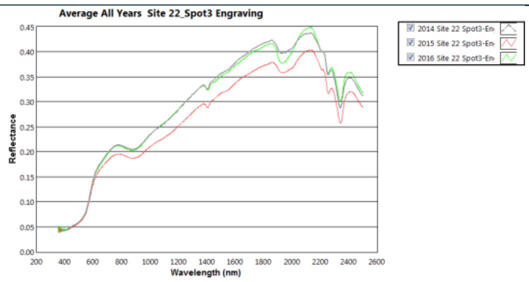
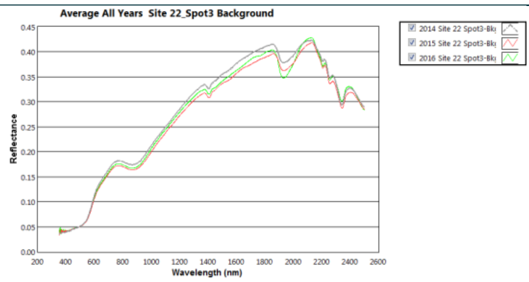
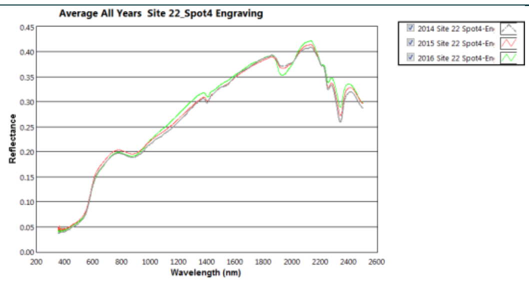
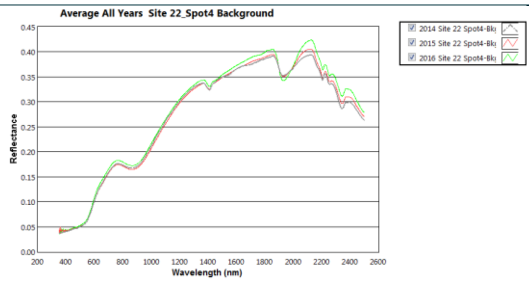
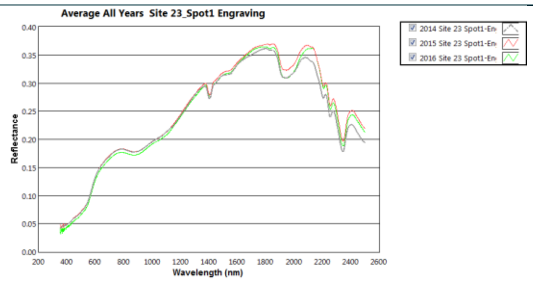
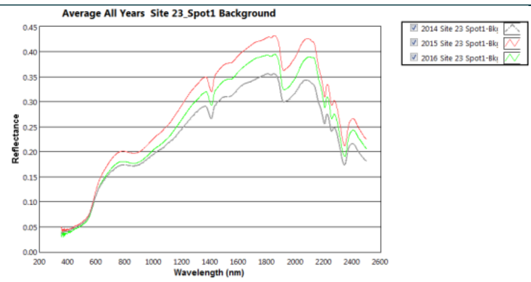
Site 22		
Site 22 Spot 1		
Site 22 Spot 2		
Site 22 Spot 3		
Site 22 Spot 4		

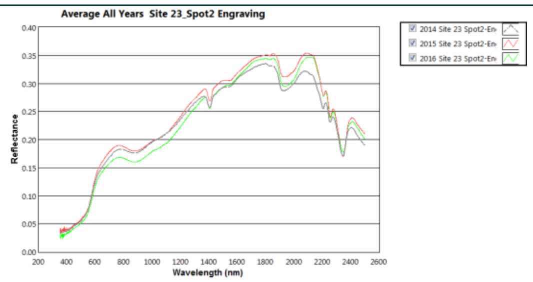
Site 23

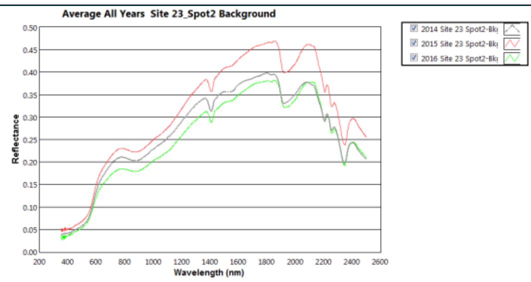
Site 23 Spot 1



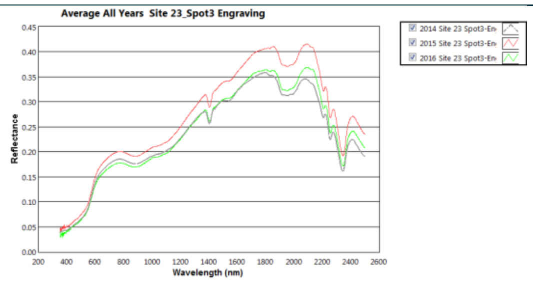


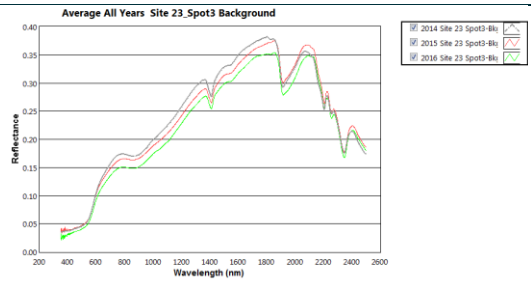
Site 23 Spot 2





Site 23 Spot 3





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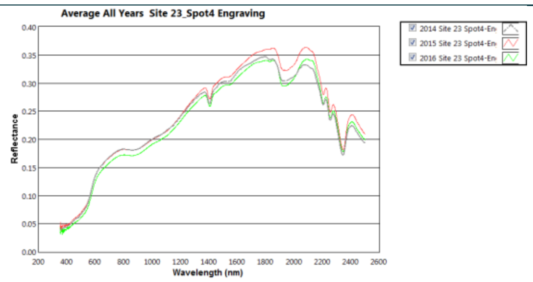


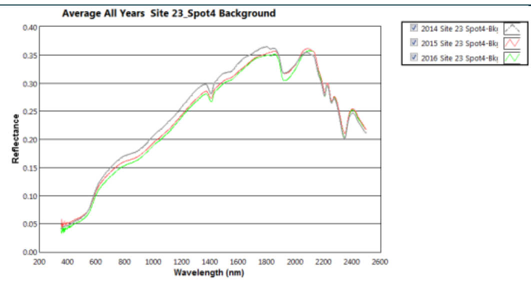


Figure 17: Digital image of the engraving with the location of the measurements (spot 1, 2, 3 and 4 for both engraving and background. Spot 4 measured from 2013). Comparison of the average spectra for the engravings and background for each of the three spots between 2004 and 2016.

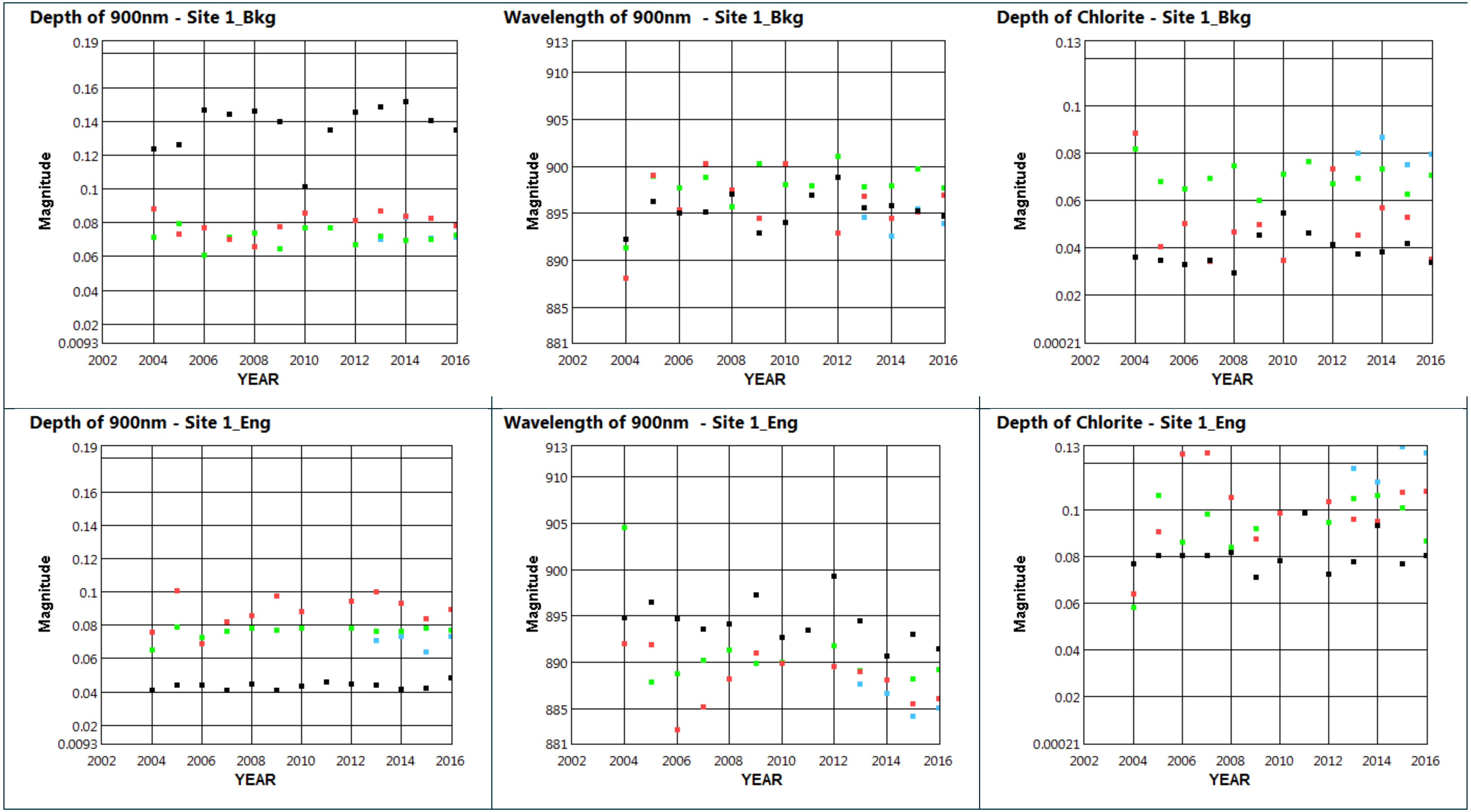
5.3 Spectral parameters

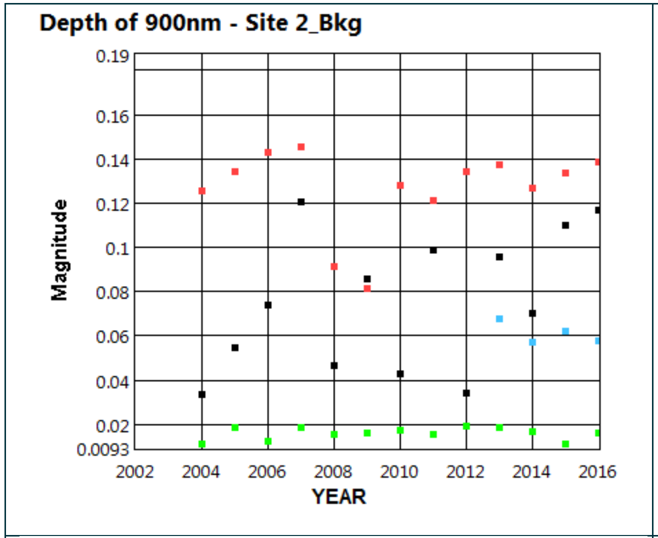
Spectral parameters were extracted from the spectra and include:

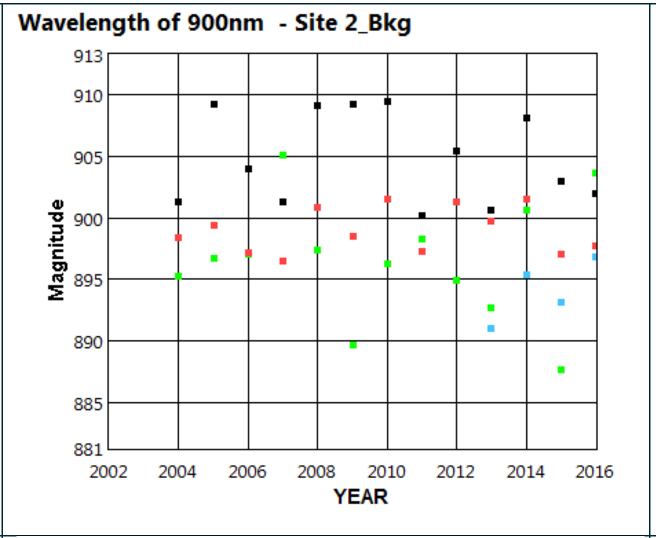
1. The depth (D900) and minimum wavelength (W900) of the large 900nm centred absorption providing information on the iron oxides
2. The depth of the chlorite absorption at 2250 nm after local Hull removal - DChlorite (residual mineral from the fresh rocks)
3. The depth of the kaolinite at 2206 nm after local Hull removal (DKaolinite) and, when present, gibbsite (DGibbsite) absorptions (secondary minerals resulting from the weathering of the primary minerals)

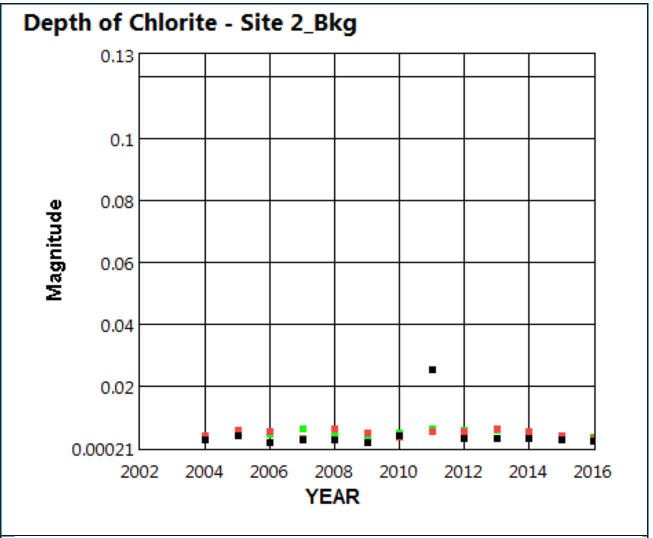
	Minimum	Maximum
D900	0.0093	0.19
W900	881	913
DChlorite	0.00021	0.13
DKaolinite	0.001	0.11
DGibbsite	0	0.025

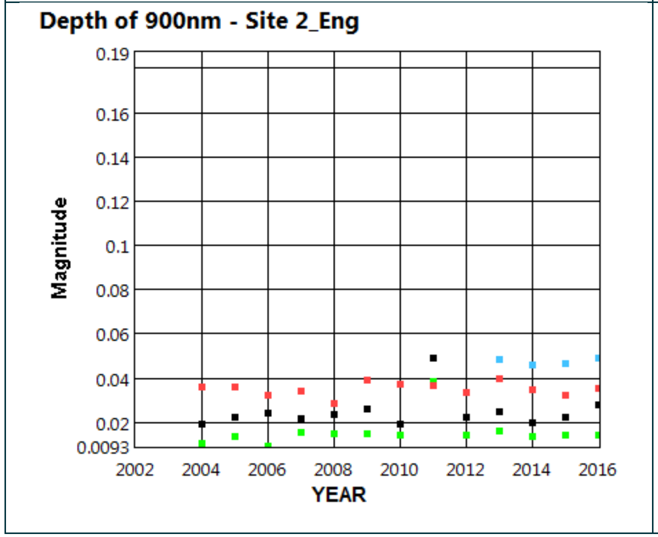
Table 16 Minimum and maximum of spectral parameters for all sites.

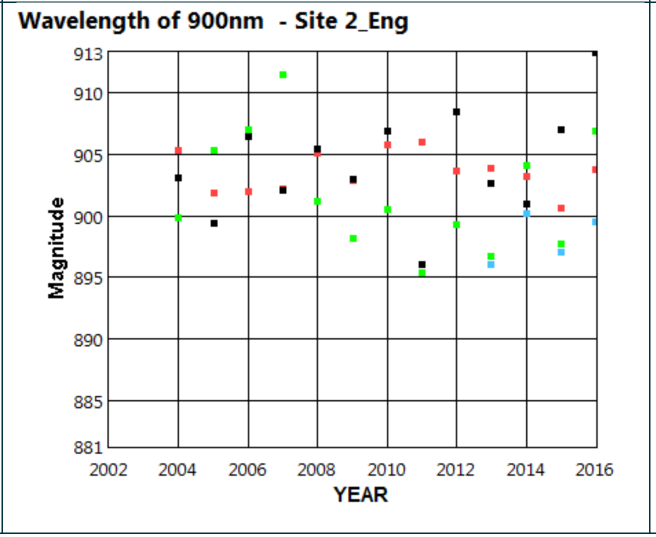

Depth of 900nm - Site 1_Bkg
Wavelength of 900nm - Site 1_Bkg
Depth of Chlorite - Site 1_Bkg
Depth of 900nm - Site 1_Eng
Wavelength of 900nm - Site 1_Eng
Depth of Chlorite - Site 1_Eng
Magnitude
YEAR
0.19
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0.0093
913
910
905
900
895
890
885
881
0.13
0.00021
2002
2004
2006
2008
2010
2012
2014
2016

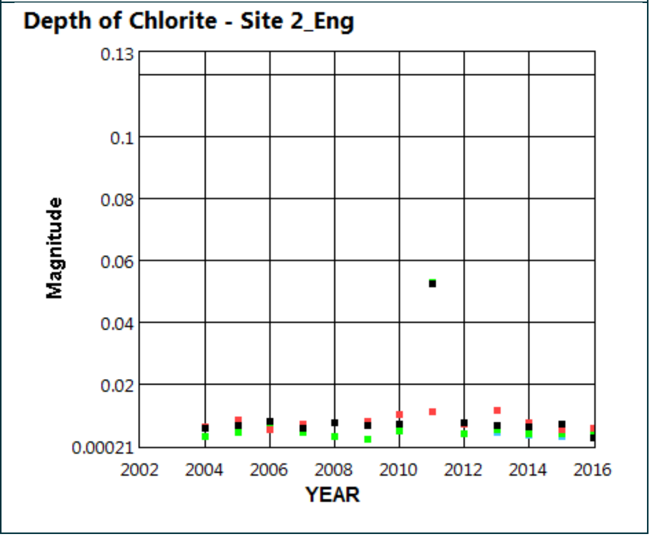

Depth of 900nm - Site 2_Bkg
Magnitude
YEAR

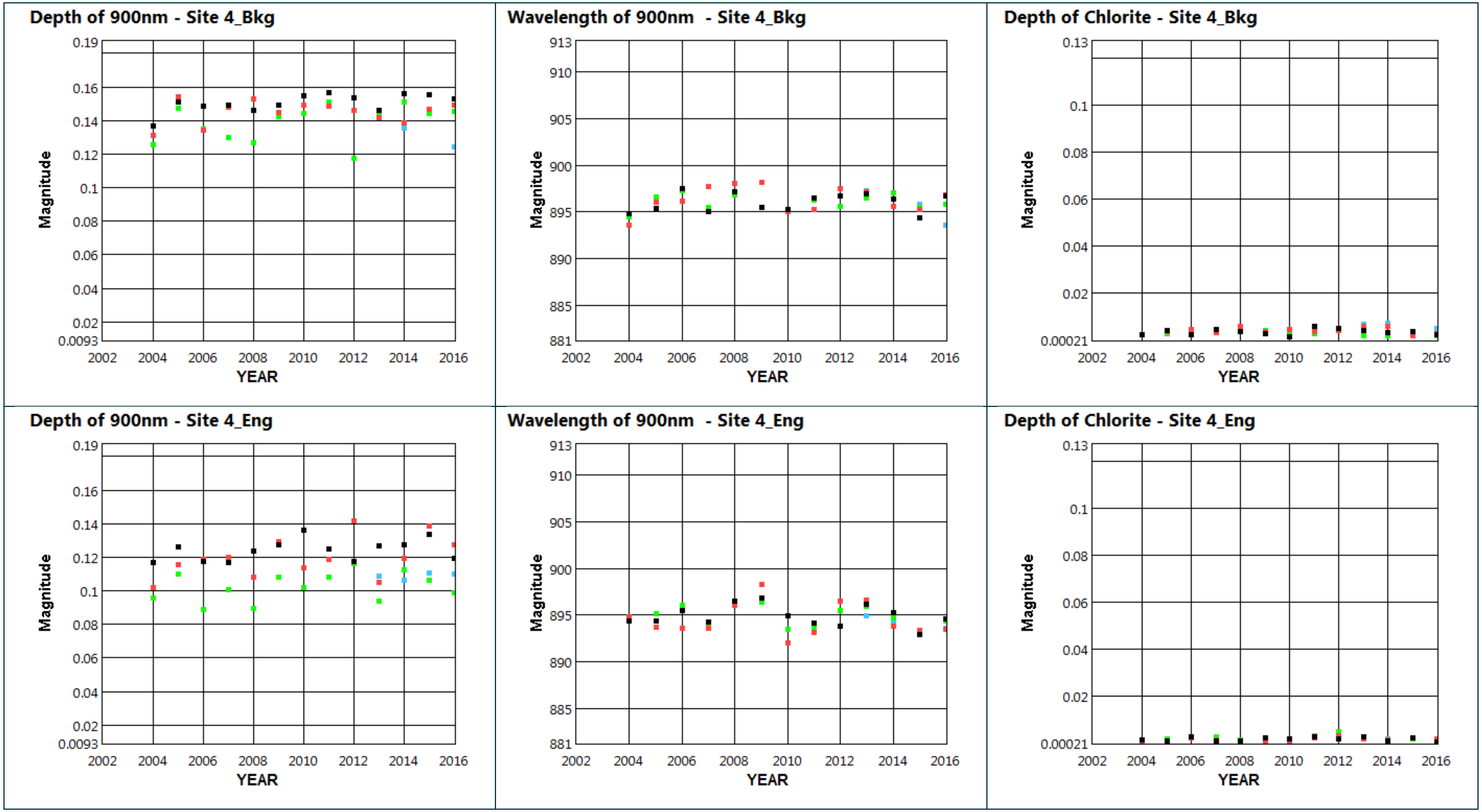

Wavelength of 900nm - Site 2_Bkg
Magnitude
YEAR

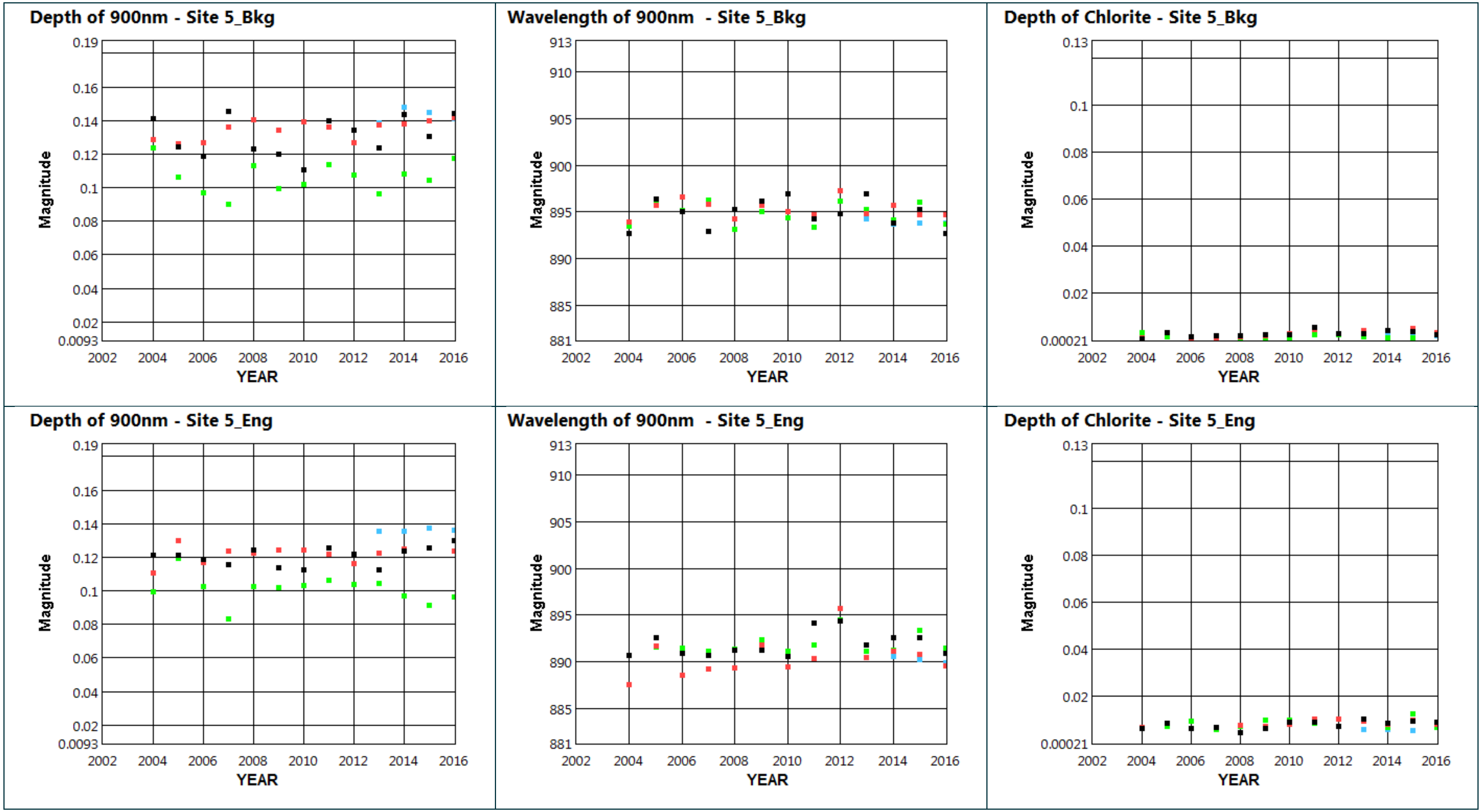

Depth of Chlorite - Site 2_Bkg
Magnitude
YEAR

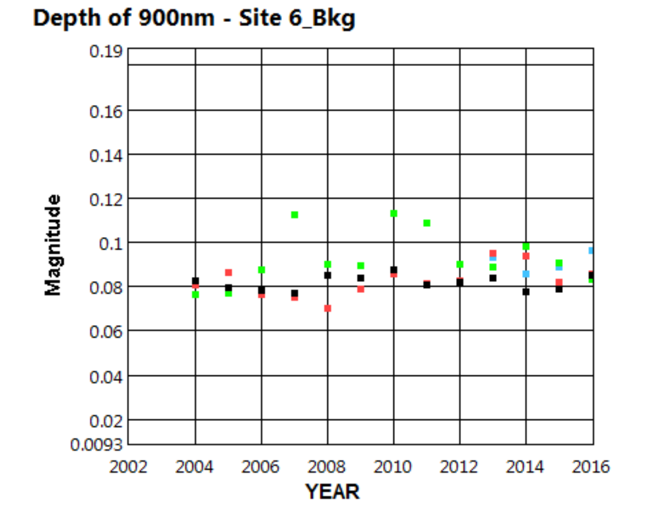

Depth of 900nm - Site 2_Eng
Magnitude
YEAR


Wavelength of 900nm - Site 2_Eng
Magnitude
YEAR


Depth of Chlorite - Site 2_Eng
Magnitude
YEAR


Depth of 900nm - Site 4_Bkg
Wavelength of 900nm - Site 4_Bkg
Depth of Chlorite - Site 4_Bkg
Depth of 900nm - Site 4_Eng
Wavelength of 900nm - Site 4_Eng
Depth of Chlorite - Site 4_Eng
Magnitude
YEAR
0.19
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0.0093
913
910
905
900
895
890
885
881
0.13
0.1
0.08
0.06
0.04
0.02
0.00021
2002
2004
2006
2008
2010
2012
2014
2016


Depth of 900nm - Site 5_Bkg
Wavelength of 900nm - Site 5_Bkg
Depth of Chlorite - Site 5_Bkg
Depth of 900nm - Site 5_Eng
Wavelength of 900nm - Site 5_Eng
Depth of Chlorite - Site 5_Eng
Magnitude
YEAR
0.19
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0.0093
913
910
905
900
895
890
885
881
0.13
0.00021
2002
2004
2006
2008
2010
2012
2014
2016


Depth of 900nm - Site 6_Bkg
Magnitude
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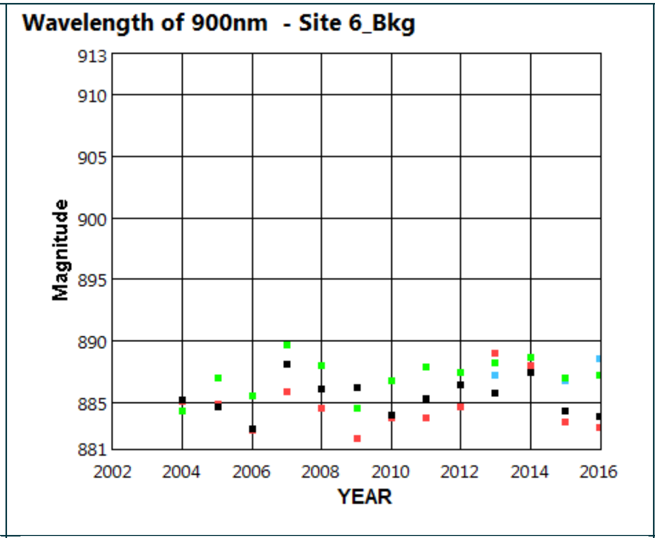
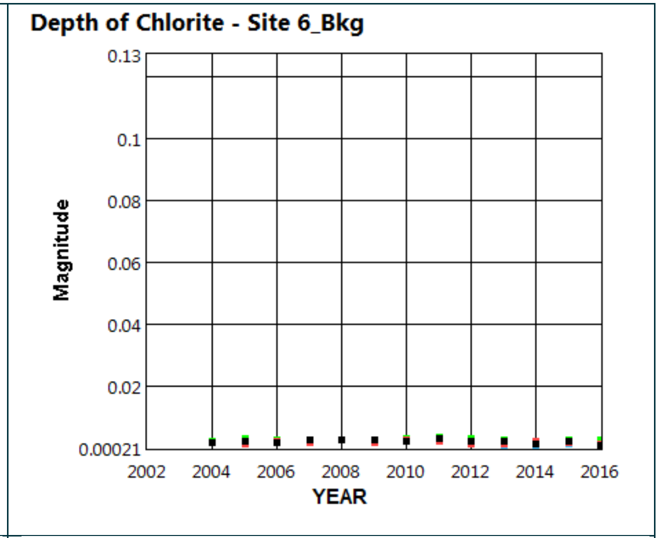
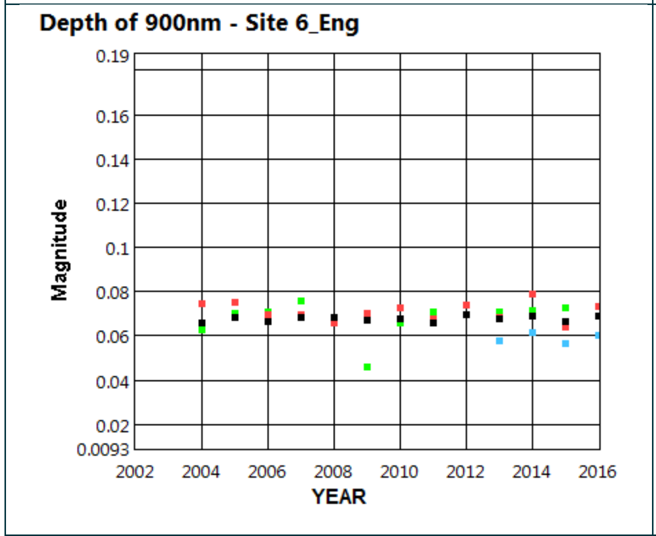
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0.0093
2002
2004
2006
2008
2010
2012
2014
2016
YEAR


Wavelength of 900nm - Site 6_Bkg
Magnitude
913
910
905
900
895
890
885
881
2002
2004
2006
2008
2010
2012
2014
2016
YEAR


Depth of Chlorite - Site 6_Bkg
Magnitude
0.13
0.1
0.08
0.06
0.04
0.02
0.00021
2002
2004
2006
2008
2010
2012
2014
2016
YEAR


Depth of 900nm - Site 6_Eng
Magnitude
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0.16
0.14
0.12
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0.08
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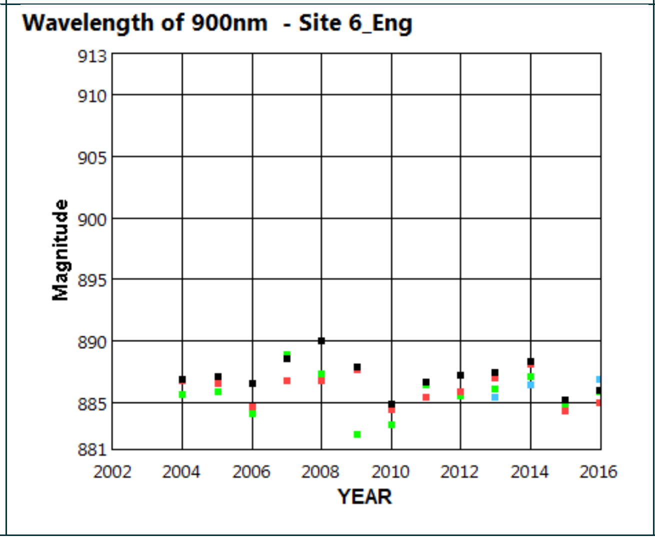
0.04
0.02
0.0093
2002
2004
2006
2008
2010
2012
2014
2016
YEAR


Wavelength of 900nm - Site 6_Eng
Magnitude
913
910
905
900
895
890
885
881
2002
2004
2006
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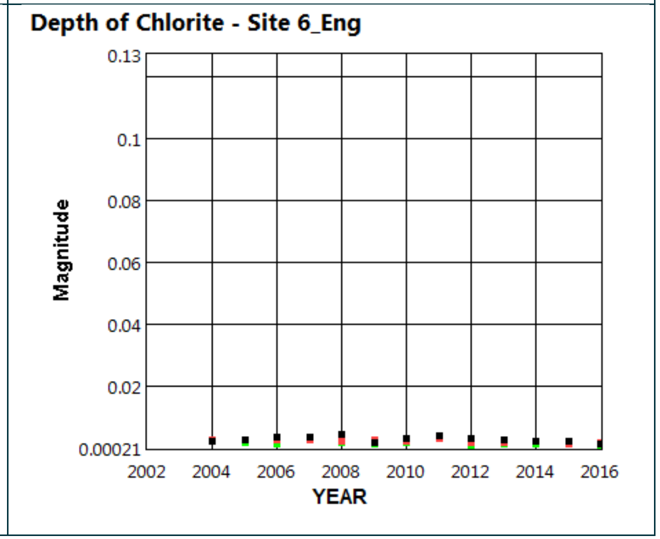
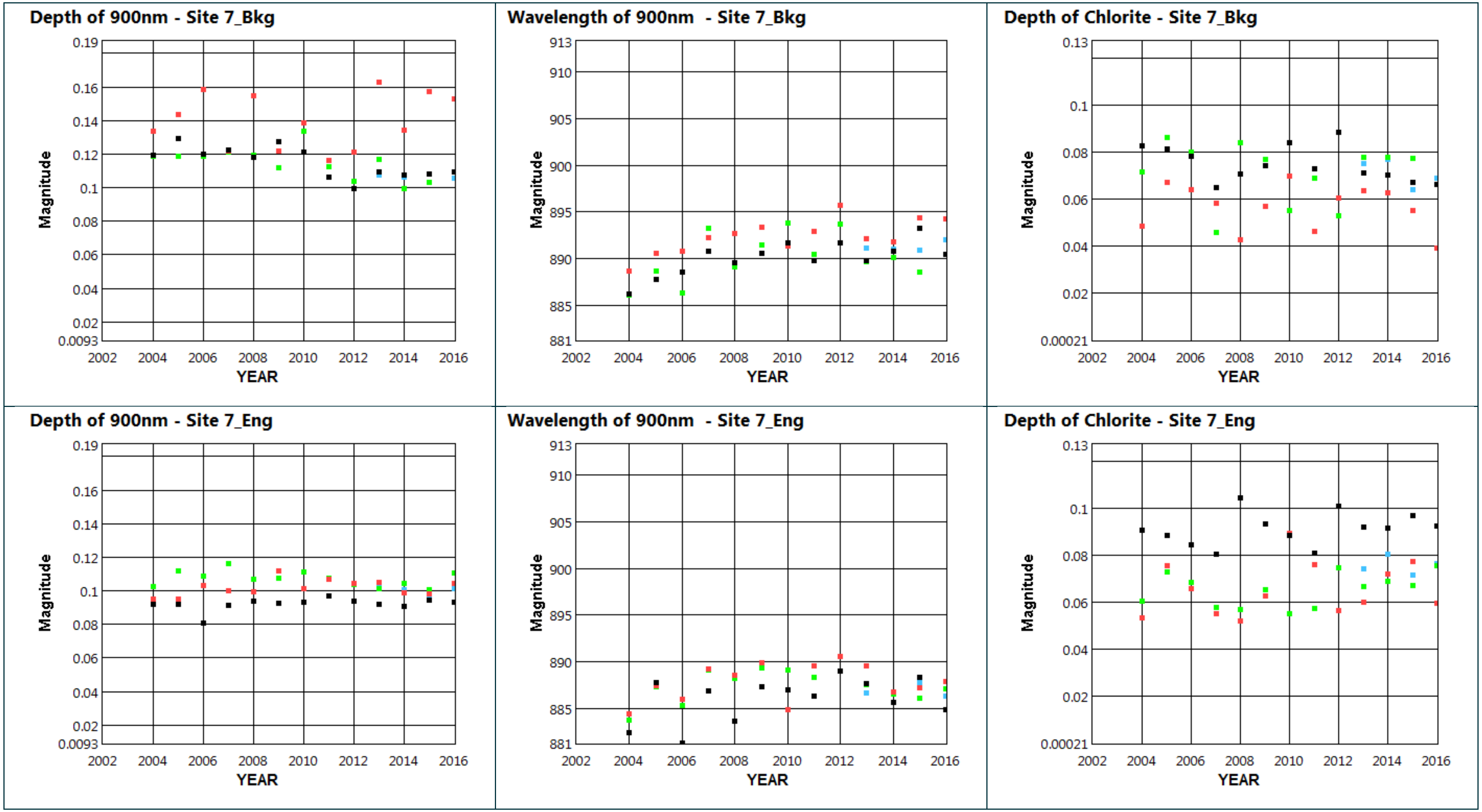
2014
2016
YEAR


Depth of Chlorite - Site 6_Eng
Magnitude
0.13
0.1
0.08
0.06
0.04
0.02
0.00021
2002
2004
2006
2008
2010
2012
2014
2016
YEAR


Depth of 900nm - Site 7_Bkg
Wavelength of 900nm - Site 7_Bkg
Depth of Chlorite - Site 7_Bkg
Depth of 900nm - Site 7_Eng
Wavelength of 900nm - Site 7_Eng
Depth of Chlorite - Site 7_Eng
Magnitude
YEAR
0.19
0.16
0.14
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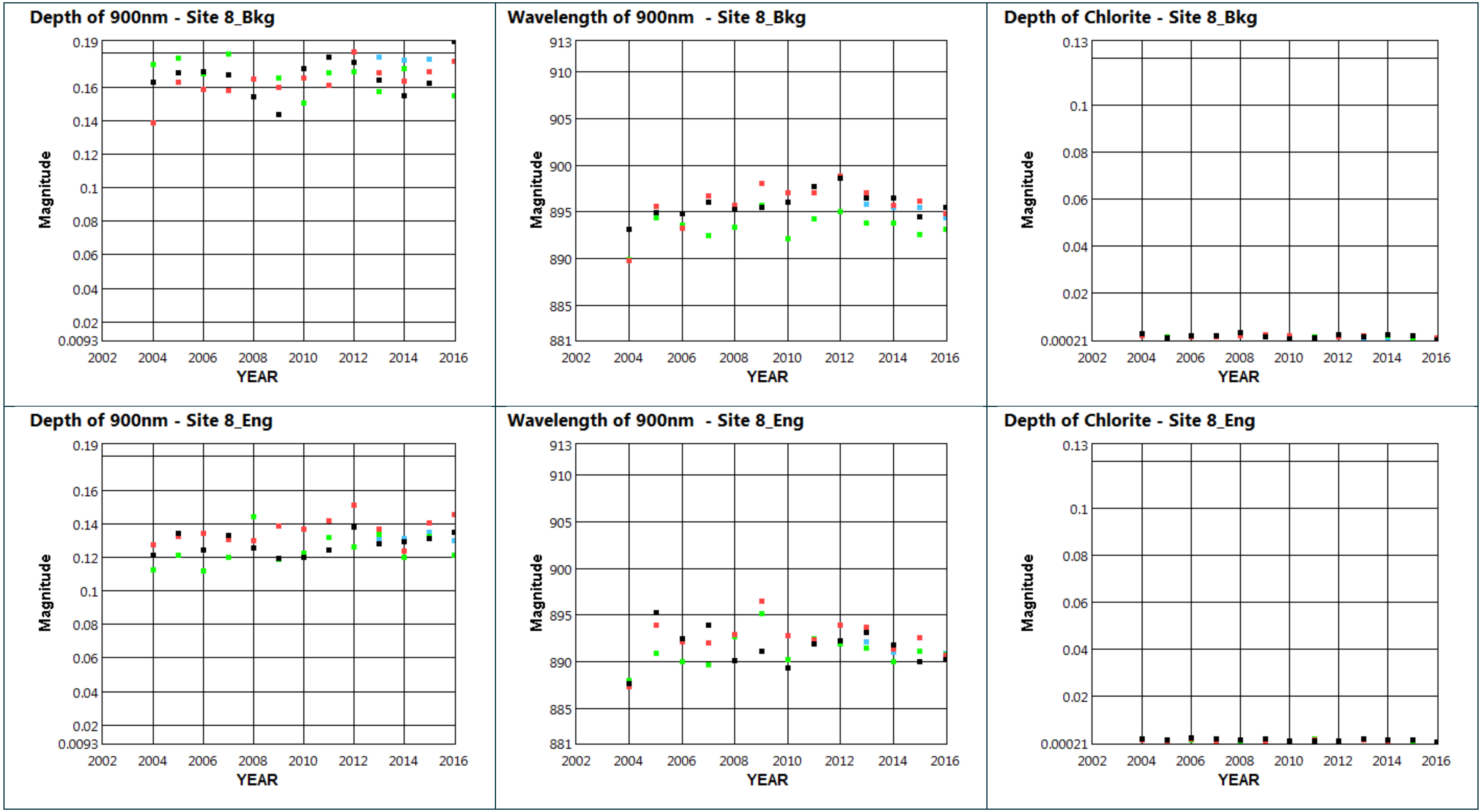
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Wavelength of 900nm - Site 8_Bkg
Depth of Chlorite - Site 8_Bkg
Depth of 900nm - Site 8_Eng
Wavelength of 900nm - Site 8_Eng
Depth of Chlorite - Site 8_Eng
Magnitude
YEAR
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0.14
0.12
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0.08
0.06
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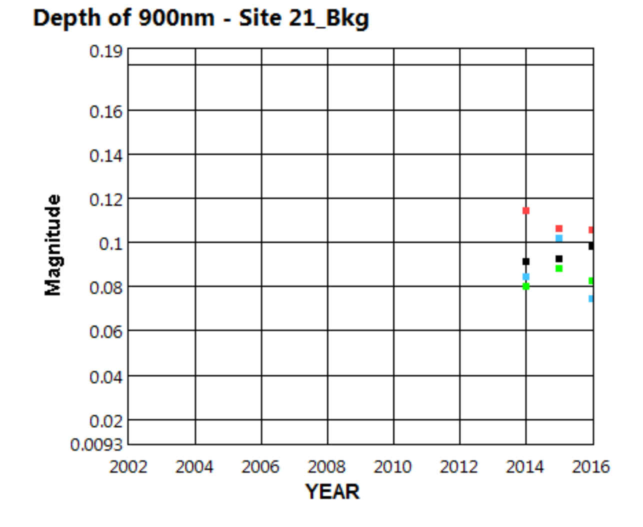
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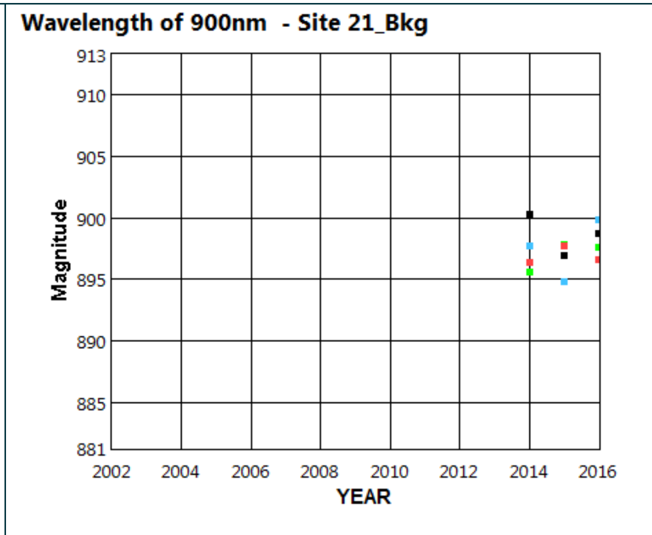
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Magnitude
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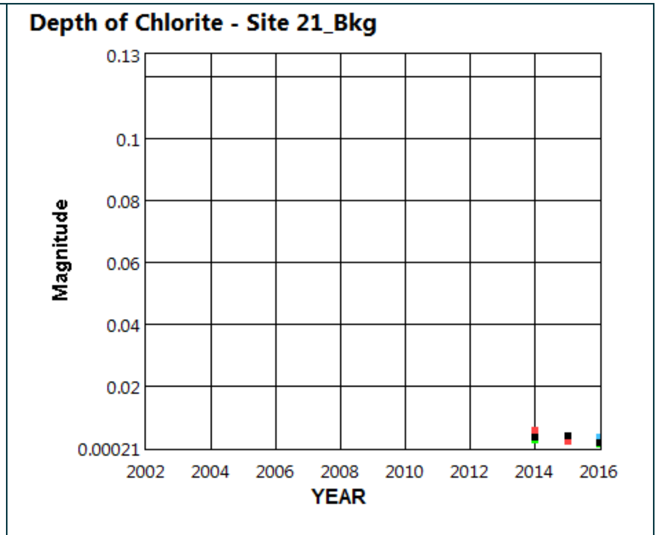
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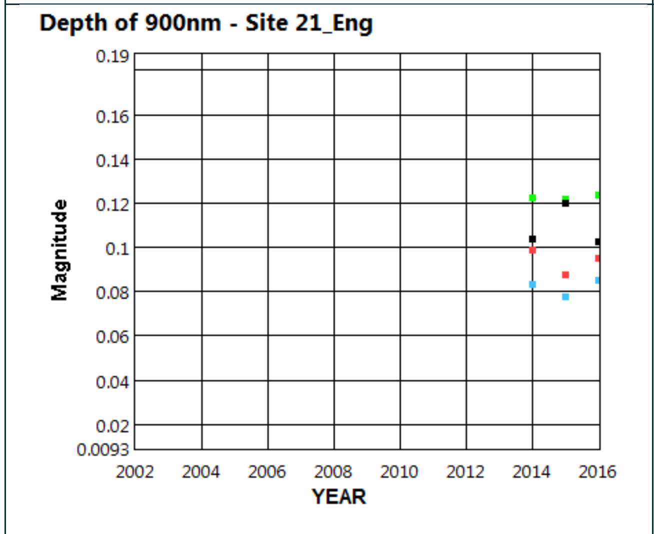
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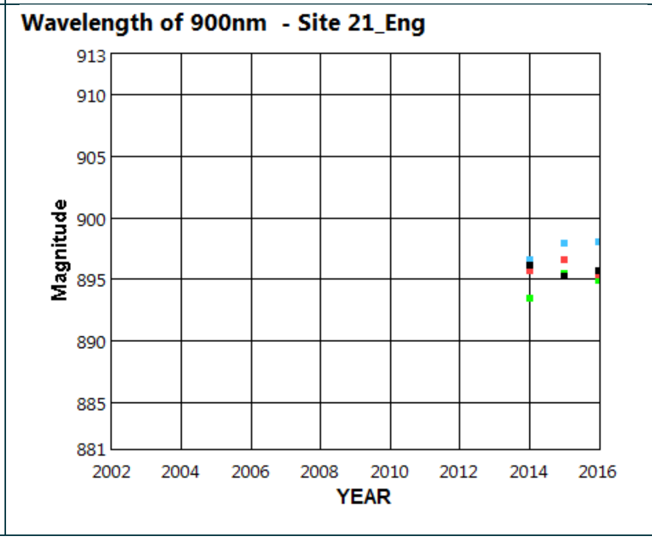
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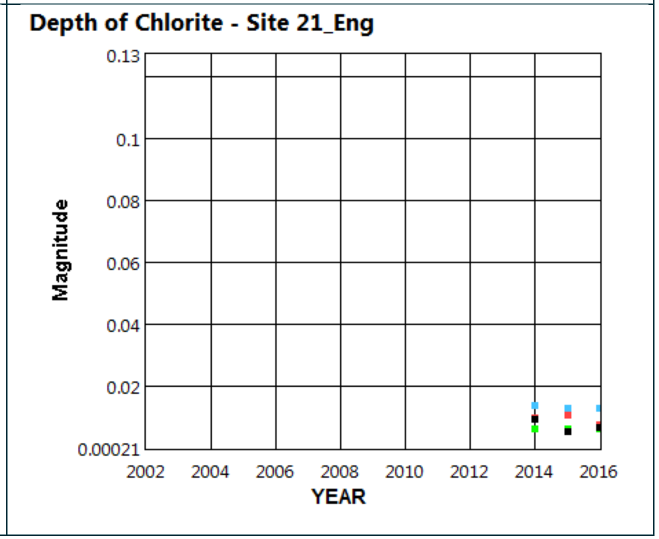
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Magnitude
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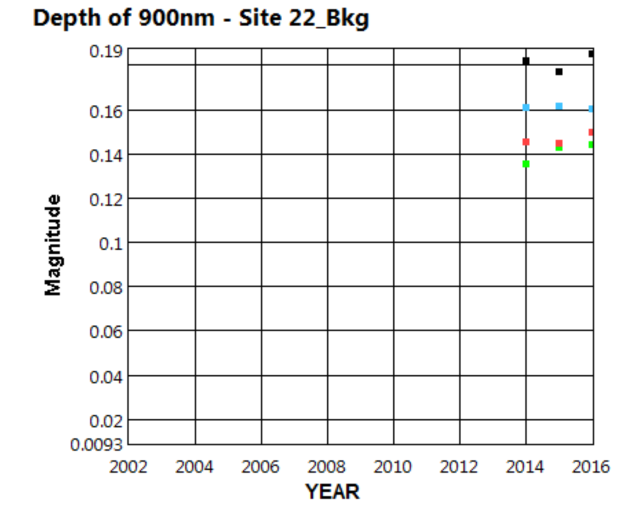
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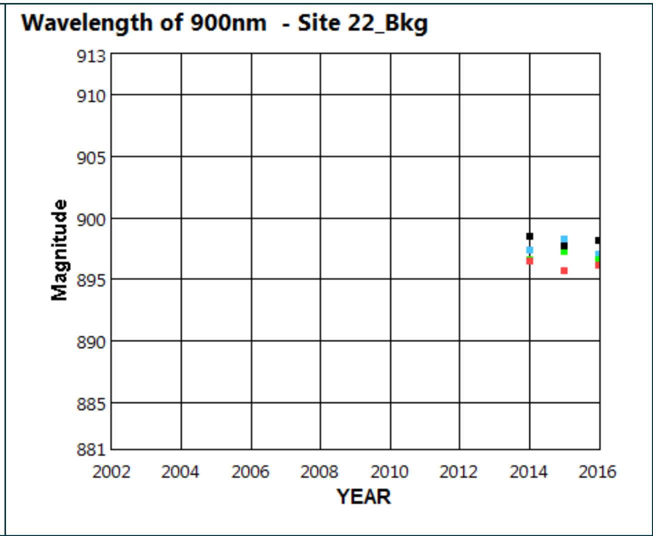
2002 2004 2006 2008 2010 2012 2014 2016
YEAR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Magnitude
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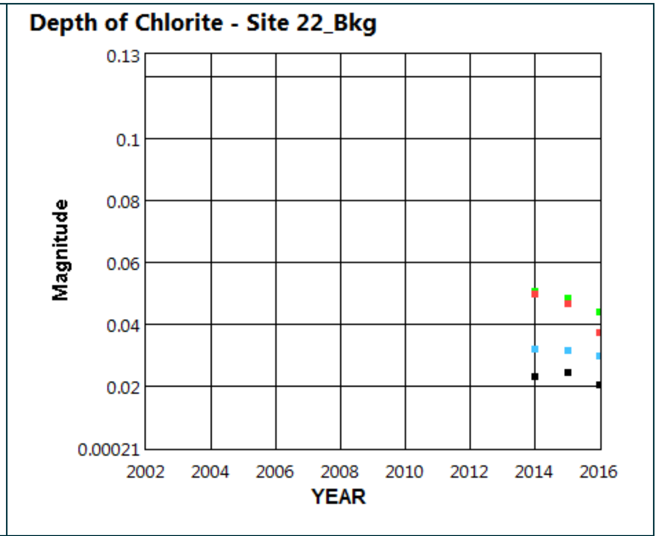
YEAR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Magnitude
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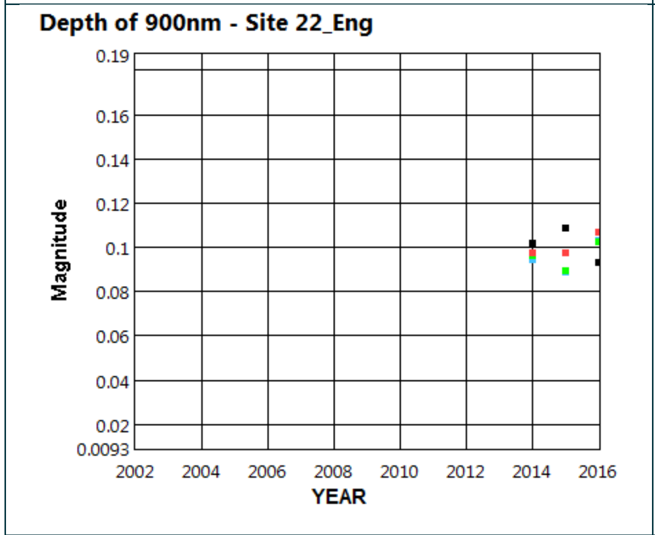
2002 2004 2006 2008 2010 2012 2014 2016
YEAR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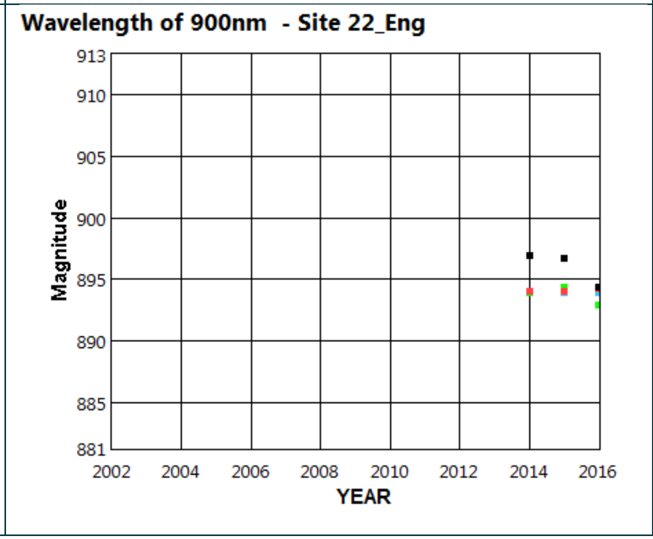
2002 2004 2006 2008 2010 2012 2014 2016
YEAR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Magnitude
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905
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890
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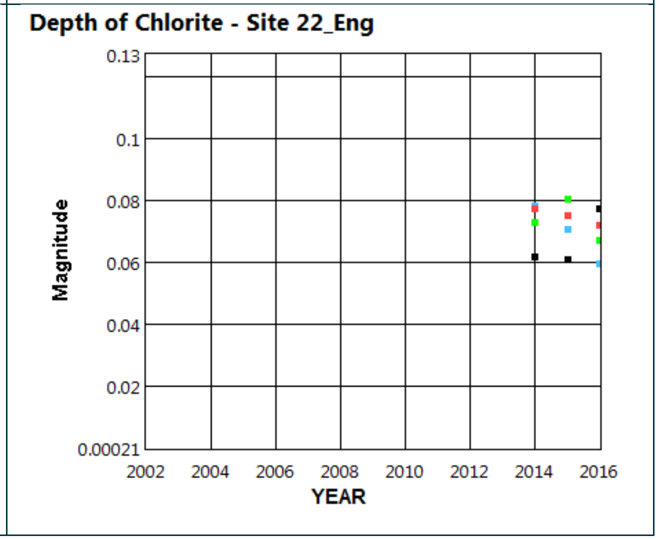
2002 2004 2006 2008 2010 2012 2014 2016
YEAR


Depth of Chlorite - Site 22_Eng
Magnitude
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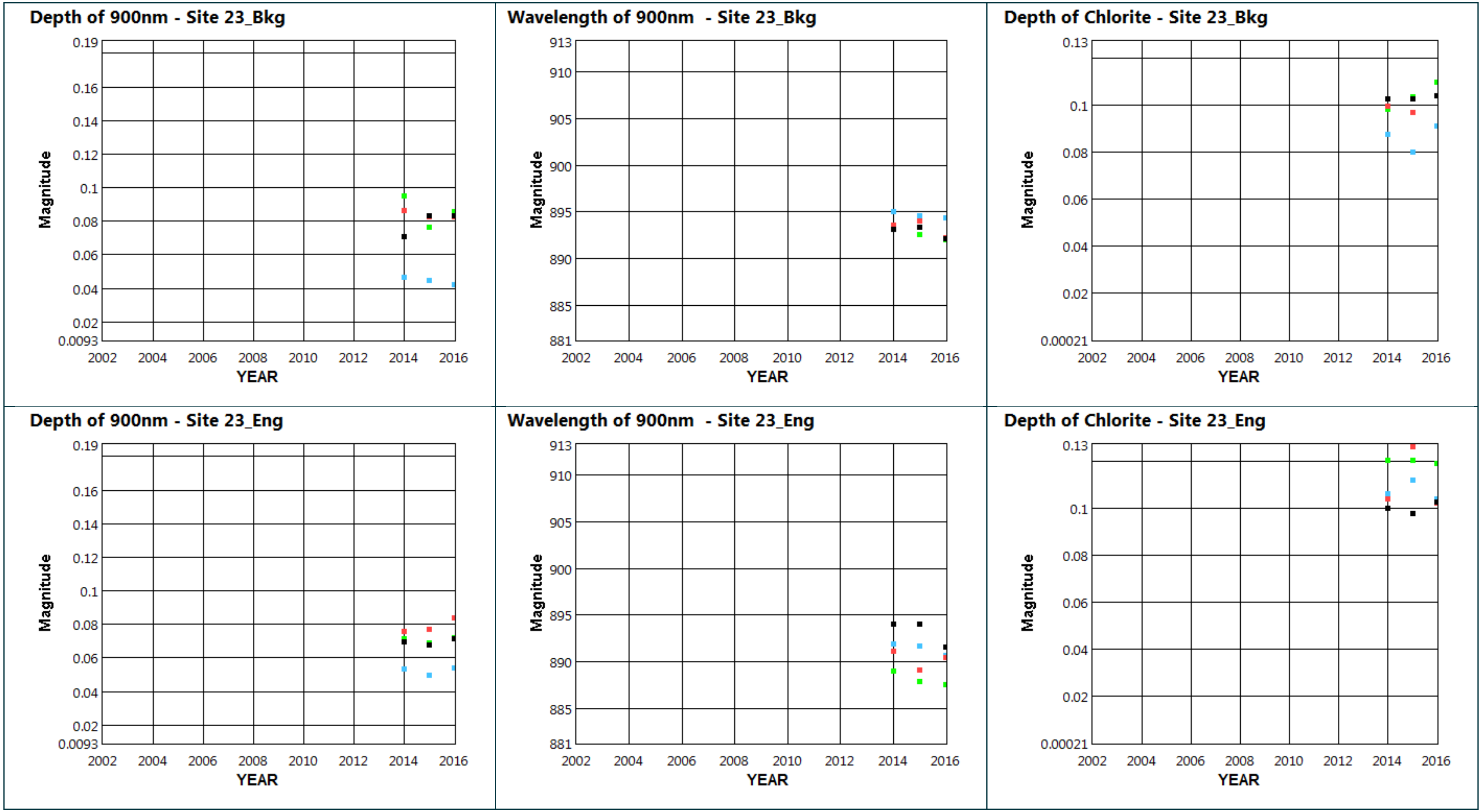
YEAR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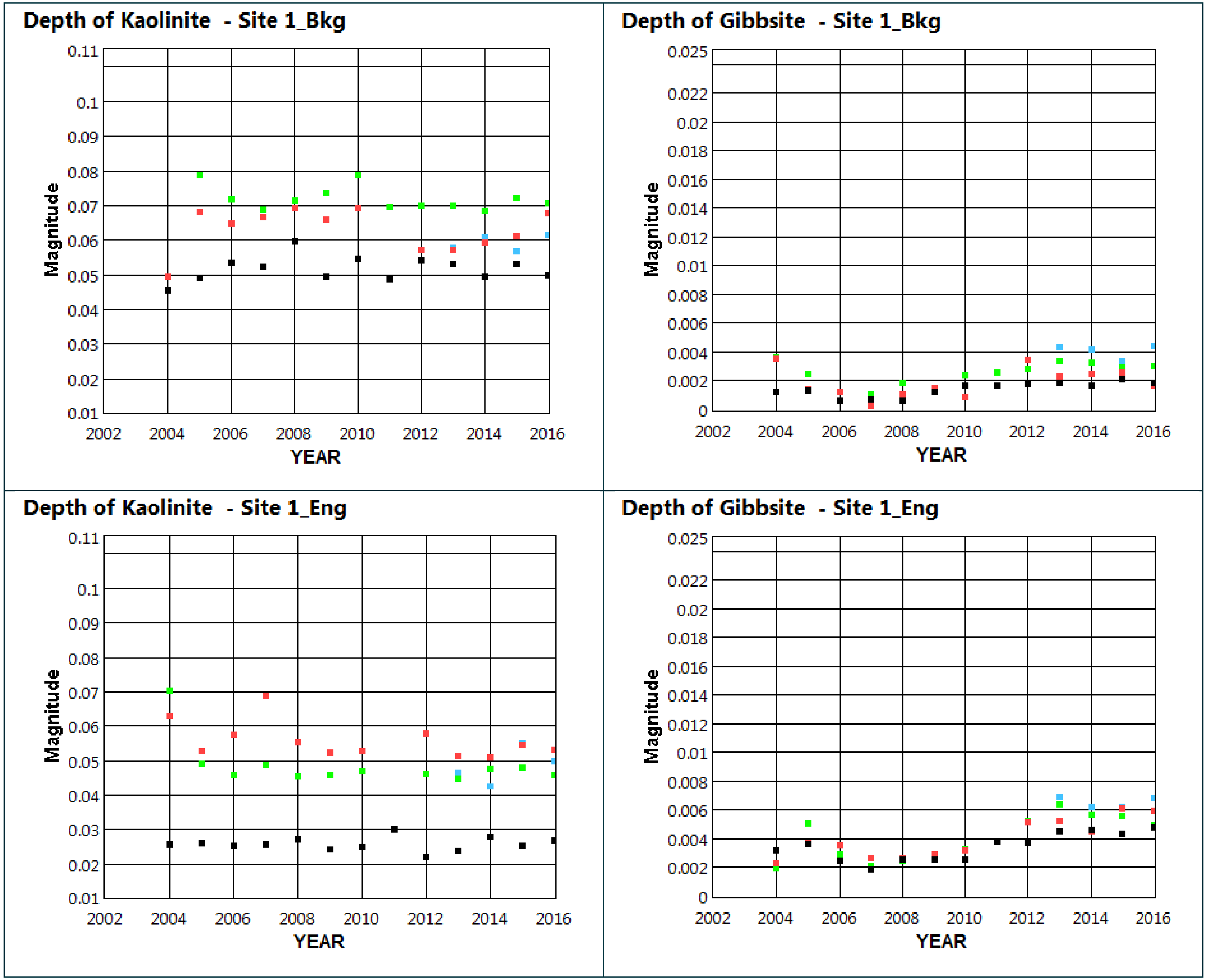
Wavelength of 900nm - Site 23_Bkg
Depth of Chlorite - Site 23_Bkg
Depth of 900nm - Site 23_Eng
Wavelength of 900nm - Site 23_Eng
Depth of Chlorite - Site 23_Eng
Magnitude
YEAR
2002 2004 2006 2008 2010 2012 2014 2016
0.0093 0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.19
881 885 890 895 900 905 910 913
0.00021 0.02 0.04 0.06 0.08 0.1 0.13


Depth of Kaolinite - Site 1_Bkg
Magnitude
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0.1
0.09
0.08
0.07
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0.05
0.04
0.03
0.02
0.01
2002 2004 2006 2008 2010 2012 2014 2016
YEAR
Depth of Gibbsite - Site 1_Bkg
Magnitude
0.025
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
2002 2004 2006 2008 2010 2012 2014 2016
YEAR
Depth of Kaolinite - Site 1_Eng
Magnitude
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
2002 2004 2006 2008 2010 2012 2014 2016
YEAR
Depth of Gibbsite - Site 1_Eng
Magnitude
0.025
0.022
0.02
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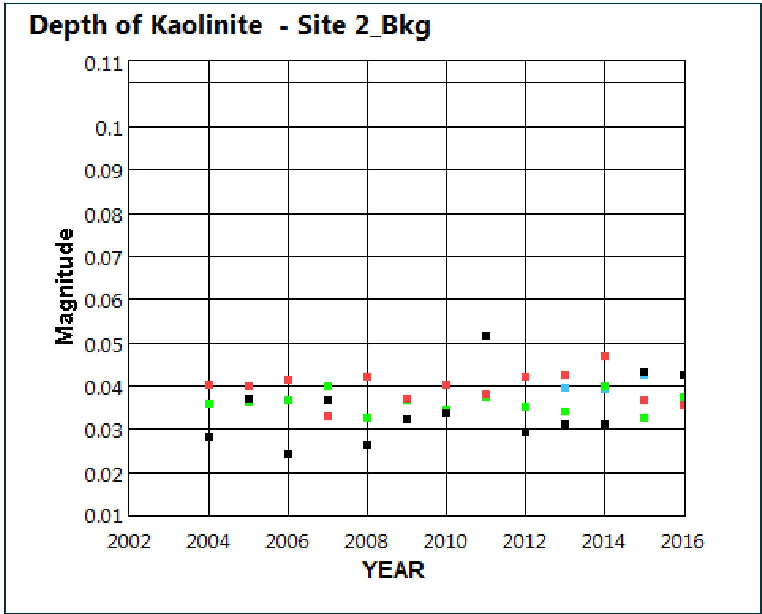
2002 2004 2006 2008 2010 2012 2014 2016
YEAR


Depth of Kaolinite - Site 2_Bkg
Magnitude
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0.02
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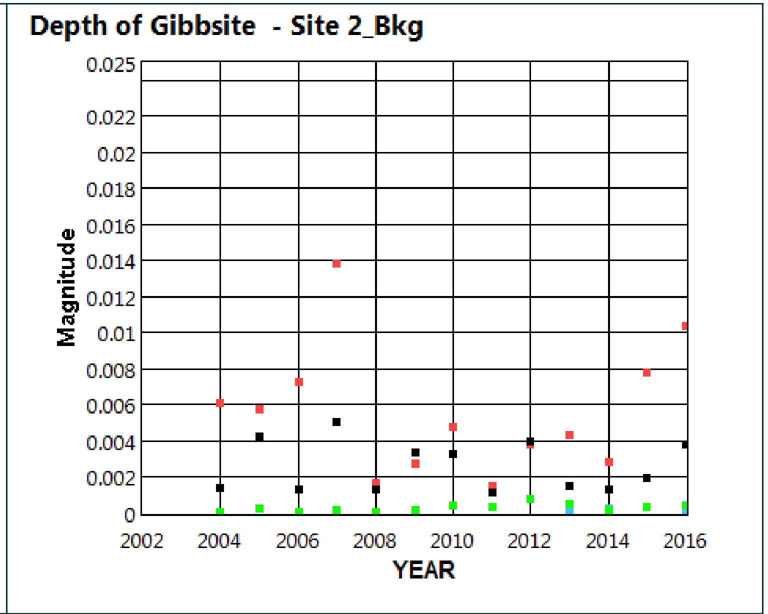
2002
2004
2006
2008
2010
2012
2014
2016
YEAR


Depth of Gibbsite - Site 2_Bkg
Magnitude
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0.02
0.018
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0.002
0
2002
2004
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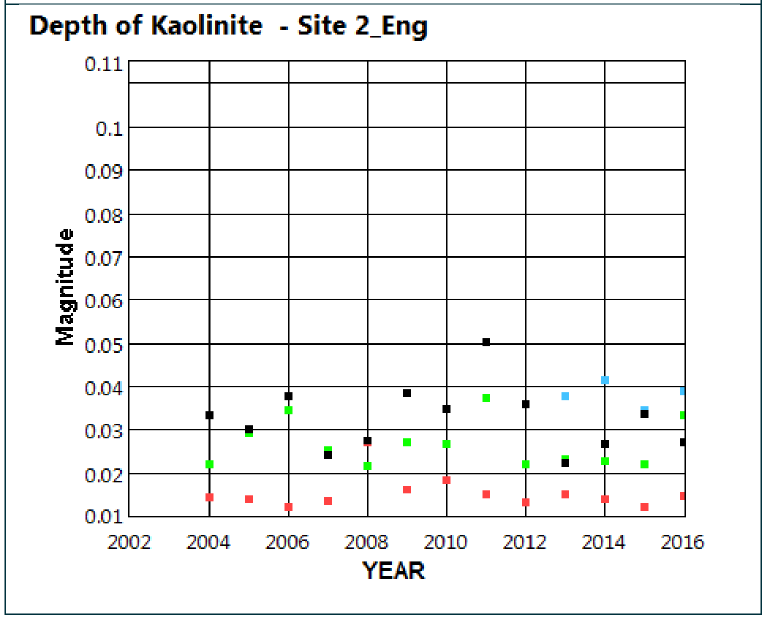
2012
2014
2016
YEAR


Depth of Kaolinite - Site 2_Eng
Magnitude
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0.02
0.01
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2004
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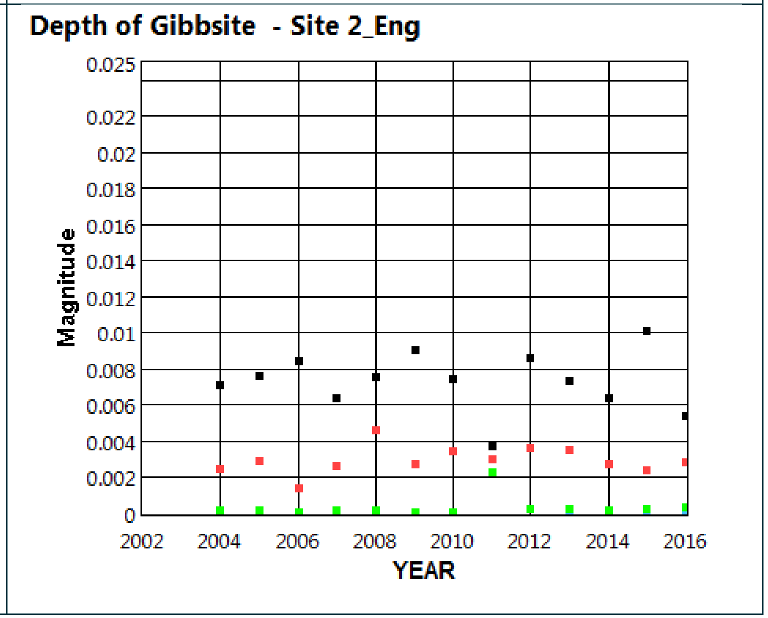
YEAR


Depth of Gibbsite - Site 2_Eng
Magnitude
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0.022
0.02
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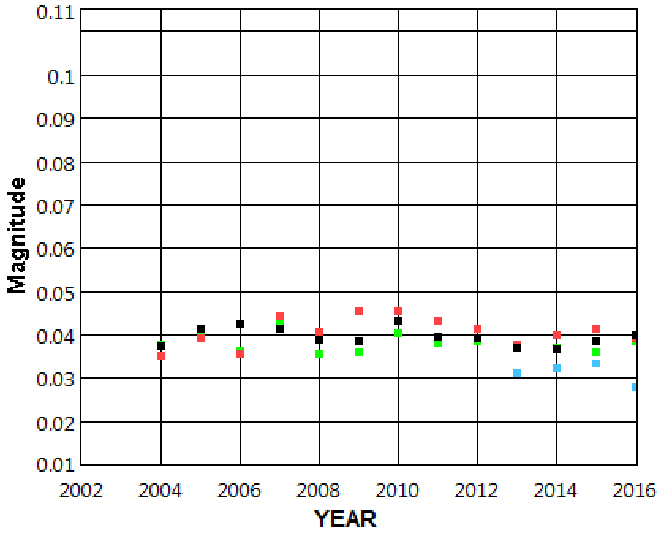
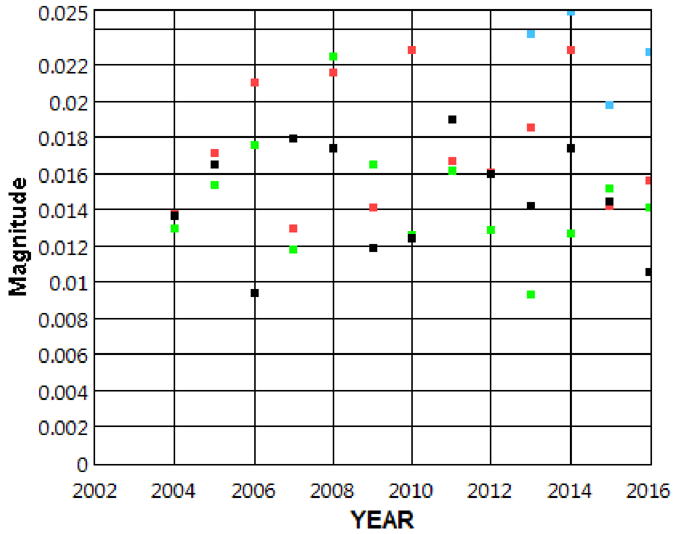
0.012
0.01
0.008
0.006
0.004
0.002
0
2002
2004
2006
2008
2010
2012
2014
2016
YEAR

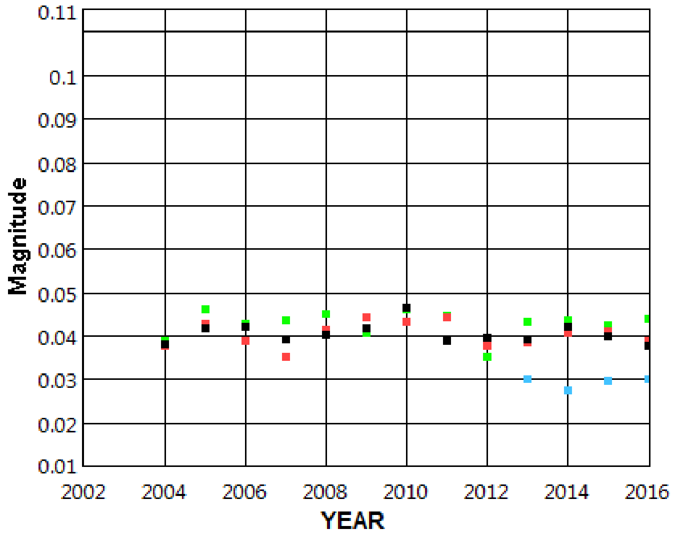
Depth of Kaolinite - Site 4_Bkg



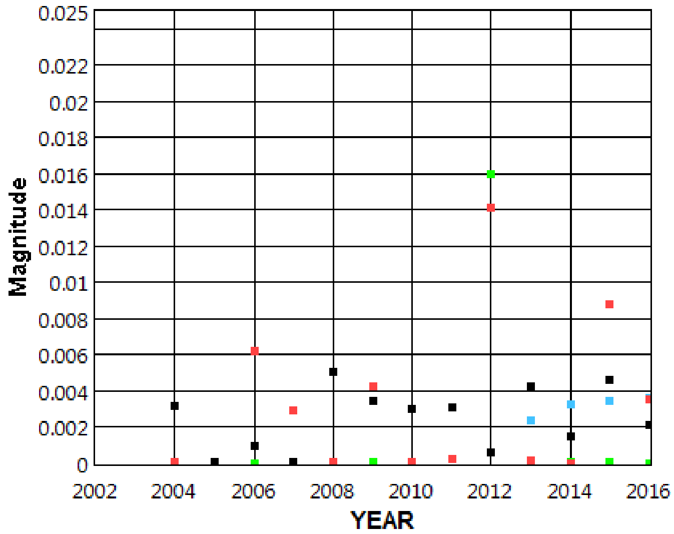
Depth of Gibbsite - Site 4_Bkg

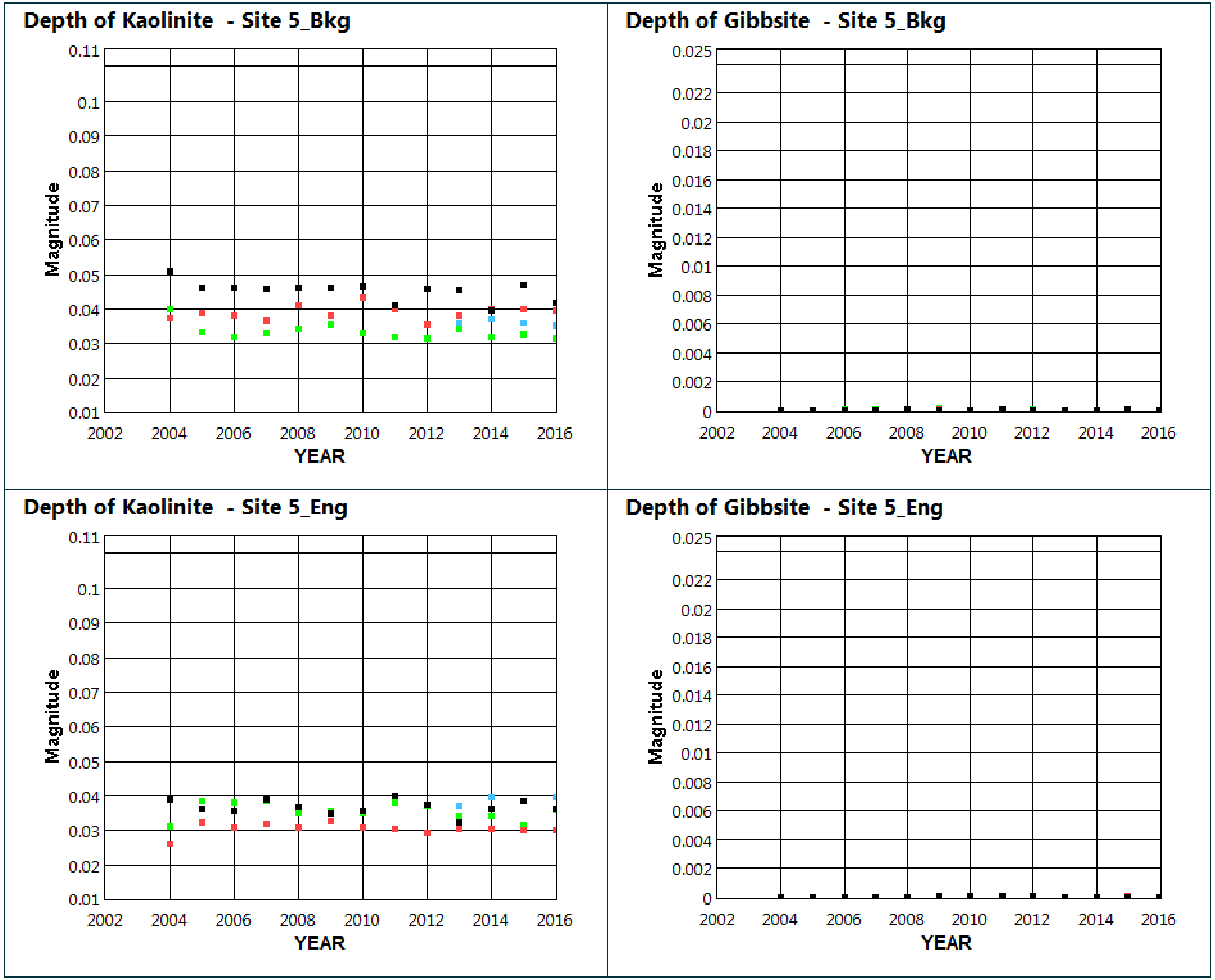


Depth of Kaolinite - Site 4_Eng



Depth of Gibbsite - Site 4_Eng




Depth of Kaolinite - Site 5_Bkg
Magnitude
YEAR
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
2002
2004
2006
2008
2010
2012
2014
2016
Depth of Gibbsite - Site 5_Bkg
Magnitude
YEAR
0.025
0.022
0.02
0.018
0.016
0.014
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0.008
0.006
0.004
0.002
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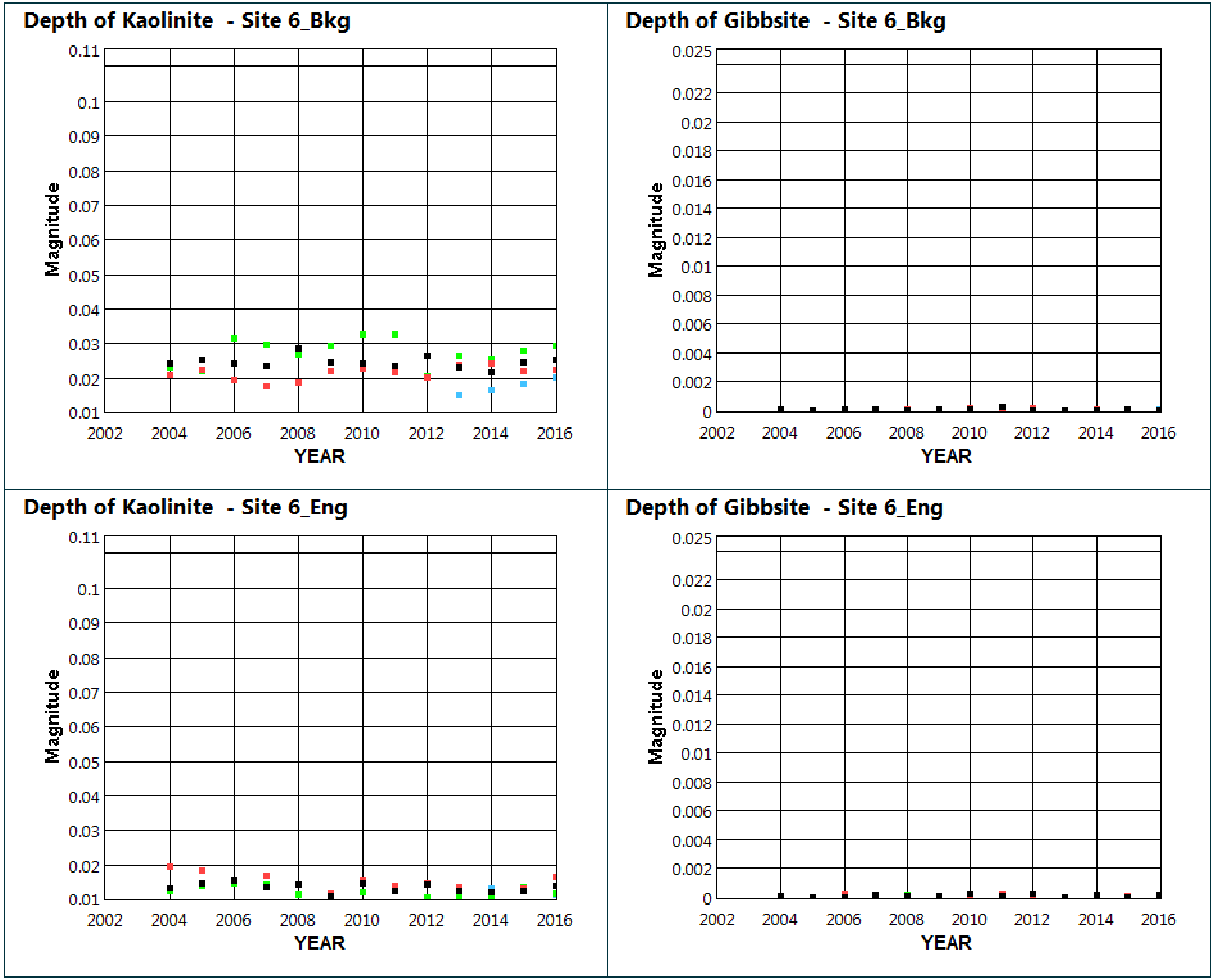
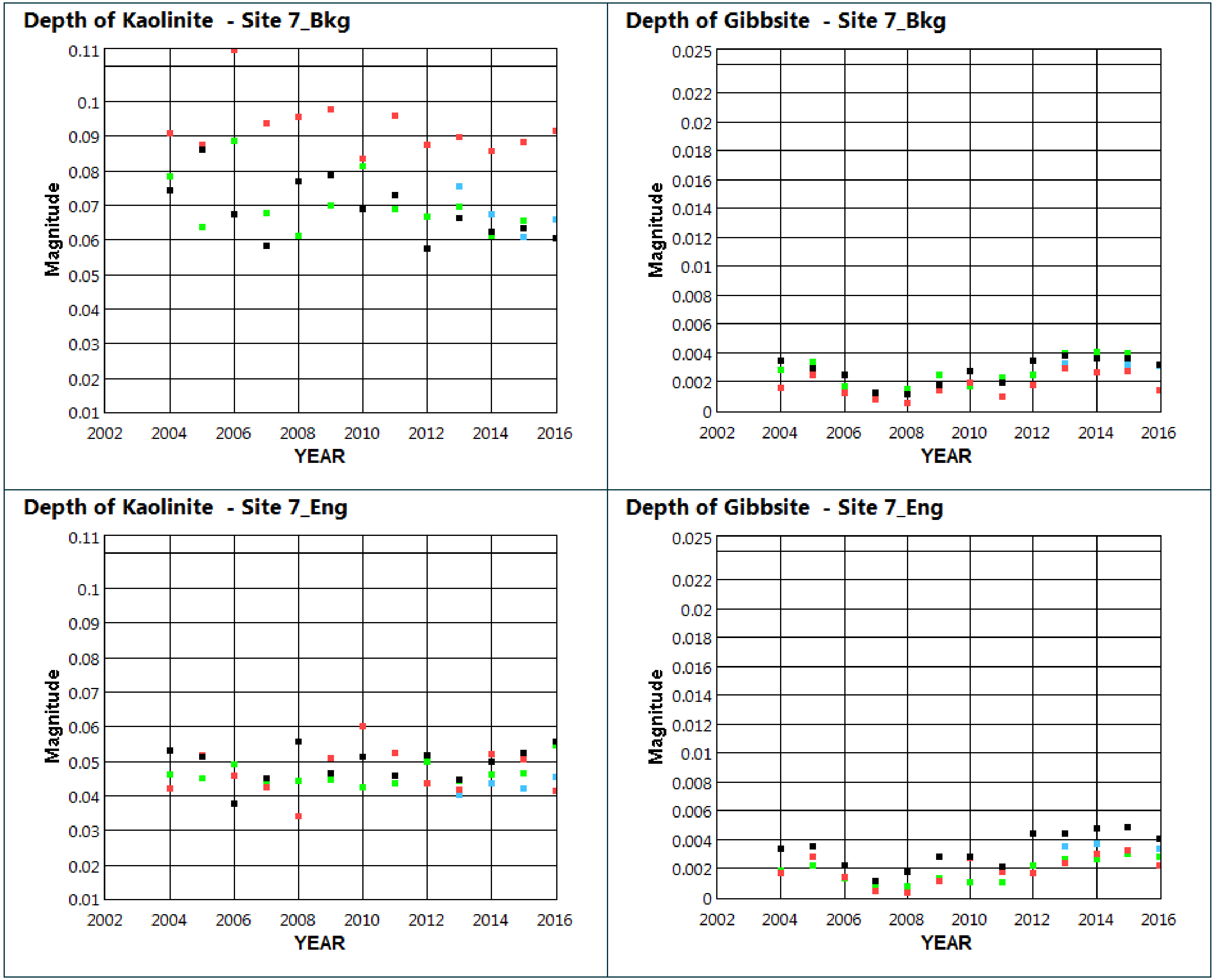
Depth of Kaolinite - Site 5_Eng
Depth of Gibbsite - Site 5_Eng


Depth of Kaolinite - Site 6_Bkg
Magnitude
YEAR
Depth of Gibbsite - Site 6_Bkg
Magnitude
YEAR
Depth of Kaolinite - Site 6_Eng
Magnitude
YEAR
Depth of Gibbsite - Site 6_Eng
Magnitude
YEAR



Depth of Kaolinite - Site 7_Bkg
Magnitude
YEAR
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0.09
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0.07
0.06
0.05
0.04
0.03
0.02
0.01
2002
2004
2006
2008
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2012
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2016
Depth of Gibbsite - Site 7_Bkg
0.025
0.022
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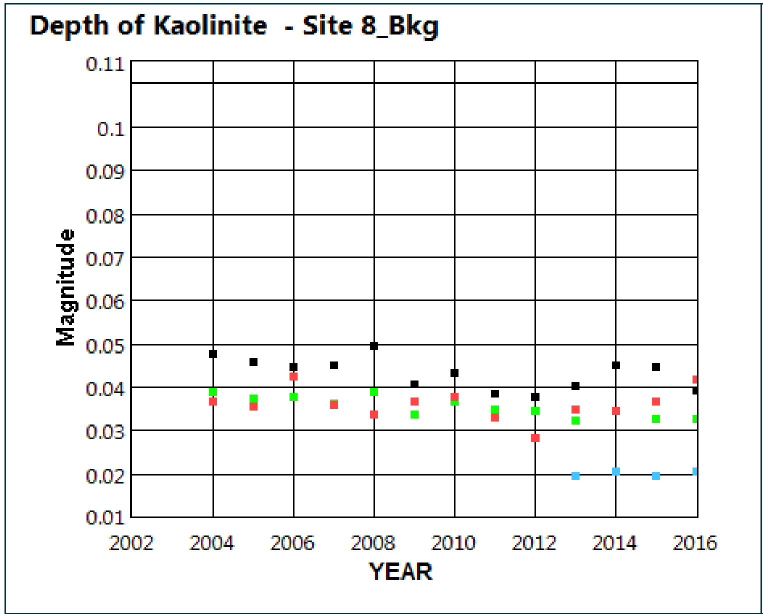
Depth of Kaolinite - Site 7_Eng
Depth of Gibbsite - Site 7_Eng


Depth of Kaolinite - Site 8_Bkg
Magnitude
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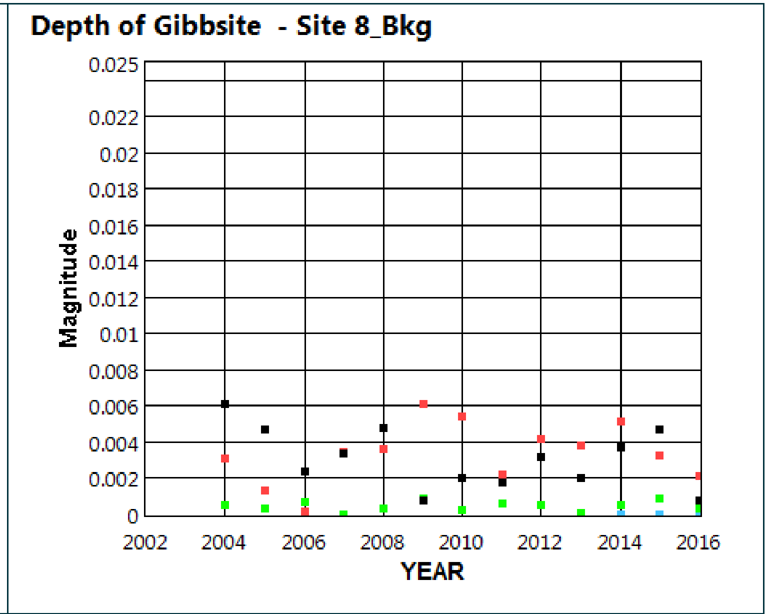
Depth of Gibbsite - Site 8_Bkg
Magnitude
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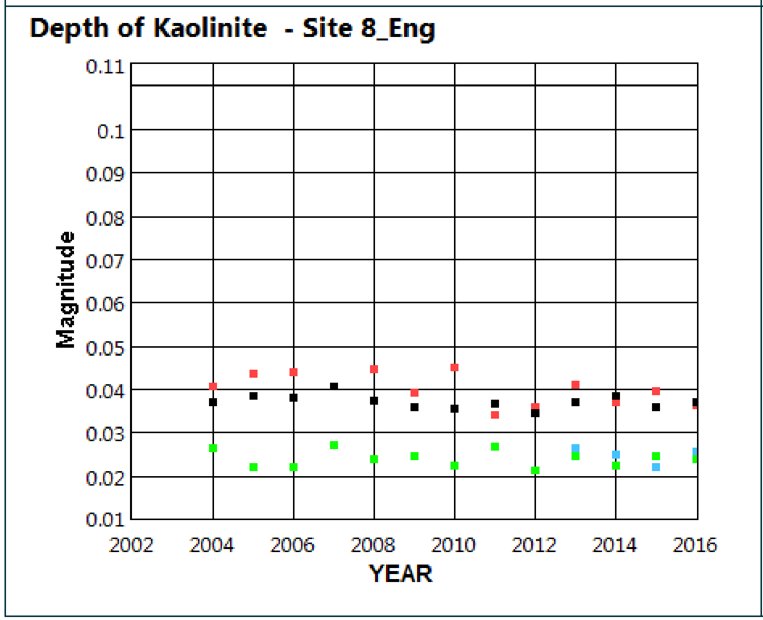
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Magnitude
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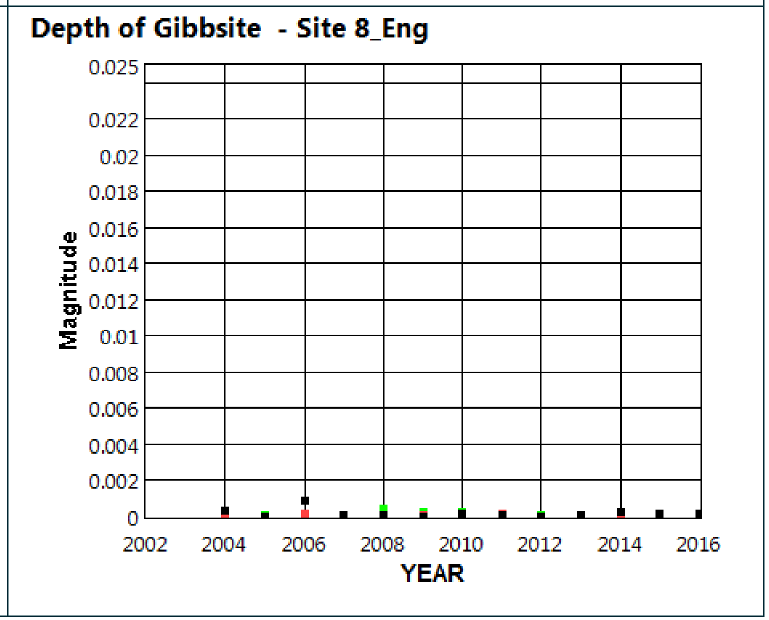
YEAR


Depth of Gibbsite - Site 8_Eng
Magnitude
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0.01
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0.006
0.004
0.002
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2002
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2008
2010
2012
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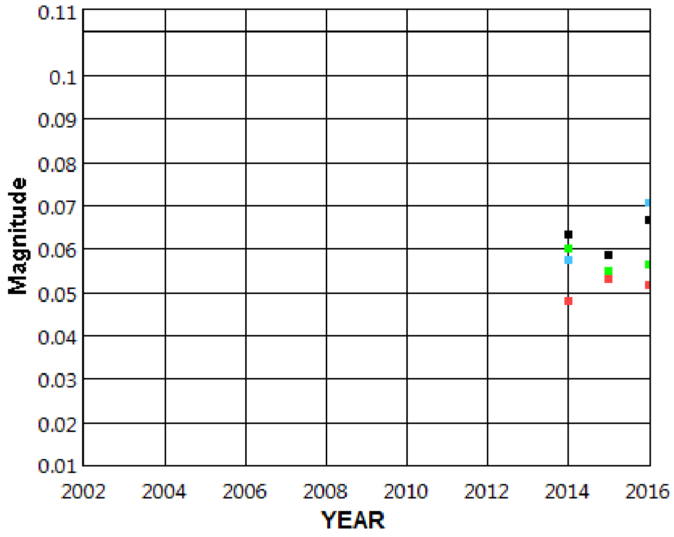
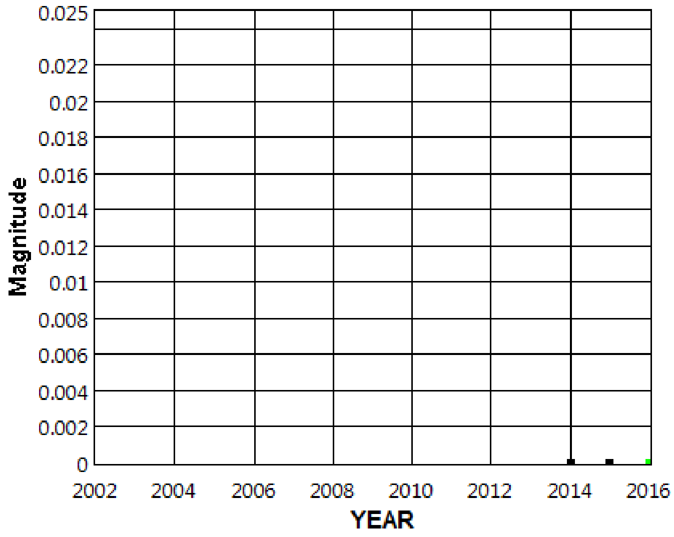
2016
YEAR

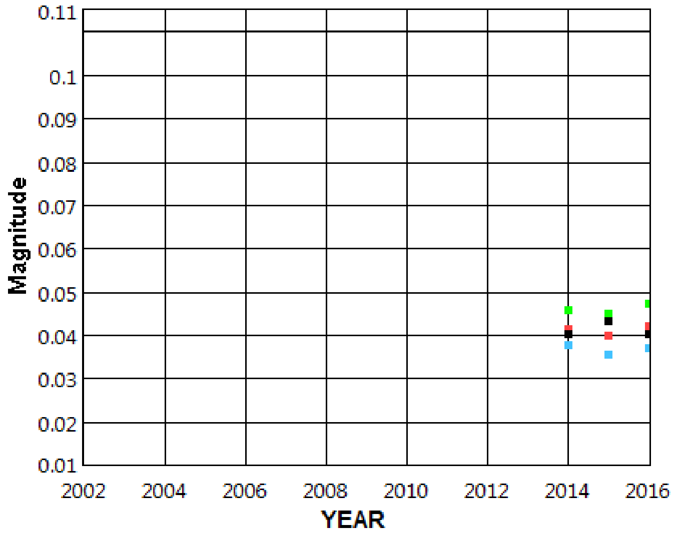
Depth of Kaolinite - Site 21_Bkg



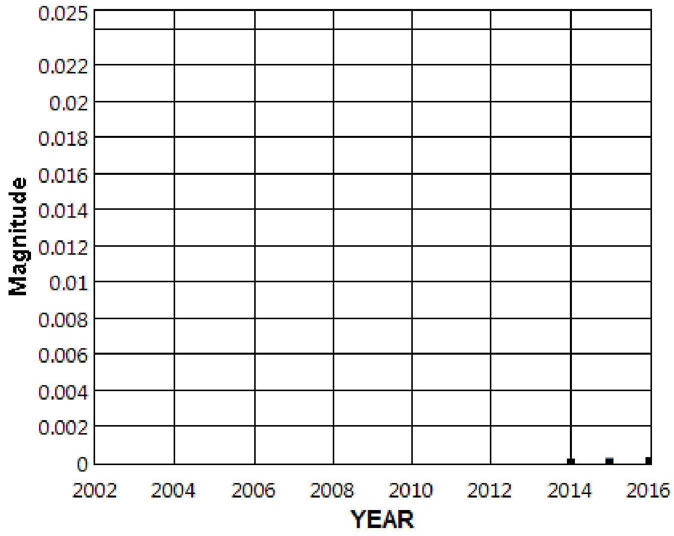
Depth of Gibbsite - Site 21_Bkg

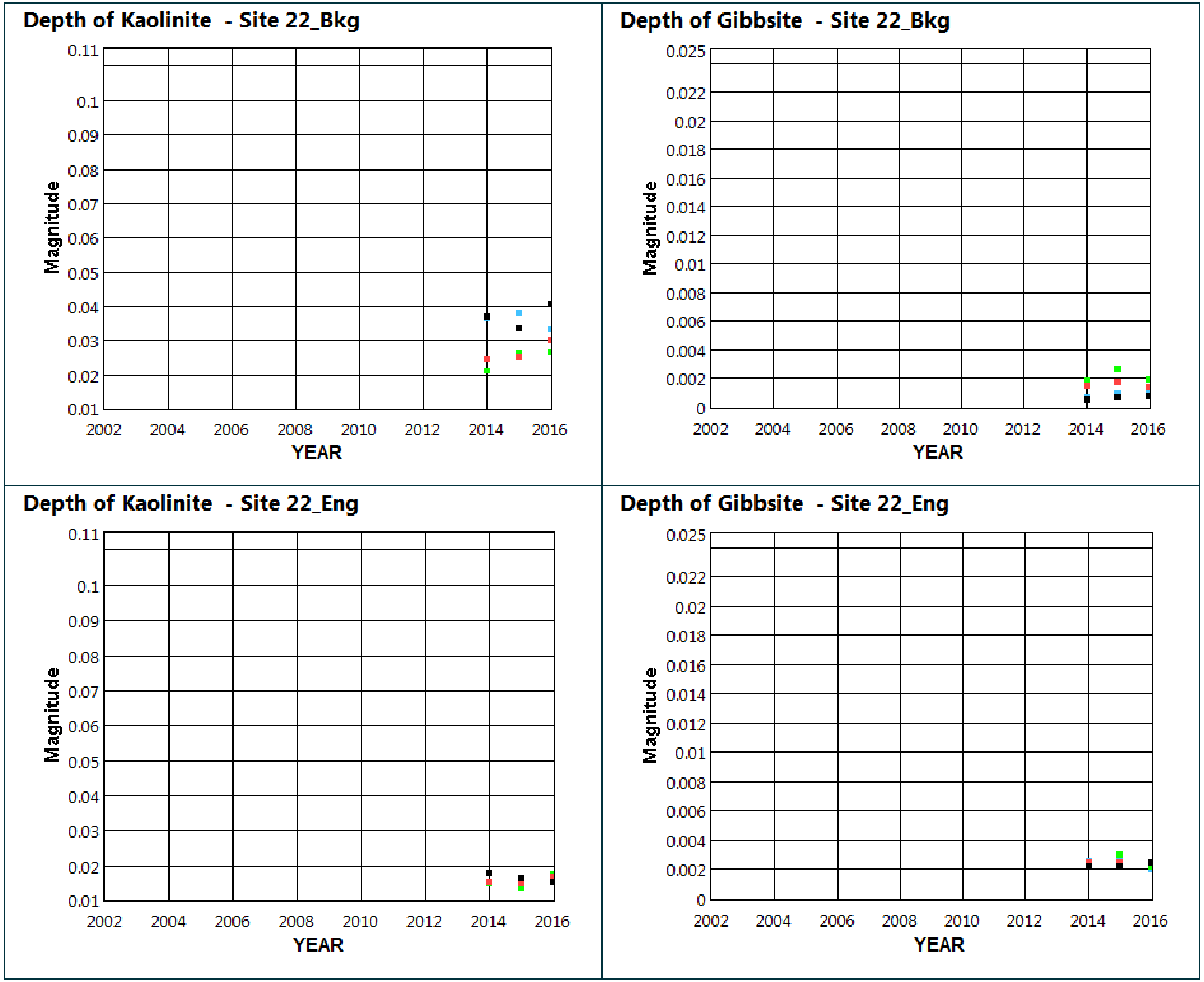


Depth of Kaolinite - Site 21_Eng



Depth of Gibbsite - Site 21_Eng




Depth of Kaolinite - Site 22_Bkg
Magnitude
YEAR
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2016
Depth of Gibbsite - Site 22_Bkg
Magnitude
YEAR
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0.016
0.014
0.012
0.01
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0.002
0
Depth of Kaolinite - Site 22_Eng
Magnitude
YEAR
Depth of Gibbsite - Site 22_Eng
Magnitude
YEAR

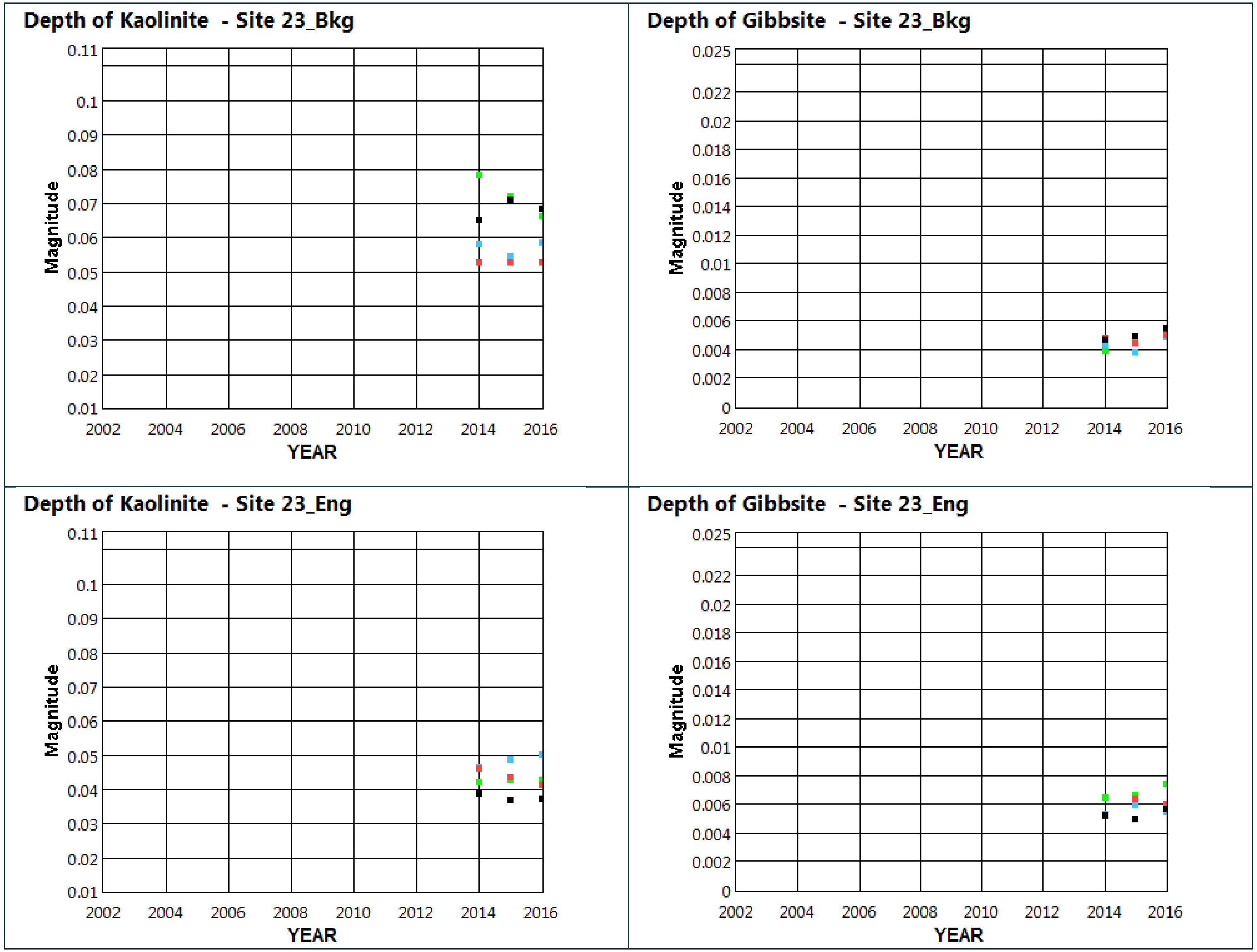

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Figure 18. Spectral parameters for all sites. Each parameter has been expressed with the same scale for all sites.

5.3.1 RESULTS FROM THE SPECTRAL PARAMETERS

The spectral parameters extracted from the reflectance spectra of all sites and, all backgrounds and engravings for both the reference sites (1 and 2) and the sites (4, 5, 6, 7, 8, 21, 22 and 23) close to the industries, show relatively large variations but no systematic changes or trend (Figure 18).

6. Statistical Analysis of BYK, KM and ASD colour measurements

6.1 Introduction

Beginning in 2004, annual measurements of colour were made on Aboriginal rock art at seven sites around the Burrup peninsula, five southern sites close to industry and two northern control sites further from industry (with three further southern sites added in 2014). The control sites are labelled as site 1 and site 2. At each site, three spots were chosen (with another spot per rock added in 2013) and at each spot, measurements were made on both the engraving and a nearby piece of background, using an ASD spectrophotometer. The same instrument has been used throughout all the years of the study.

Measurements of colour values L*, a* and b* were also made with a BYK spectrophotometer from 2004 to 2012. For reasons mentioned earlier, a new KM photospectrometer was introduced in 2009, and has been used each year from then until now. Both BYK and KM measurements (as well as ASD measurements) were thus made from 2009 to 2012.

L* is a measure of lightness, from 0 (black) to 100 (white); a* and b* can take positive or negative values. Higher a* values correspond to increasing red colour and lower values to increasing green colour; b* similarly records the contrast between yellow (high values) and blue (low values). Data has been calculated relative to the D65 standard illuminant, intended to represent average daylight.

Following recent reviews, and correction of a small number of coding errors in the data files, an updated statistical analysis of all the data – totalling over 24,000 colour measurements – was undertaken. Each data point is plotted in Figure 19 to Figure 58. Further reference is made to these figures below.

Summarising the results of this section: there is reason to doubt the validity of data from the BYK spectrophotometer, which contradicts data from the other spectrometers. Data from the KM spectrophotometer appears to suggest that there is significant change in L* values over time, but not in a* or b* values. Data from the ASD spectrometer indicates possible change over time in the L* and a* data, but not the b* data. None of the instruments demonstrates any difference in the rate of change between northern and southern sites.

6.2 Comparing BYK and KM photospectrometers

Among the reasons for replacing the BYK photospectrometer was the high variation in measurements taken with it, as illustrated in plots of the data (e.g. Figure 19). Note that the variation in BYK measurements is generally larger on the engraving. This is likely in part because engravings are in most cases not very wide and tend to be rougher than the background rock. Thus, it may be harder to place the spectrophotometer perfectly flat against the rock surface (measurements are made by holding the spectrophotometer against the targeted part of the rock). This problem does not affect the KM instrument, which has a smaller head, to the same extent as it does the BYK spectrophotometer.

The BYK instrument also recorded some very dark colours, even on the engravings, which on most rocks are lighter than the background rock. The average colour recorded by each instrument on the background and engraving at each spot on each rock is drawn in Figure 19 to Figure 58. The BYK instrument, alone, has extremely dark average colour measurements at some sites. This may indicate the instrument was unable to be placed flat on the rock. Low lightness values can indicate that some reflected light has escaped through the tiny gap between instrument and rock surface. There are even several cases such as that shown in Figure 19 where the BYK instrument recorded the engraving to be lighter than the background, while the other instruments gave the opposite conclusion.

A regression calibration between the two instruments in 2013 suggested that KM measurements could be predicted 'with at least reasonable accuracy' using the BYK data, despite 'occasional strong differences' between the two data sets. The report noted that KM data can be predicted with reasonable accuracy simply by knowing the site, spot and type (background or engraving). Indeed, the variation that can be explained by these factors is greater than that explicable by the BYK measurements of the same features. However, taking these factors into account, the BYK measurement of L* significantly improved the estimation of the KM measurement of L*, and tests show the BYK measurements of a* and b* to contribute less information, offering no significant improvement alongside the BYK L* measurement. The same applies to corresponding estimation of a* and b*.

However, this only shows the measurements are correlated – and by a different relationship on each spot. (As noted, this means the regressions give no general method of predicting KM data from BYK – but for the purposes of the analysis, no such generalisation is needed.) The dependence on spot again suggests that the BYK photospectrometer was affected by the varying nature of the surfaces of the rocks to which it was applied. The given standard errors for predicting KM data were around 1 unit for each of L*, a* and b*, quite large given that the median range of these variables on any spot (as depicted in Figure 19 to Figure 58) is around 7 units (L*, b*) or 4 units (a*). In addition, a calibration model independent of measurement location would have substantially greater standard errors again.

A more important concern is that the largest changes in BYK occurred before any KM measurements were made (see for example Figure 39). Regardless of the calibration method used, it is questionable whether correlations calculated from stable BYK data would extrapolate to the earlier data, which is more variable and lies outside the range on which the correlations were established. The early trends of BYK data show in some cases dramatic change; but in later years, these trends are much more stable. (A simple solution would be that the last years of BYK data plotted in Figure 19 to Figure 58 have in fact already been converted, via the above calibration, in order to compare more closely with KM data; however, a check of the data that was used for calibration regressions rules out this explanation.)

An objective assessment of both BYK and KM data becomes available by calculating L*, a* and b* from the spectra recorded with the ASD spectrophotometer. Conversion from the recorded spectra to L*, a* and b* data was performed using proprietary CSIRO software. These converted L*, a* and b* values are the ASD data plotted in Figure 19 to Figure 58. As illustrated for example in Figure 19, the ASD data is steady across the entire time period, comparable with the KM values and contrasting with some BYK data.

(Note that L*, a* and b* values have been calculated from each individual spectrum recorded on the ASD spectrophotometer. The average values used in this document are averages of these individual transformed values, though the transformation process is nonlinear so this result differs slightly from the values calculated from an average spectrum. This approach follows independent advice obtained from Data Analysis Australia.)

Figure 59 to Figure 61 compare the colour measurements of BYK and KM measurements with those calculated from ASD spectra across the background and engraving of all sites and spots in all years. The agreement with the KM instrument is fairly close, with fairly high values of R^2 around 0.8 (meaning the correlation between the values is around 90 %) and the dashed regression lines close to the theoretical solid line. However, the correlations with the BYK instrument are fairly poor, with low R^2 values of 0.4 or less, and the regression lines diverge far from the solid line, indicating that measurements on the two instruments are far from equivalent. The BYK instrument tends to give lower estimates of L*, as noted, as well as a* and b*.

Figure 59 to Figure 61 show the difference between measurements from the ASD and BYK instruments varies widely across the sites, and is more pronounced on engravings. This again suggests that unevenness, which varies across sites but tends to be greater on engravings, may have caused BYK data to be unreliable.

Since the ASD and KM values agree well, and the BYK instrument agrees with neither, this tends to discredit the accuracy of data measured using the BYK instrument. As noted previously, the BYK instrument has higher variation, particularly on engravings; meaning that some colours appear darker than the backgrounds. This contradicts the other instruments where the backgrounds are always darker than the associated engravings. The strong trends identified in the BYK data are not found in either the KM or ASD data, this suggests that the BYK data is of doubtful value in understanding colour change in the rocks.

This agrees with the recent independent conclusions of Data Analysis Australia.

While it is important to be clear that the recorded BYK data do show significant directional colour change over time, at differing rates on background and engraving of each spot at each site, the doubts over this BYK data make it impossible to conclude that it proves colour change actually occurred.

(Ignoring for a moment these reservations, it is noteworthy that the trends in BYK data from southern sites near industry do not differ significantly from the trends recorded at northern control sites further from industry. The BYK data from northern site 1, plotted in Figures 19-21, shows as much change as the southern sites, and more than several (compare for example the BYK data from site 6, plotted in Figure 35 to Figure 37). The BYK data thus does not demonstrate any difference in colour change between southern sites close to industry and northern control sites.)

However, for the reasons given above, conclusions on the changes in the rocks cannot reliably be based on the BYK data. Rather, analysis should be conducted of data both from the KM spectrophotometer since its introduction and from the ASD spectrophotometer (the only instrument used for all years of the study), before overall conclusions are drawn.

It should be noted that, as data from the BYK spectrophotometer appears unreliable for drawing conclusions on colour change in the rock art, the cross calibration issues with the BYK – Gardner (BYK) portable photospectrometer and the Konica Minolta (KM) photospectrometer will not be undertaken.

All the photospectrometer data have been provided to DER for safekeeping.

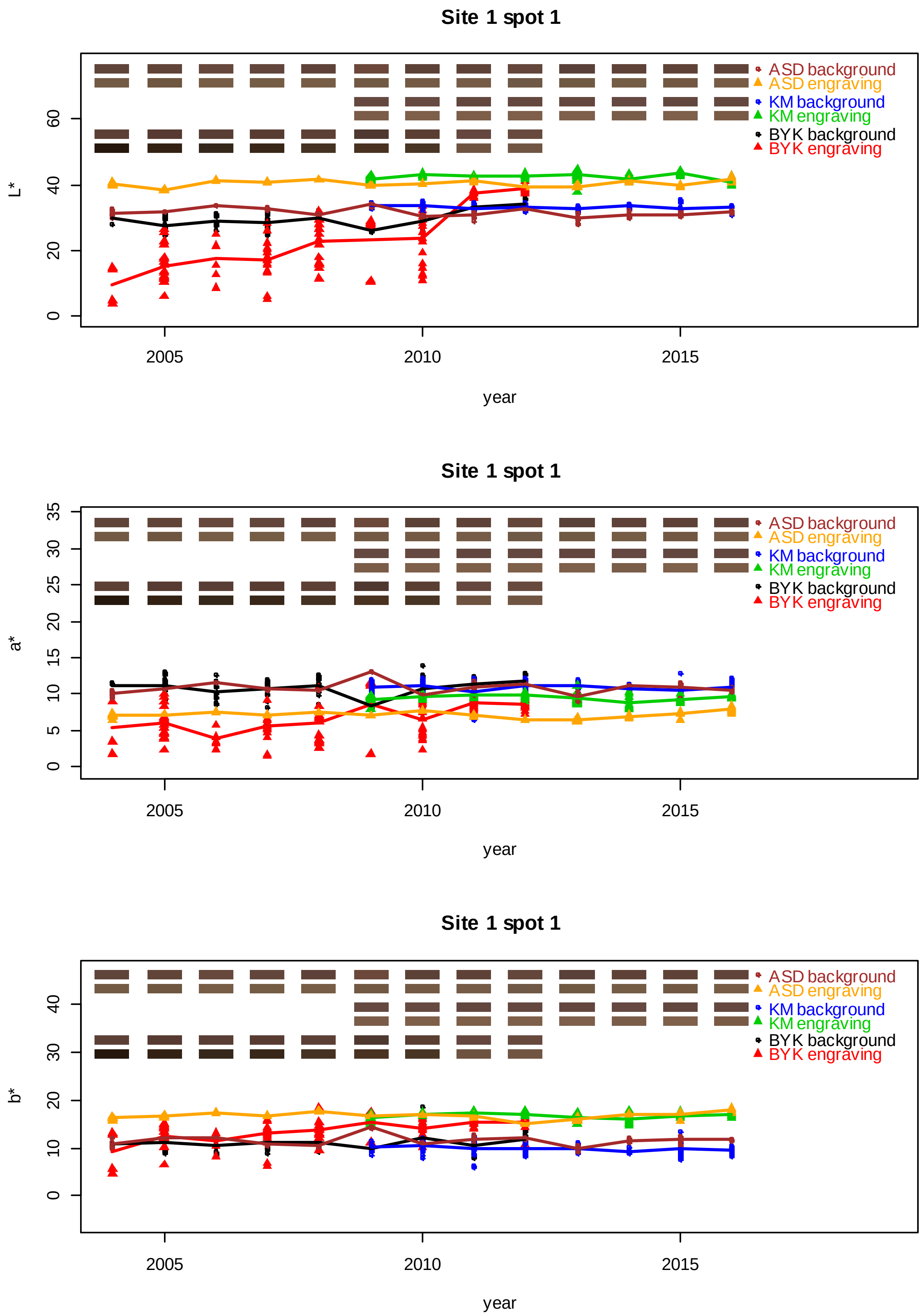
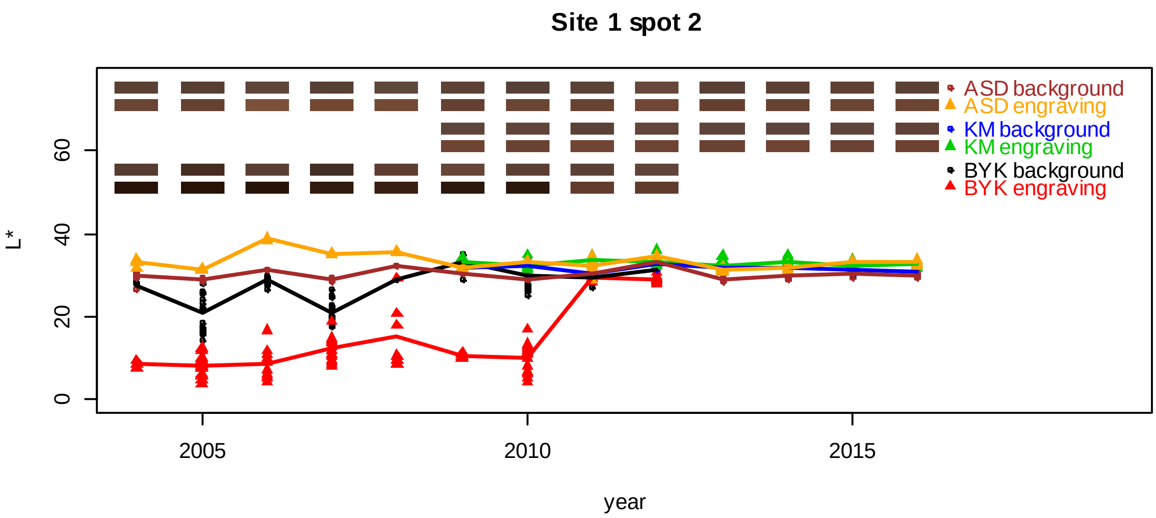


Figure 19. The three plots show L*, a* and b* measurements respectively from BYK, KM and ASD spectrometers for background and engraving on site 1 spot 1. Rectangles above each graph show the average recorded colour for each measurement in each year (identical in each graph). Change in these recorded colours over time is hard to detect visually, except in the BYK data.



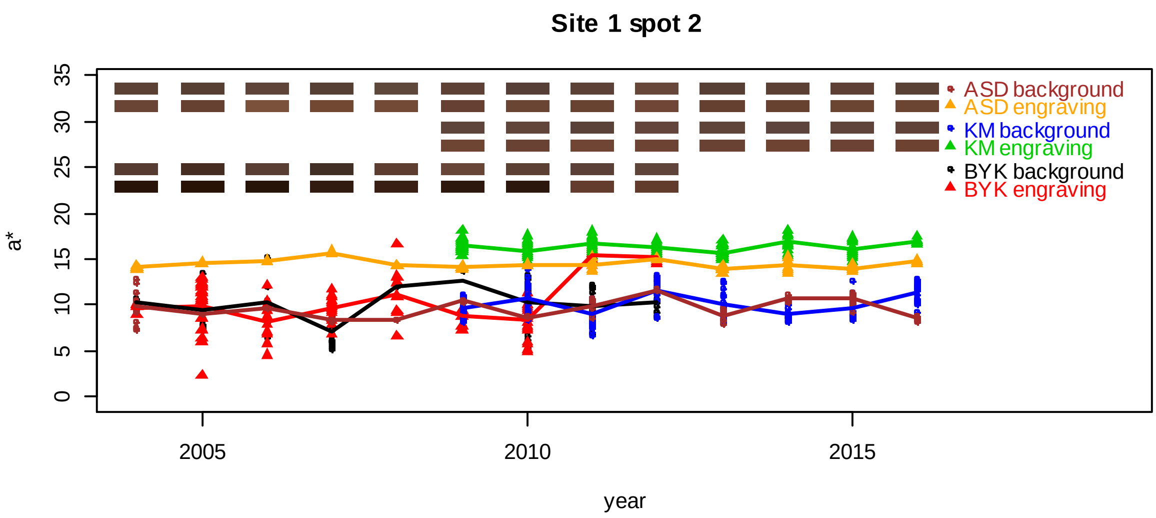


Figure 20. Site 1 spot 2 colour measurements, plotted as in Figure 19

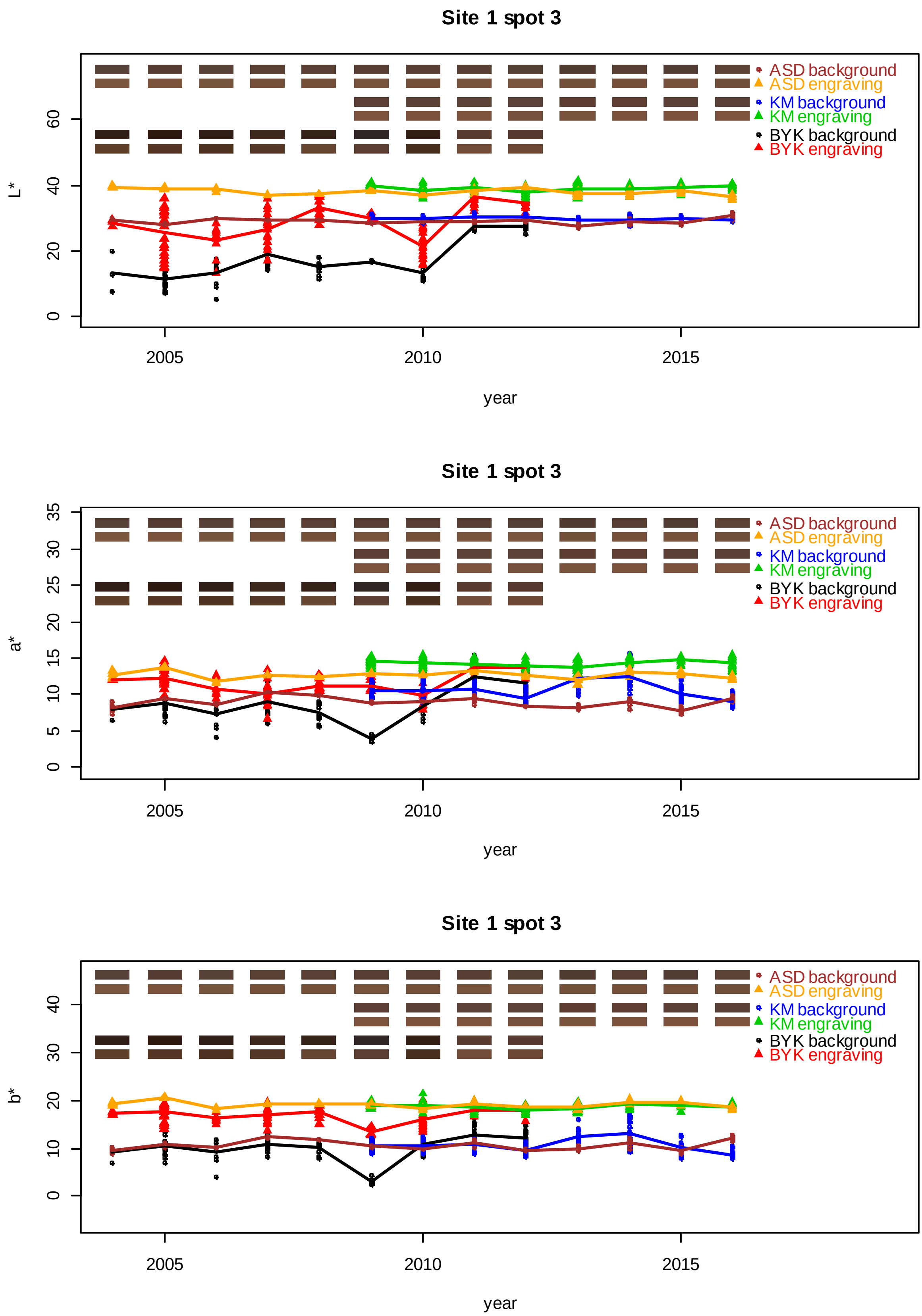


Figure 21. Site 1 spot 3 colour measurements, plotted as in Figure 19.

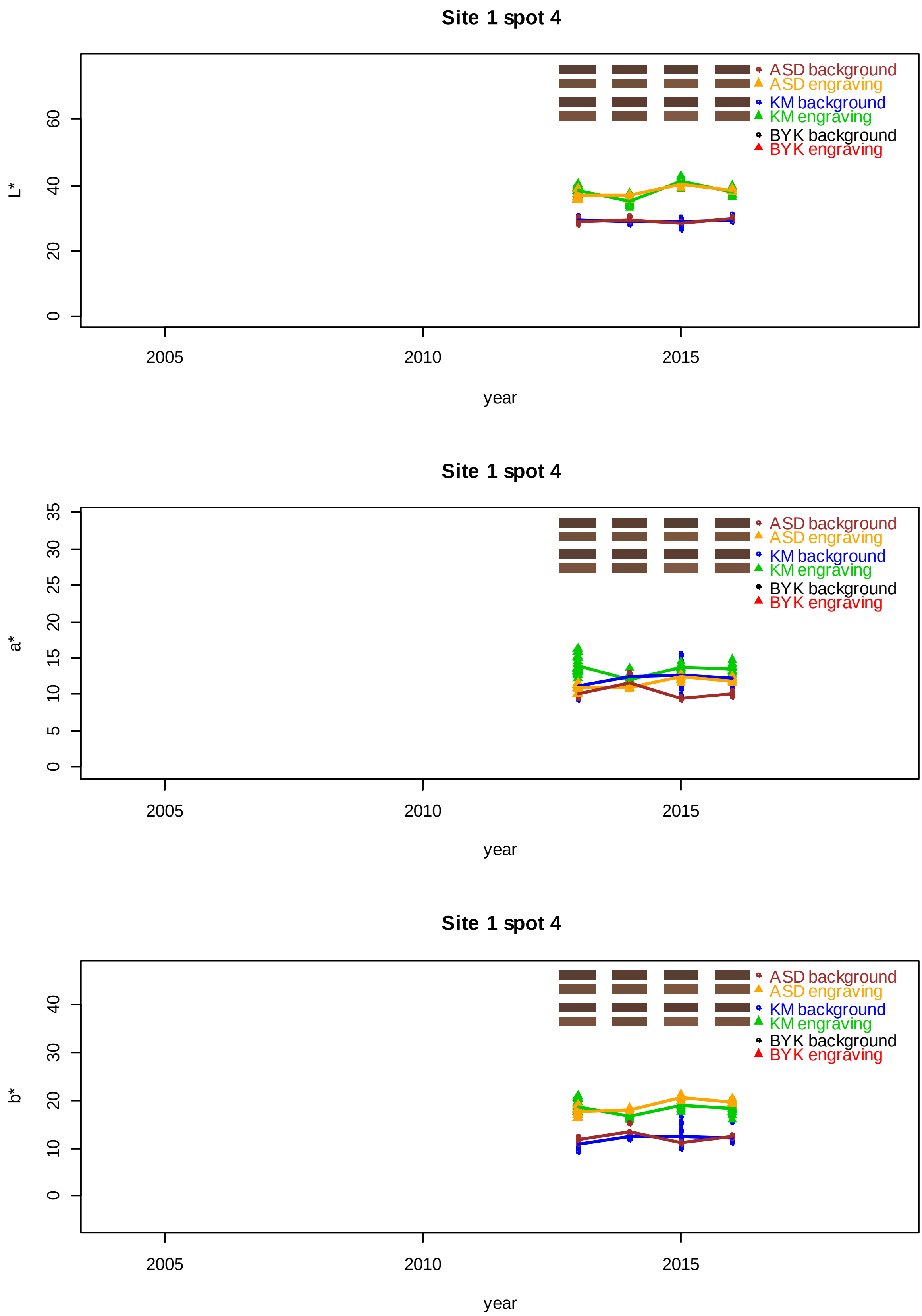


Figure 22. Site 1 spot 4 colour measurements, plotted as in Figure 19.

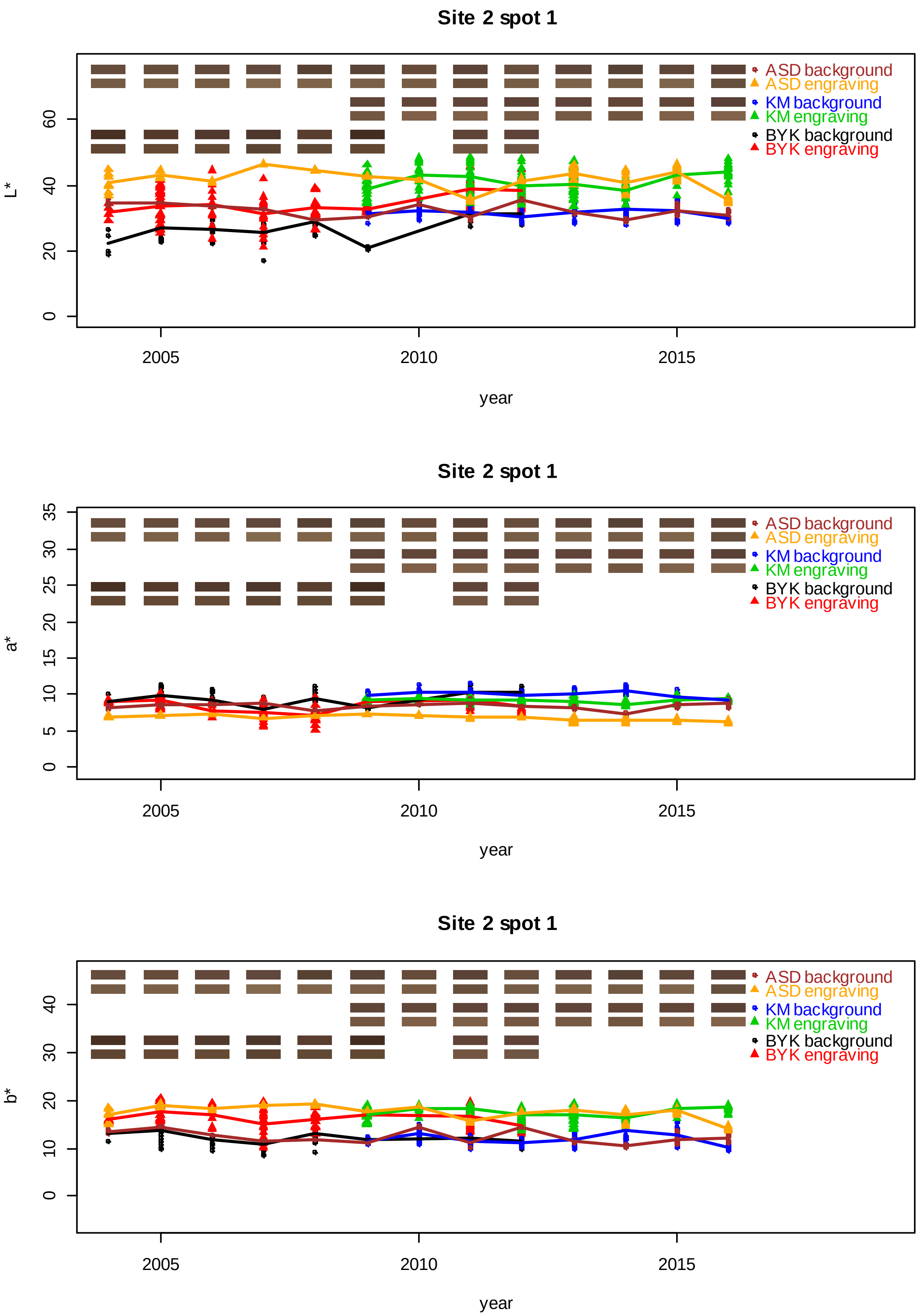


Figure 23. Site 2 spot 1 colour measurements, plotted as inFigure 19.

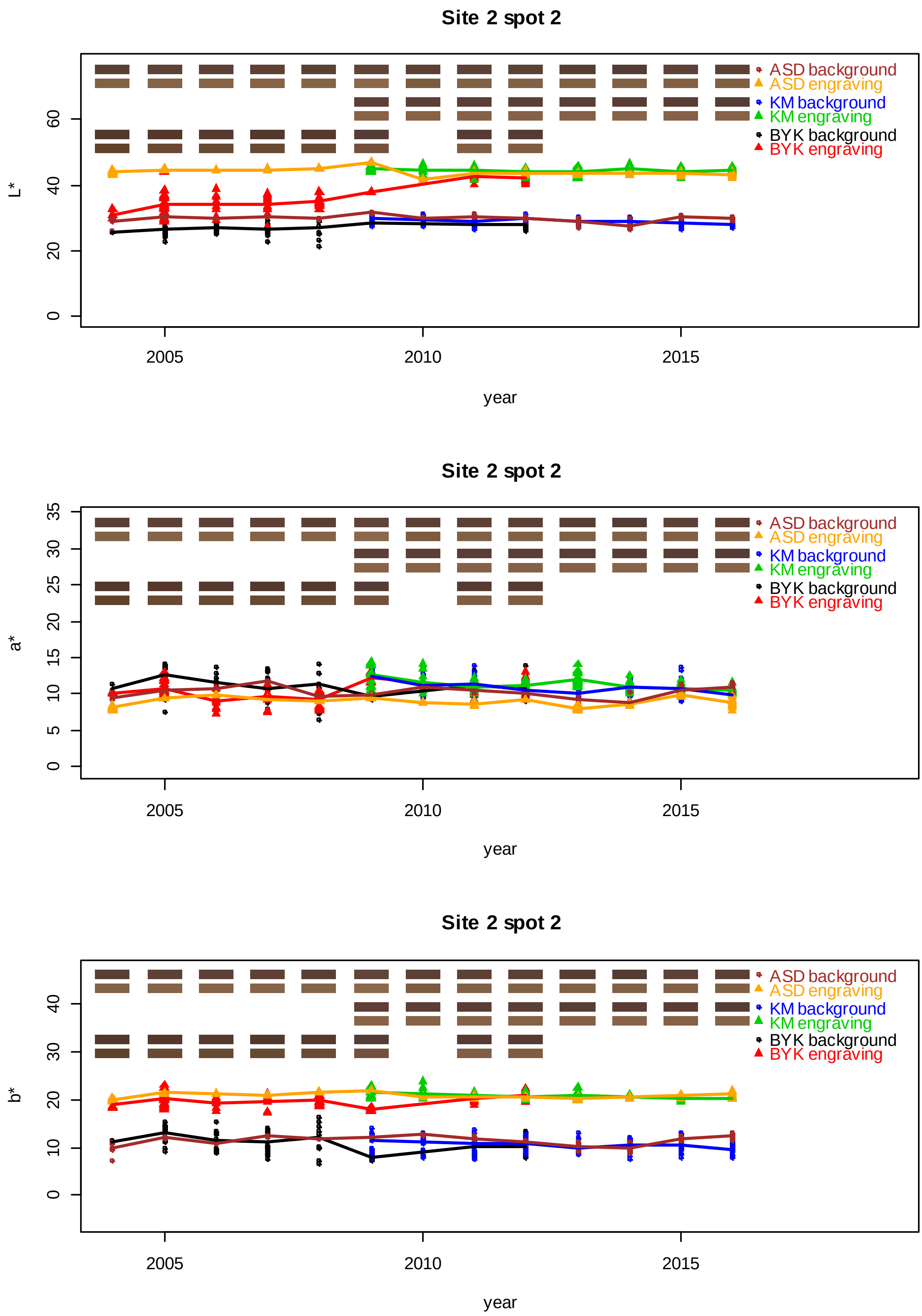


Figure 24. Site 2 spot 2 colour measurements, plotted as in Figure 19.

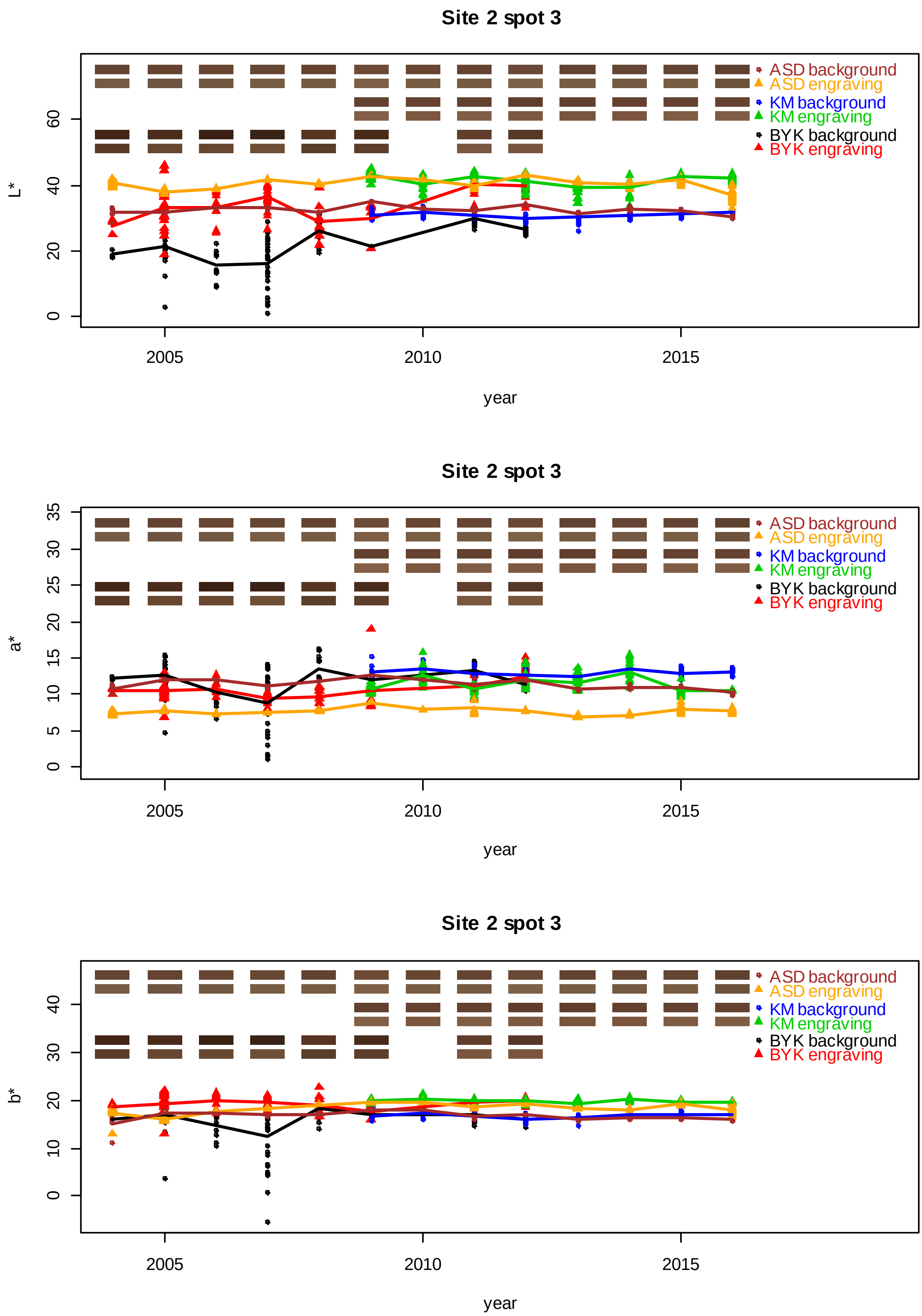


Figure 25. Site 2 spot 3 colour measurements, plotted as in Figure 19.

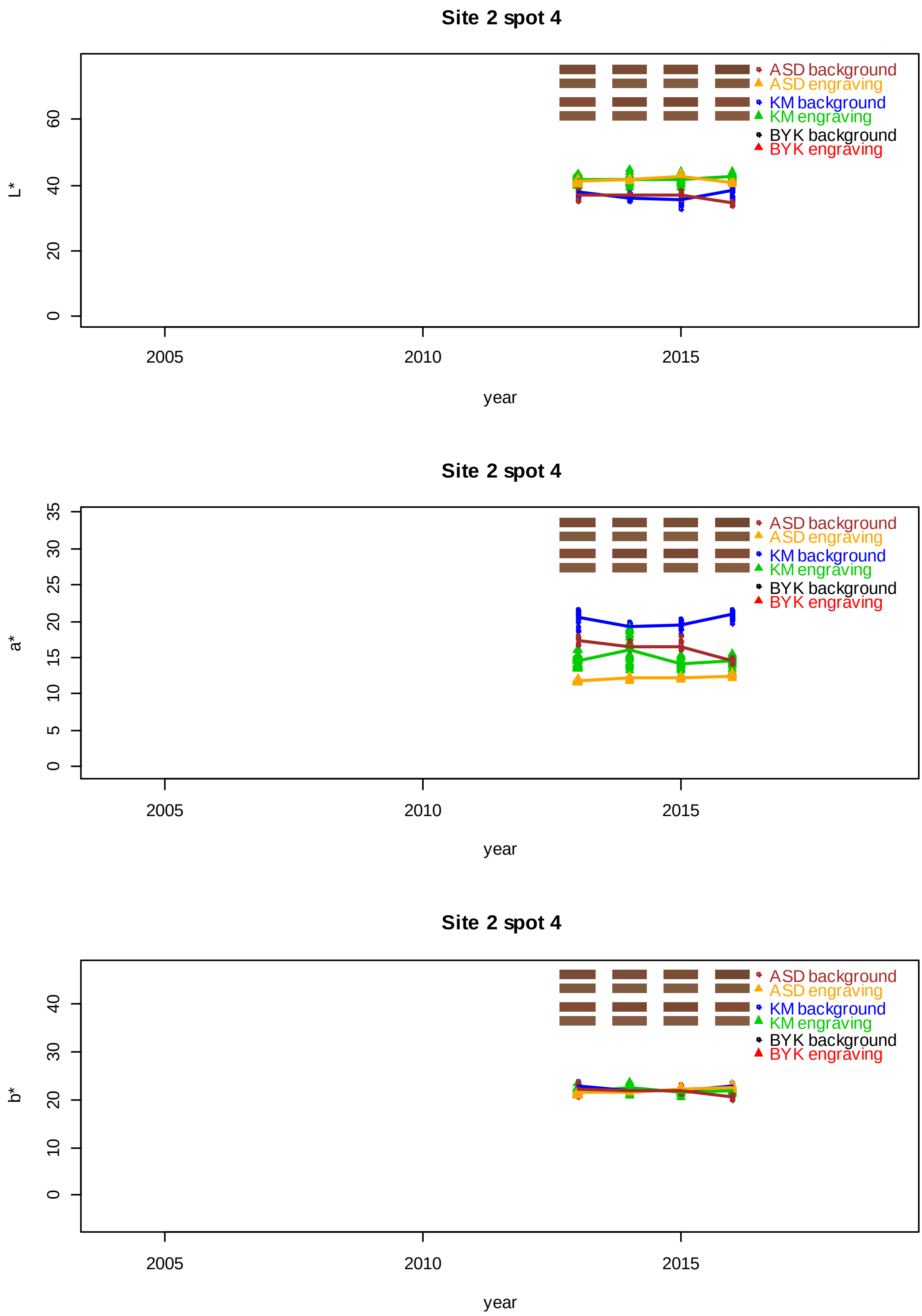


Figure 26. Site 2 spot 4 colour measurements, plotted as in Figure 19.

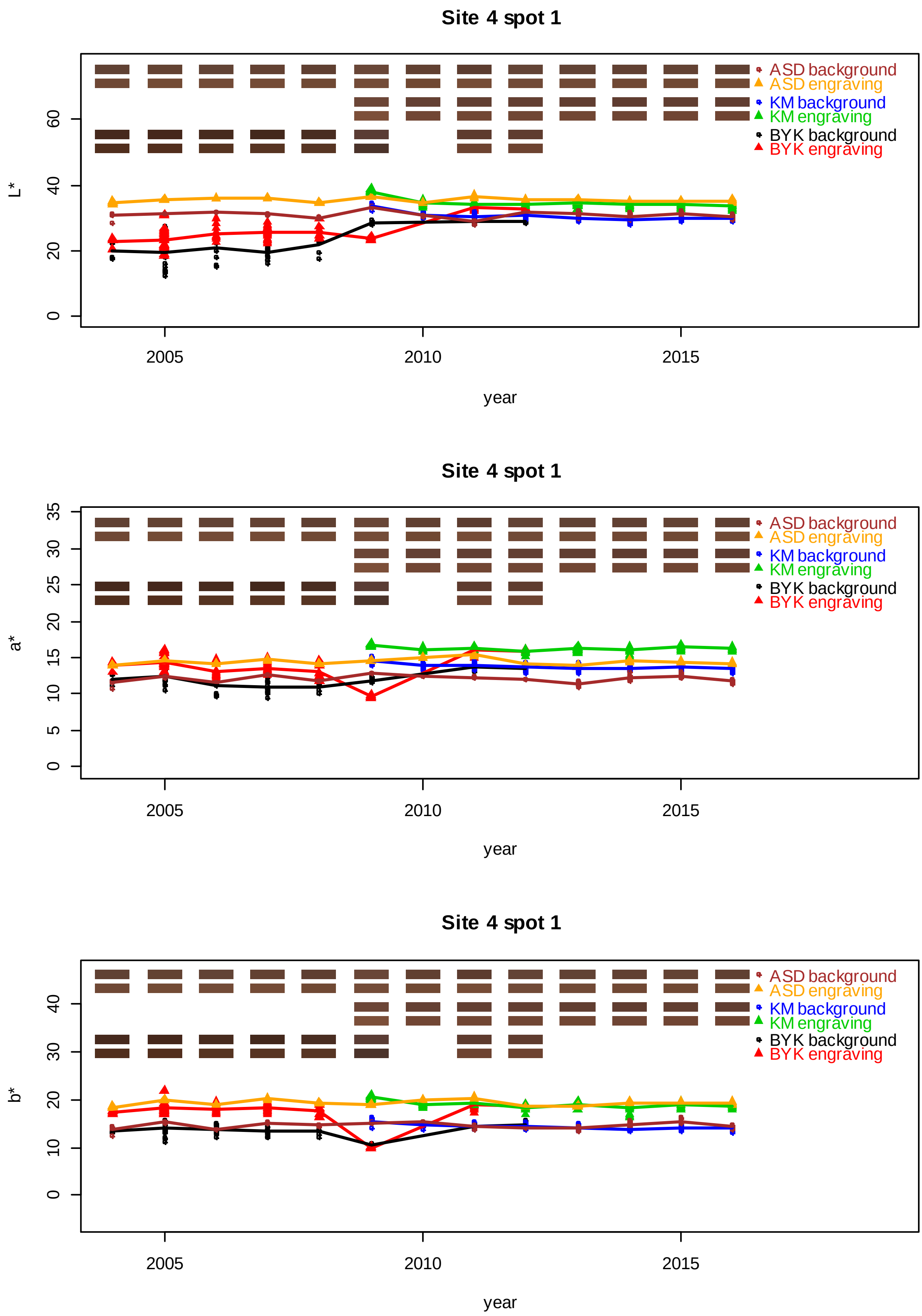


Figure 27. Site 4 spot 1 colour measurements, plotted as in Figure 19.

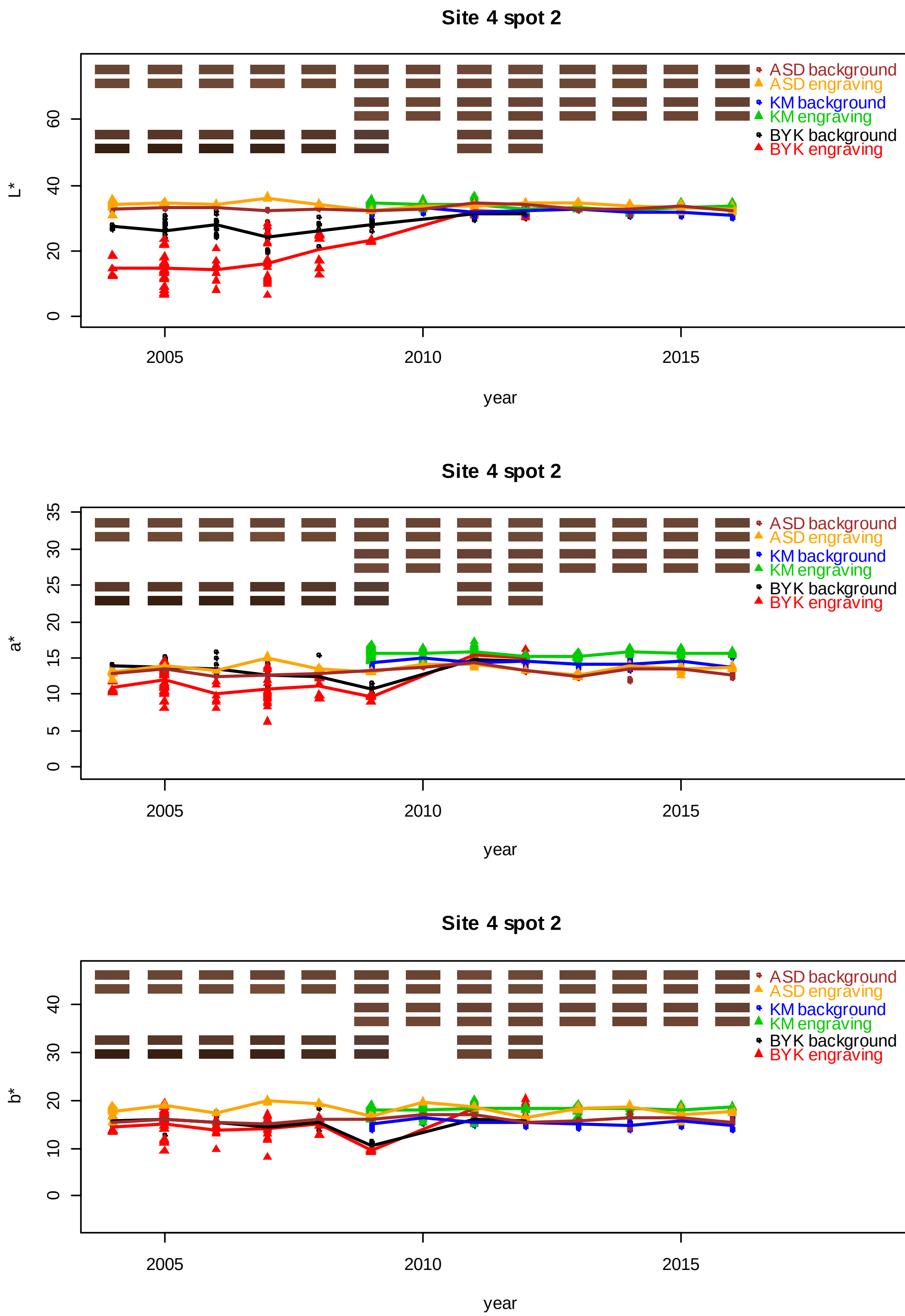


Figure 28. Site 4 spot 2 colour measurements, plotted as in Figure 19.

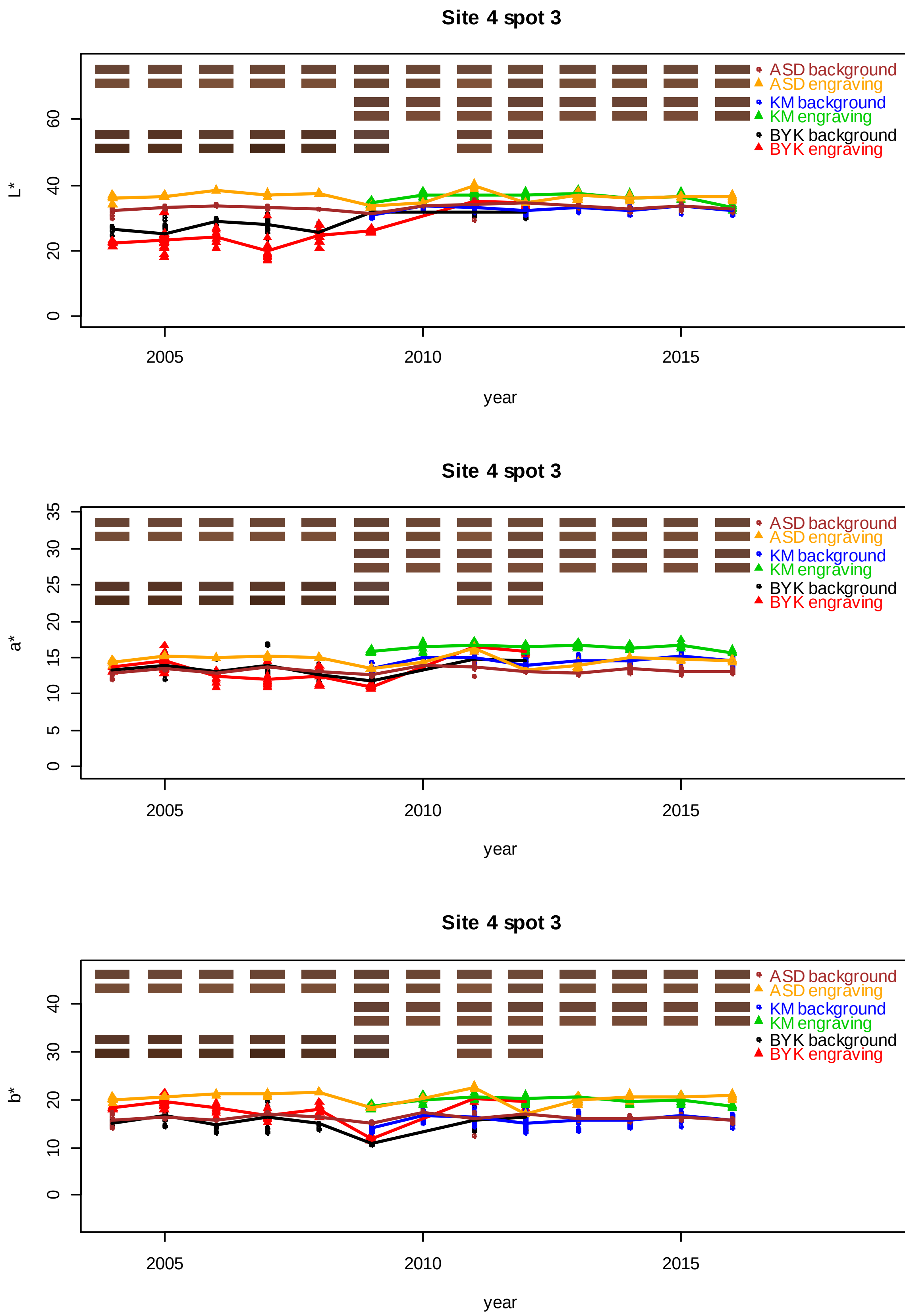


Figure 29. Site 4 spot 3 colour measurements, plotted as in Figure 19.

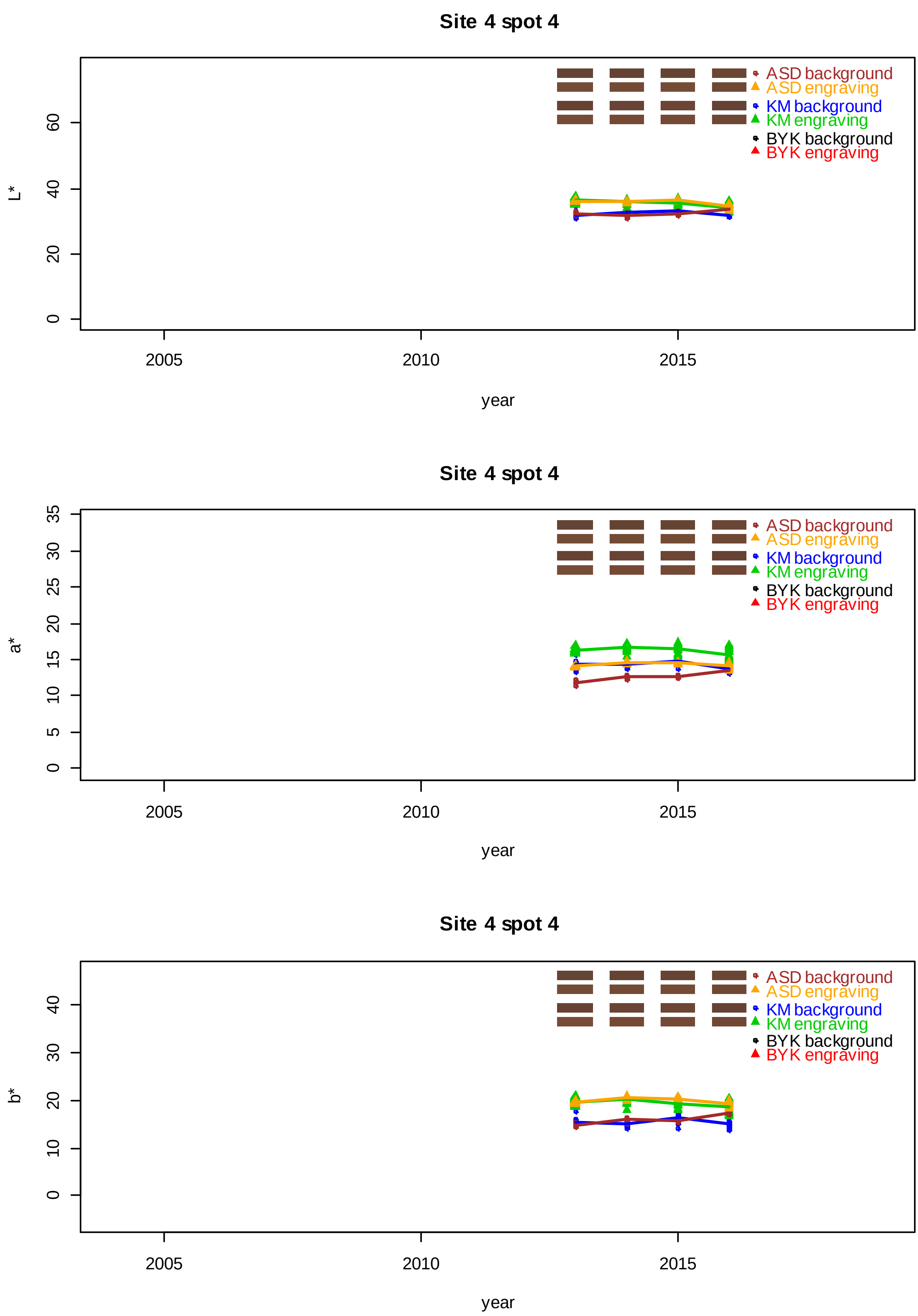


Figure 30. Site 4 spot 4 colour measurements, plotted as in Figure 19.

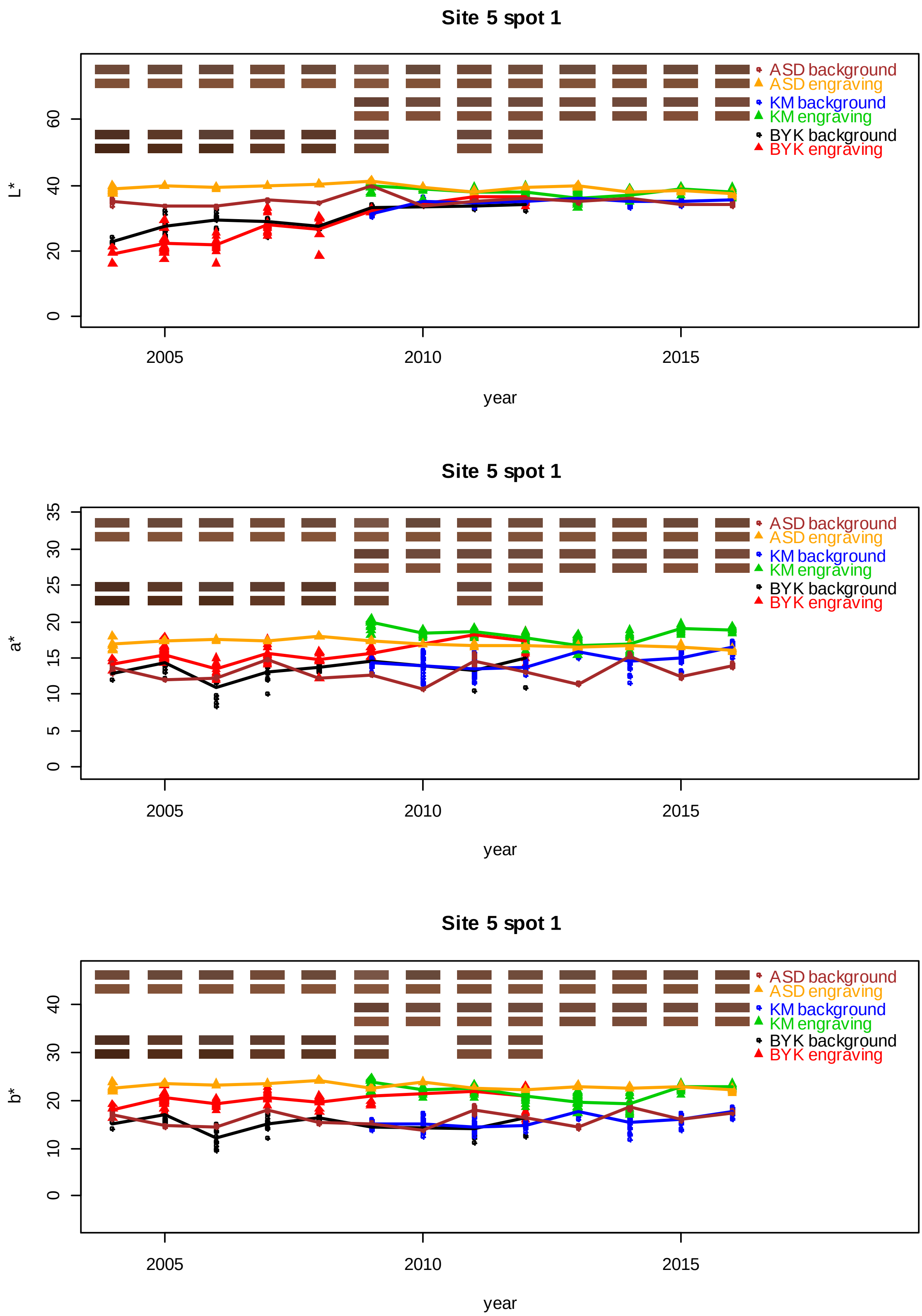
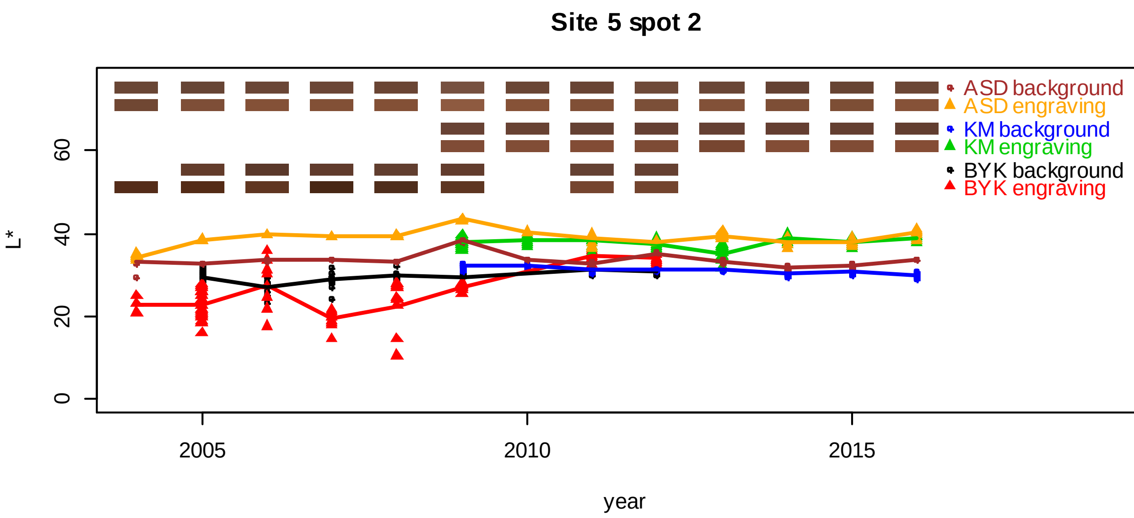
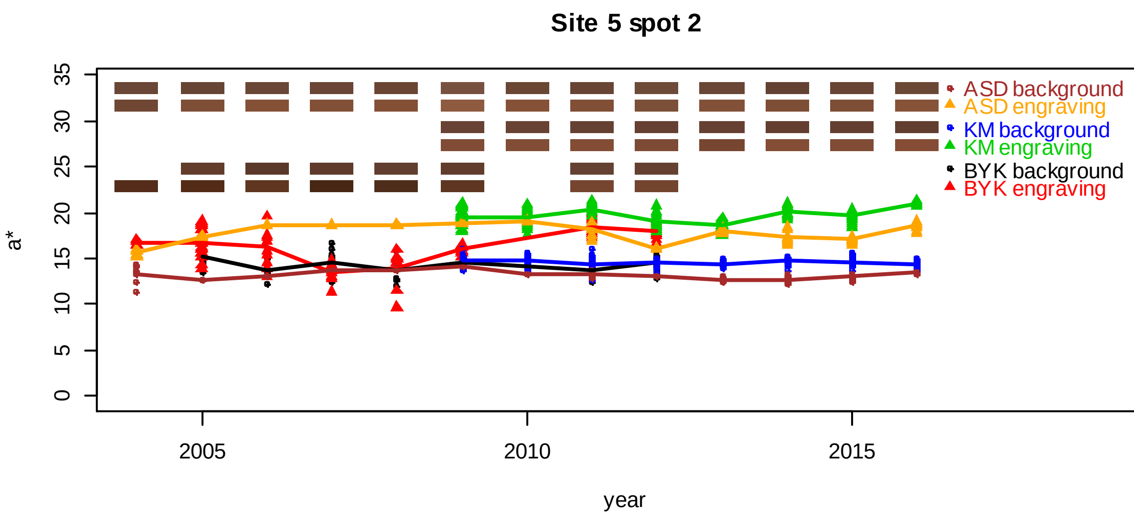


Figure 31. Site 5 spot 1 colour measurements, plotted as in Figure 19.





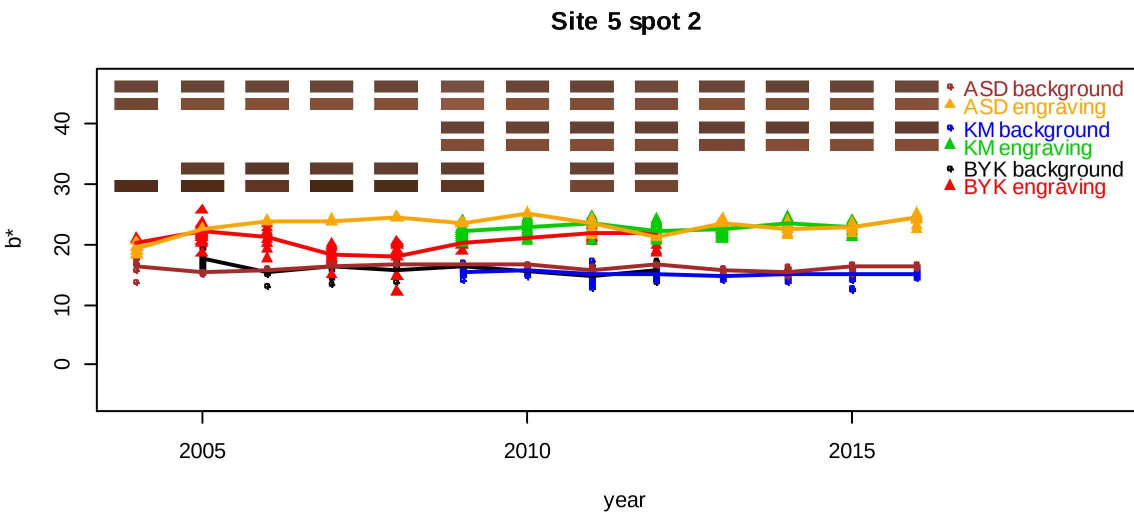


Figure 32. Site 5 spot 2 colour measurements, plotted as in Figure 19.

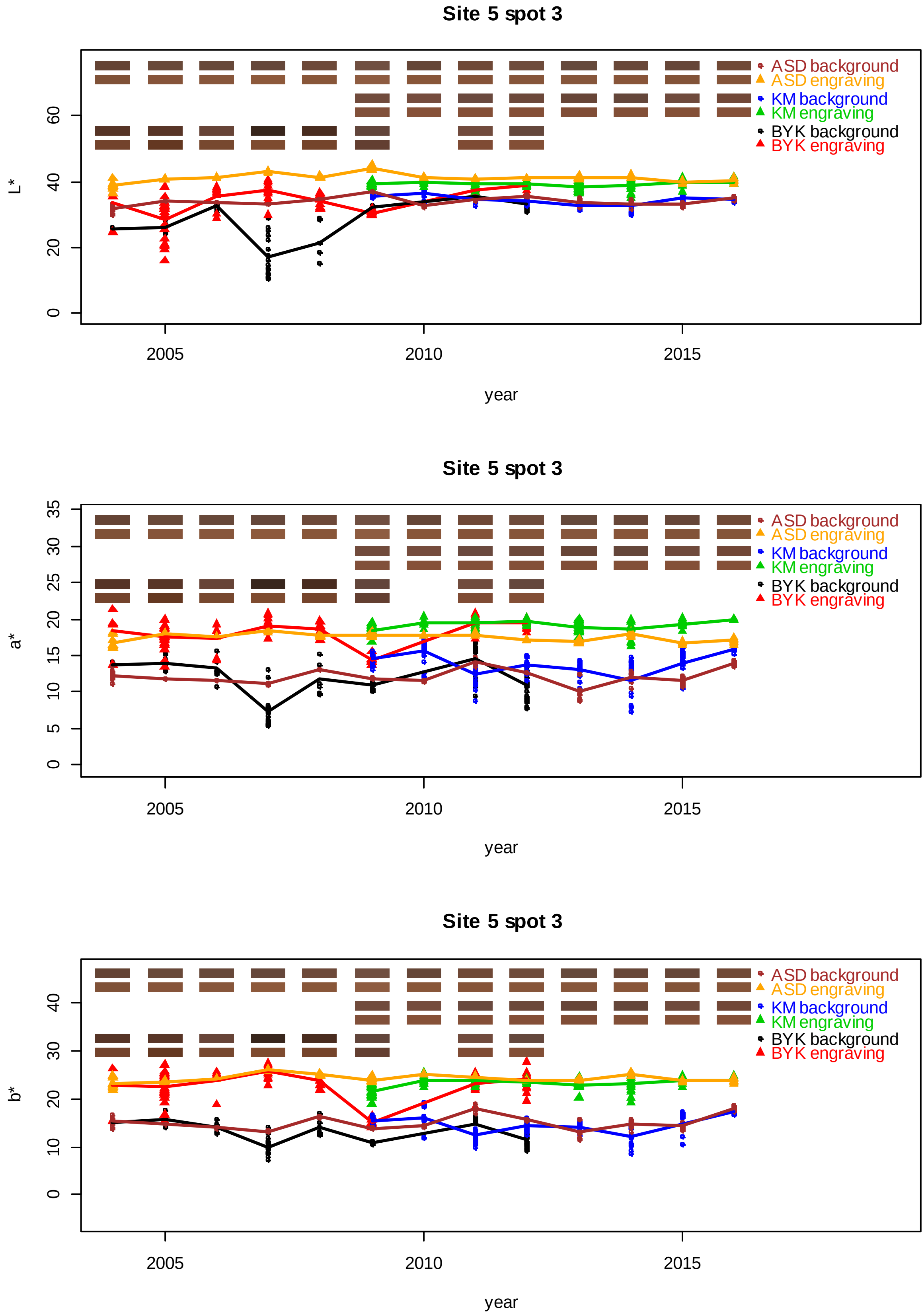


Figure 33. Site 5 spot 3 colour measurements, plotted as in Figure 19.

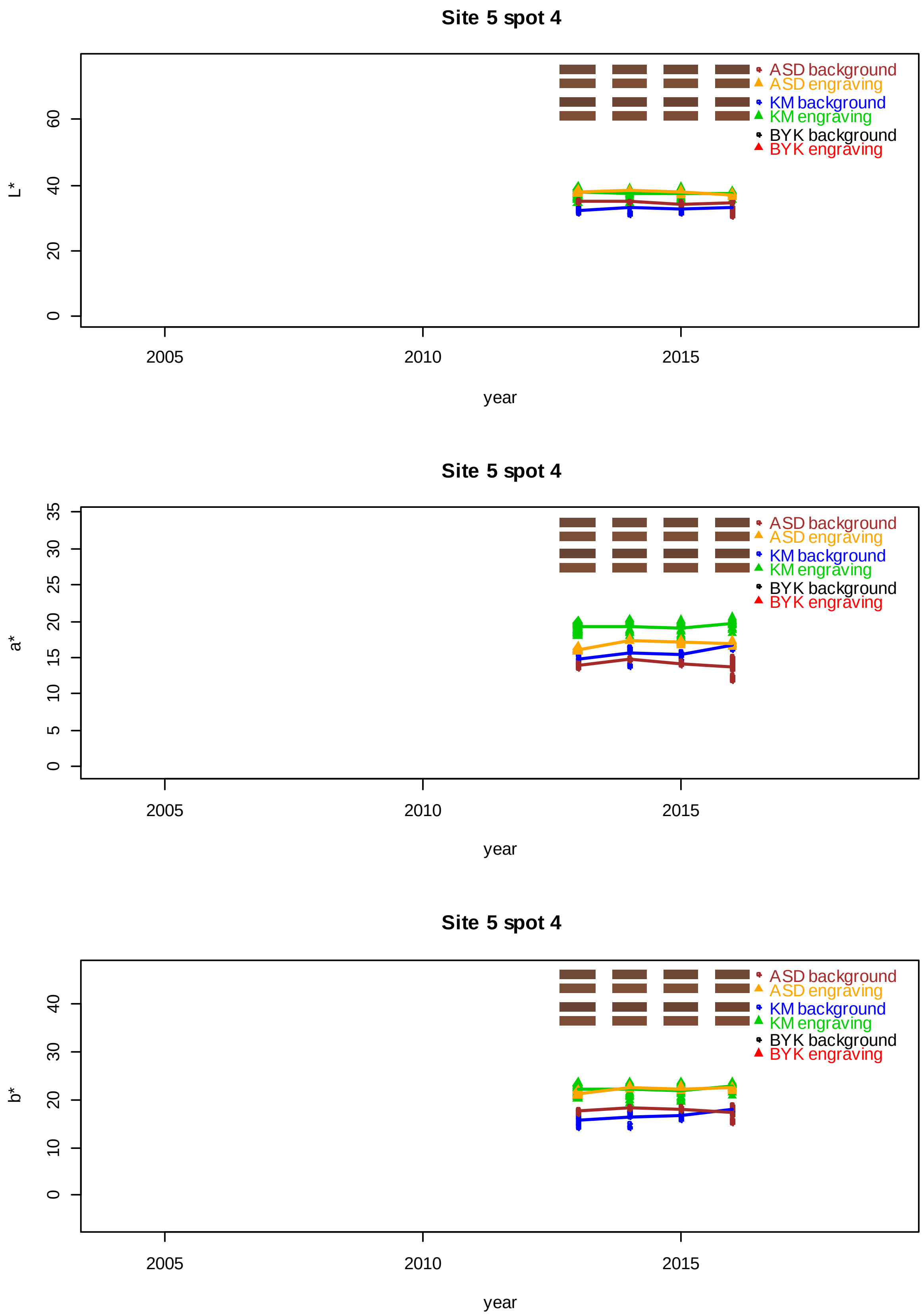


Figure 34. Site 5 spot 4 colour measurements, plotted as in Figure 19.

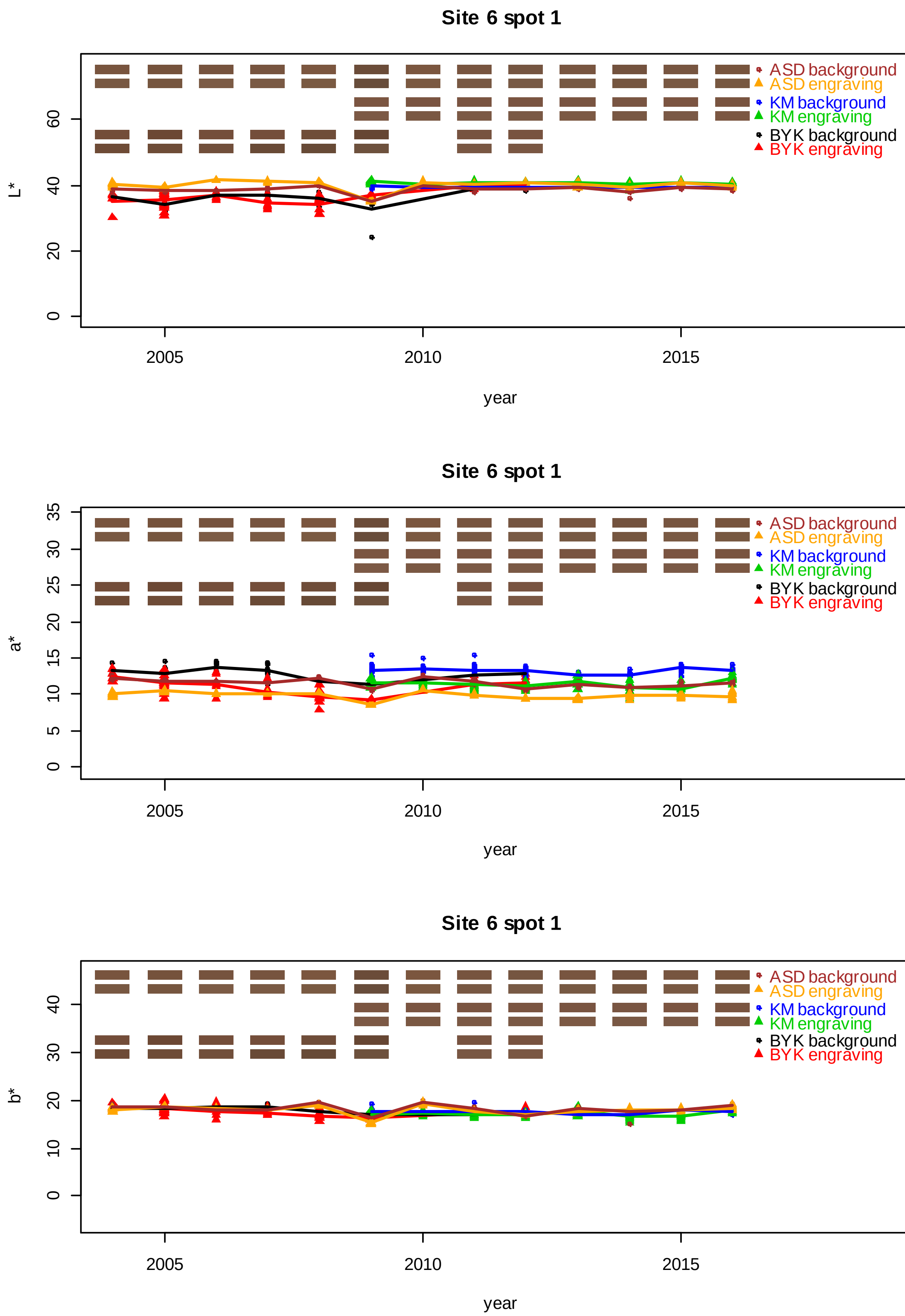


Figure 35. Site 6 spot 1 colour measurements, plotted as in Figure 19.

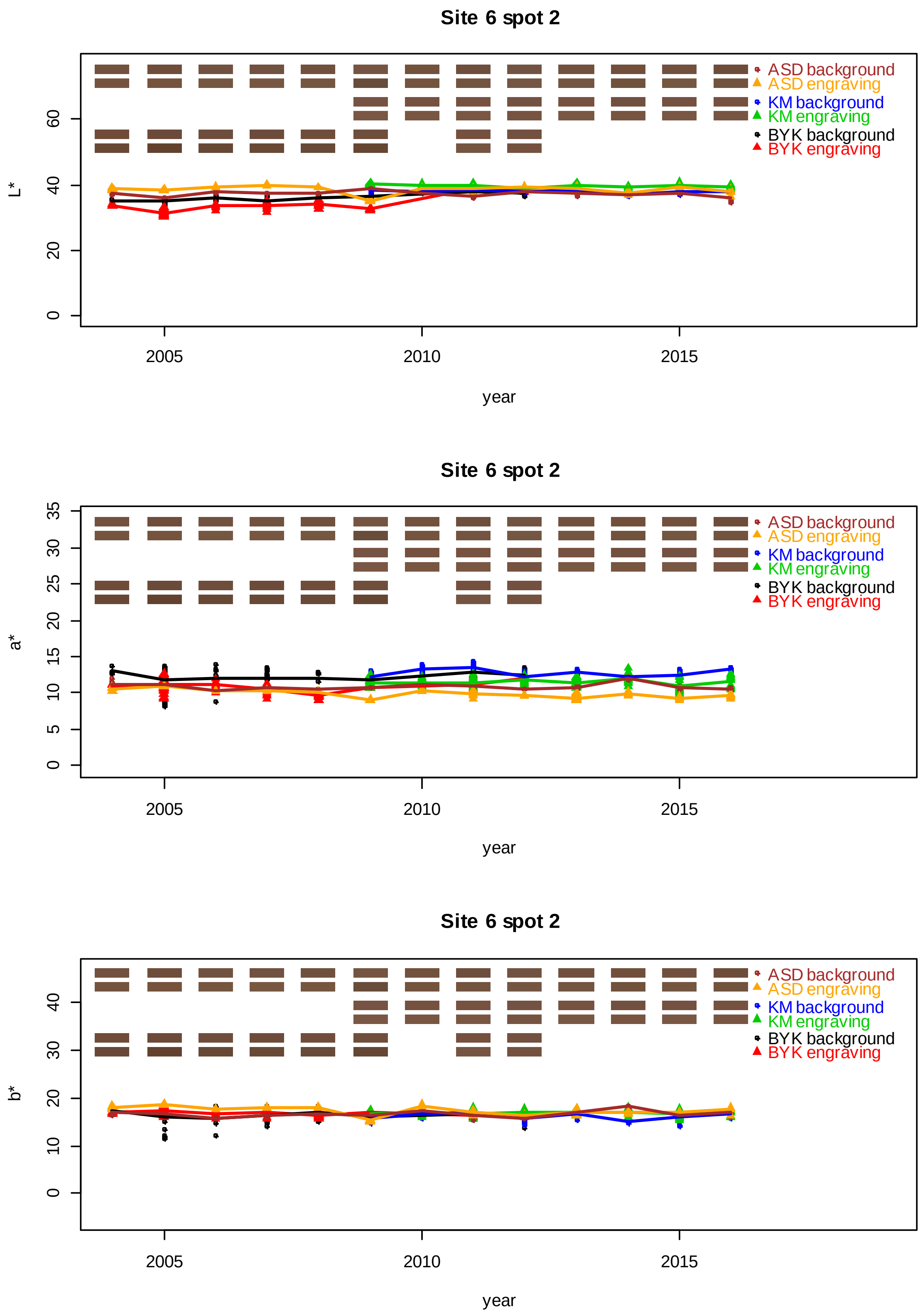
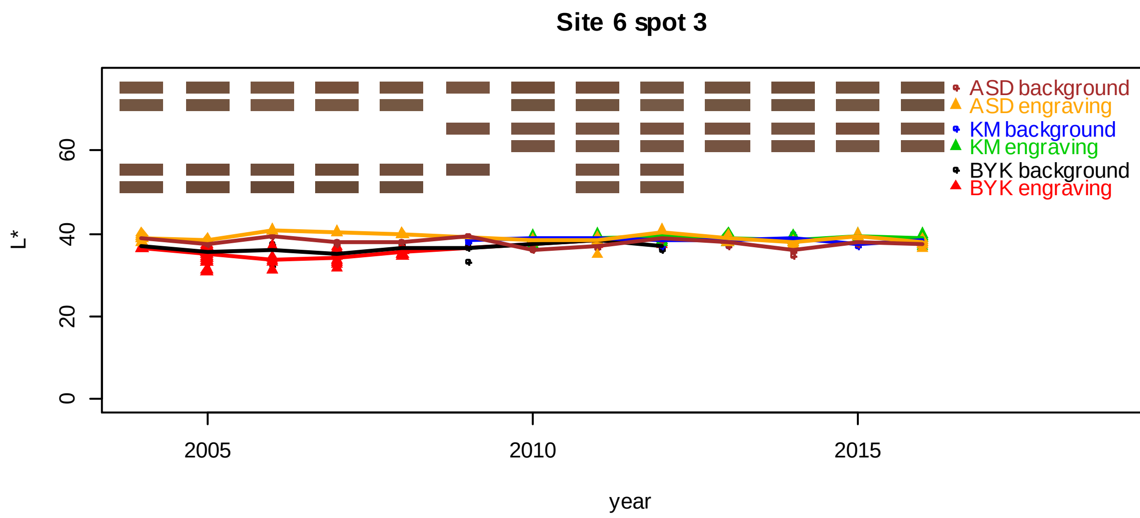
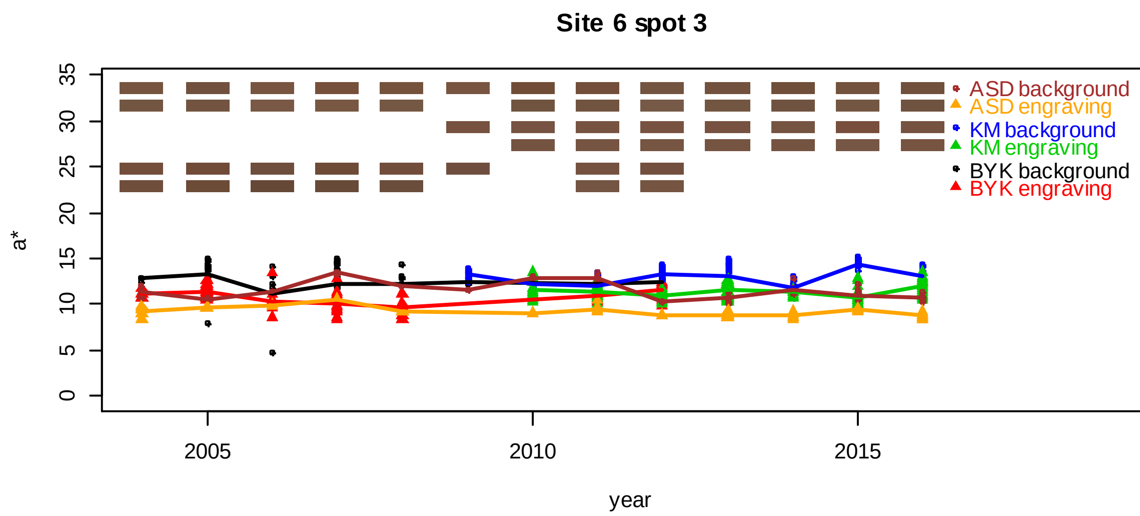


Figure 36. Site 6 spot 2 colour measurements, plotted as in Figure 19.





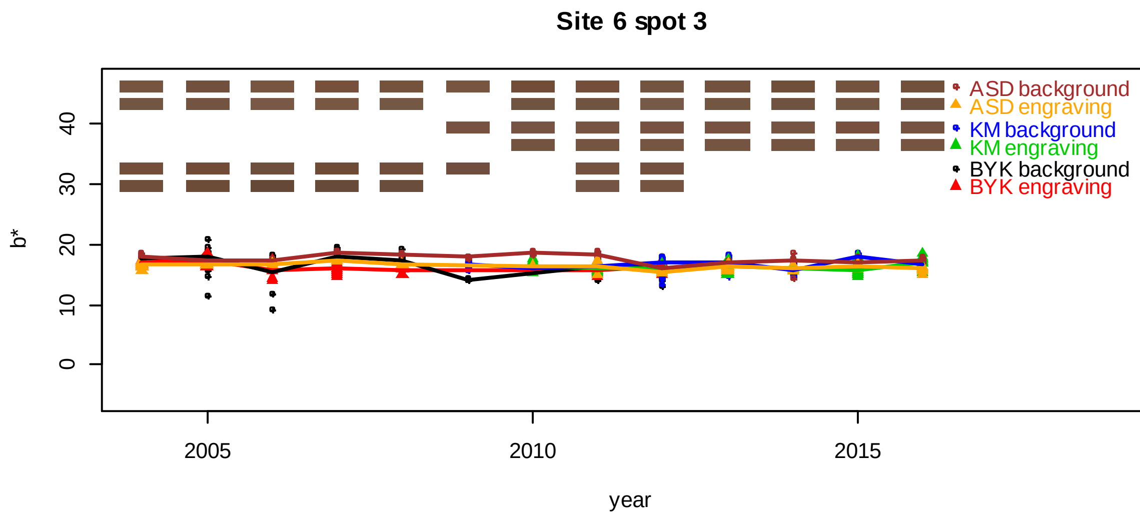


Figure 37. Site 6 spot 3 colour measurements, plotted as in Figure 19.

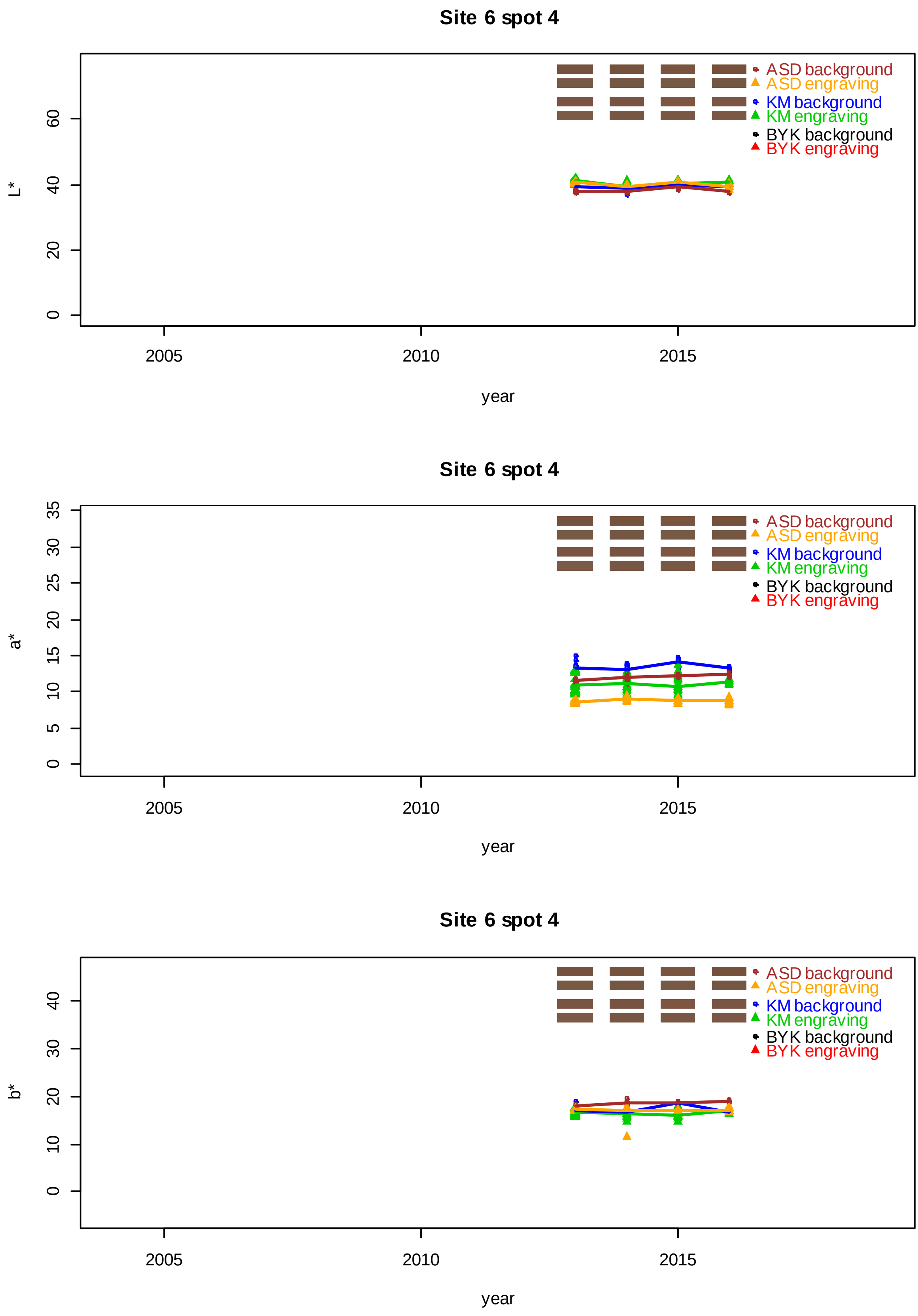


Figure 38. Site 6 spot 4 colour measurements, plotted as in Figure 19.

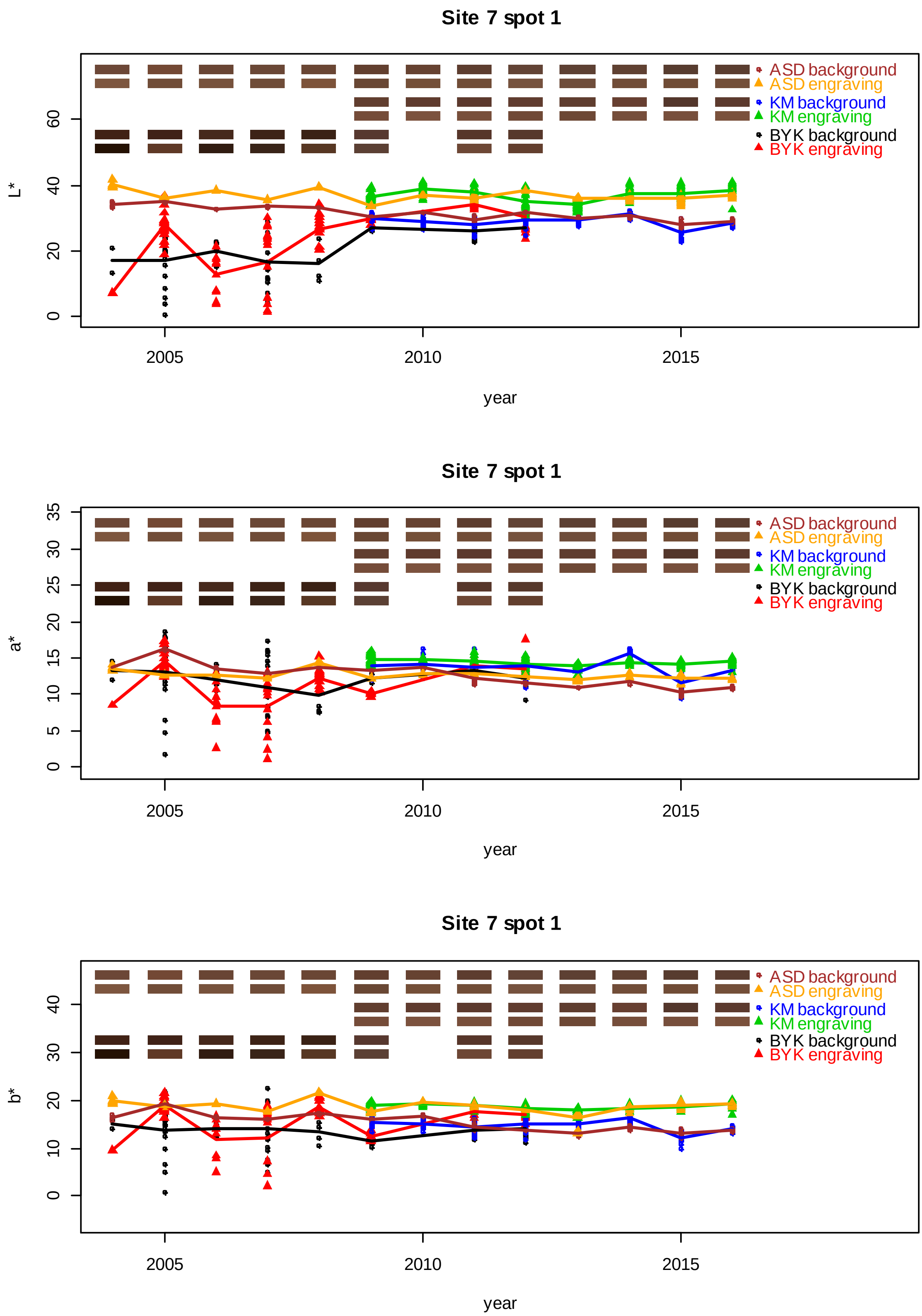


Figure 39. Site 7 spot 1 colour measurements, plotted as in Figure 19.

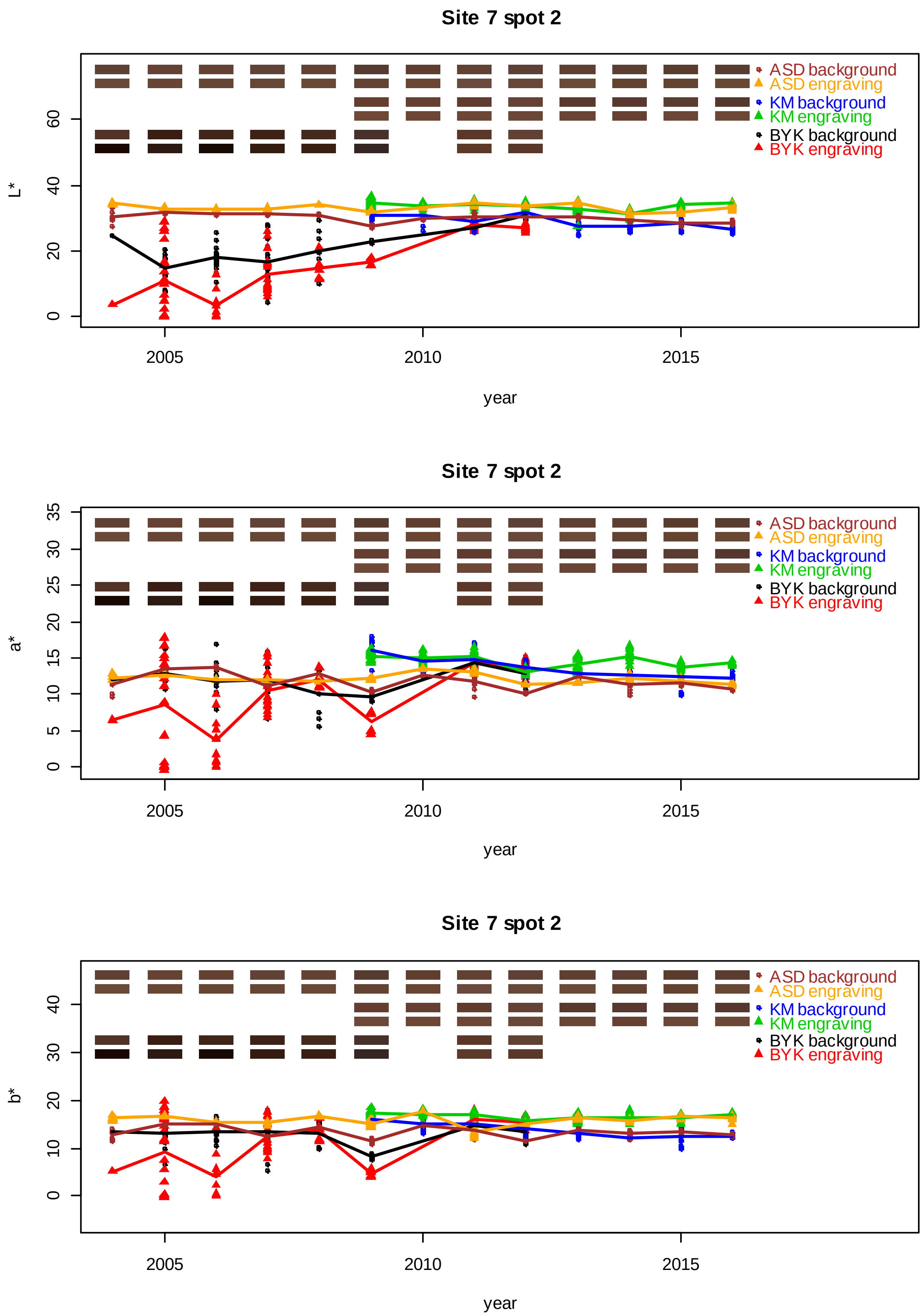


Figure 40. Site 7 spot 2 colour measurements, plotted as in Figure 19

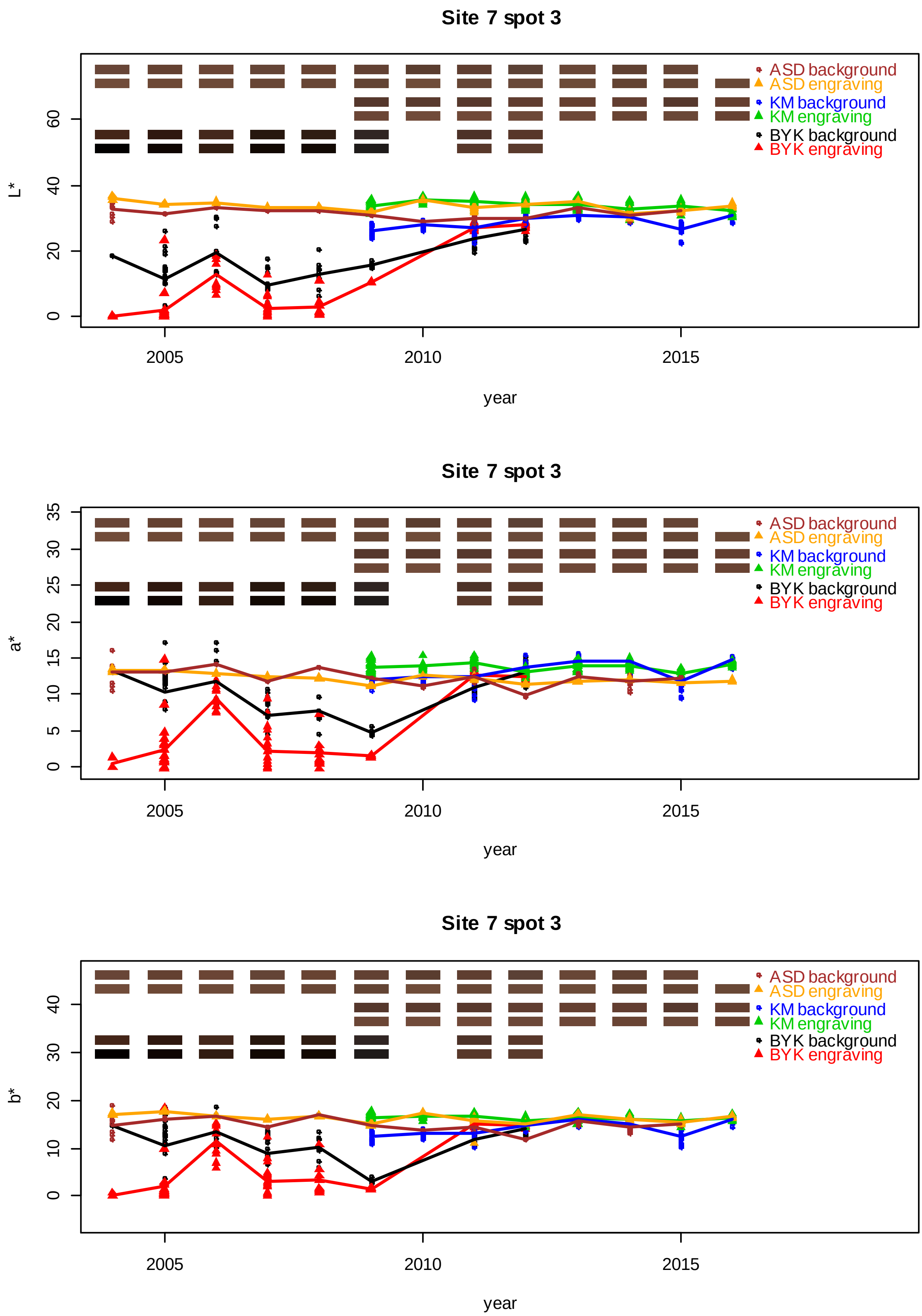


Figure 41. Site 7 spot 3 colour measurements, plotted as in Figure 19.

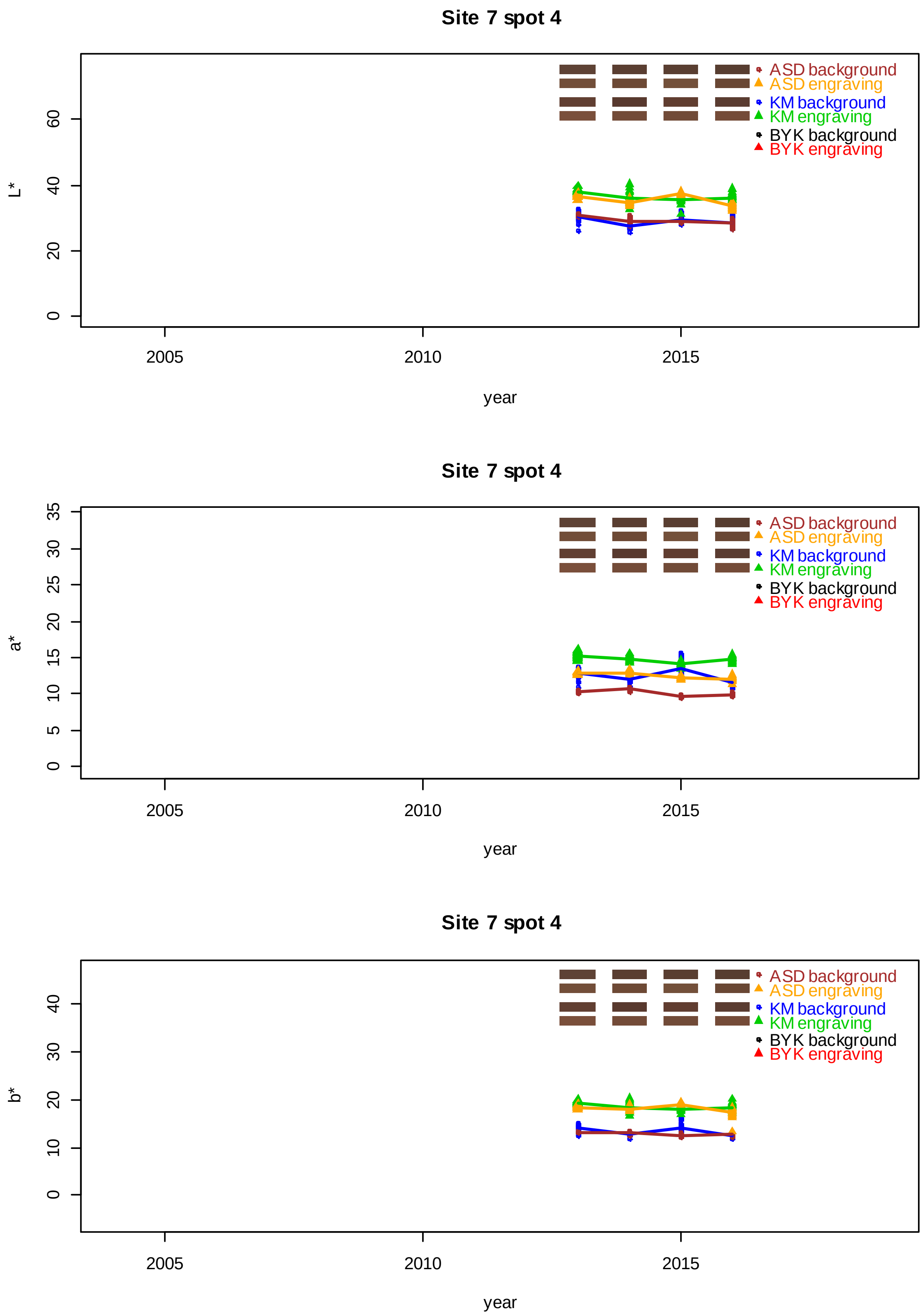


Figure 42. Site 7 spot 4 colour measurements, plotted as in Figure 19.

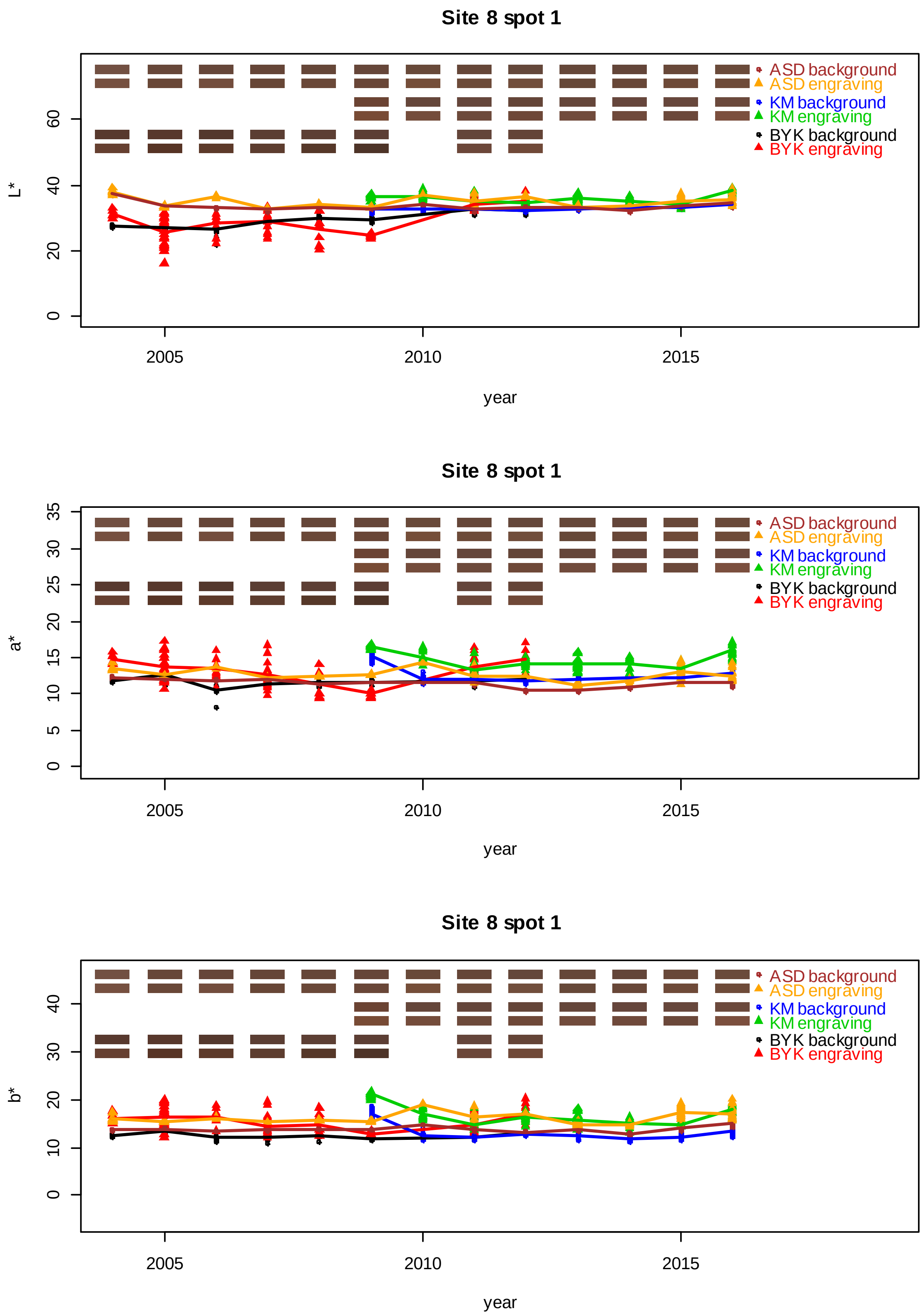


Figure 43. Site 8 spot 1 colour measurements, plotted as in Figure 19.

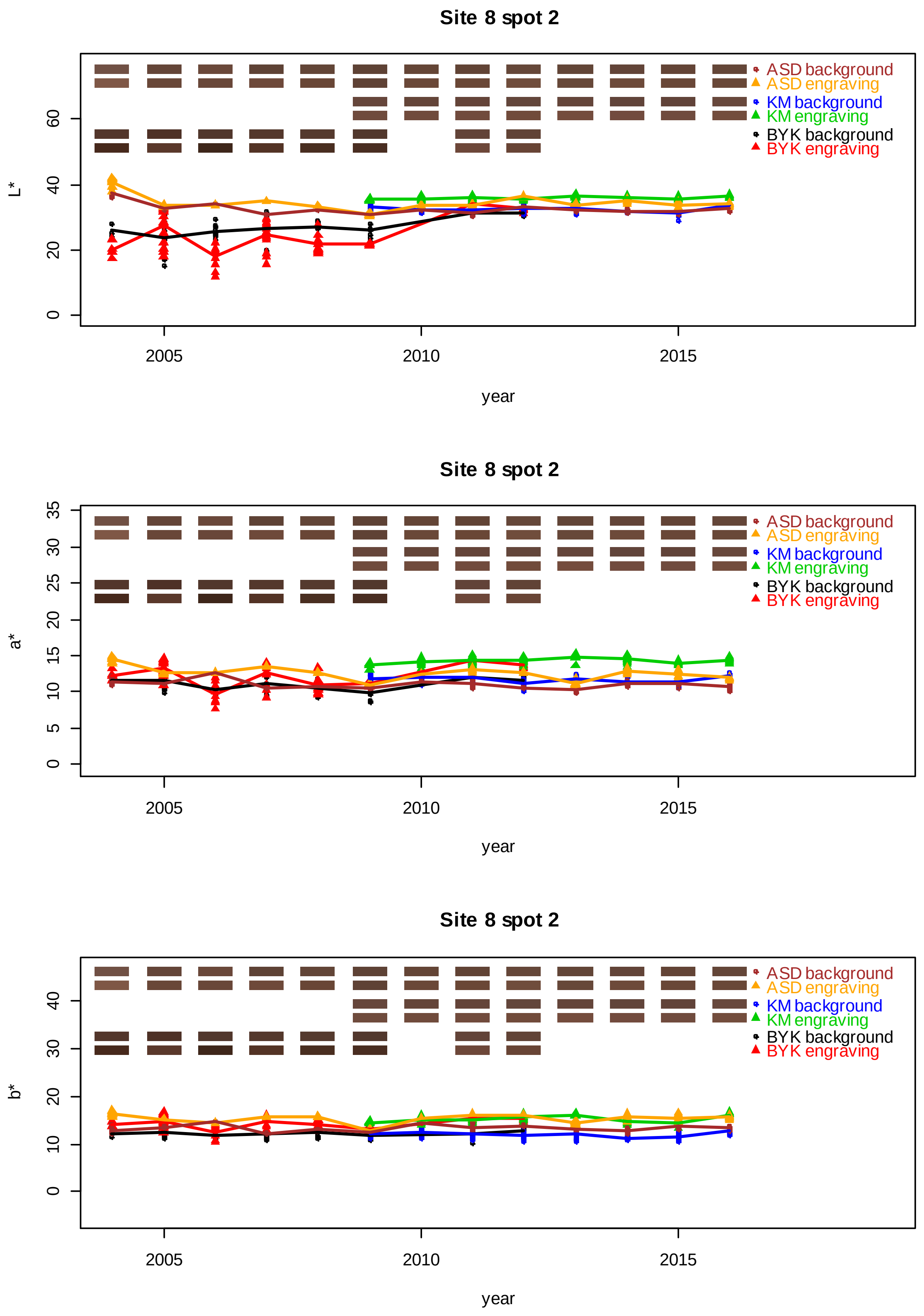


Figure 44. Site 8 spot 2 colour measurements, plotted as in Figure 19.

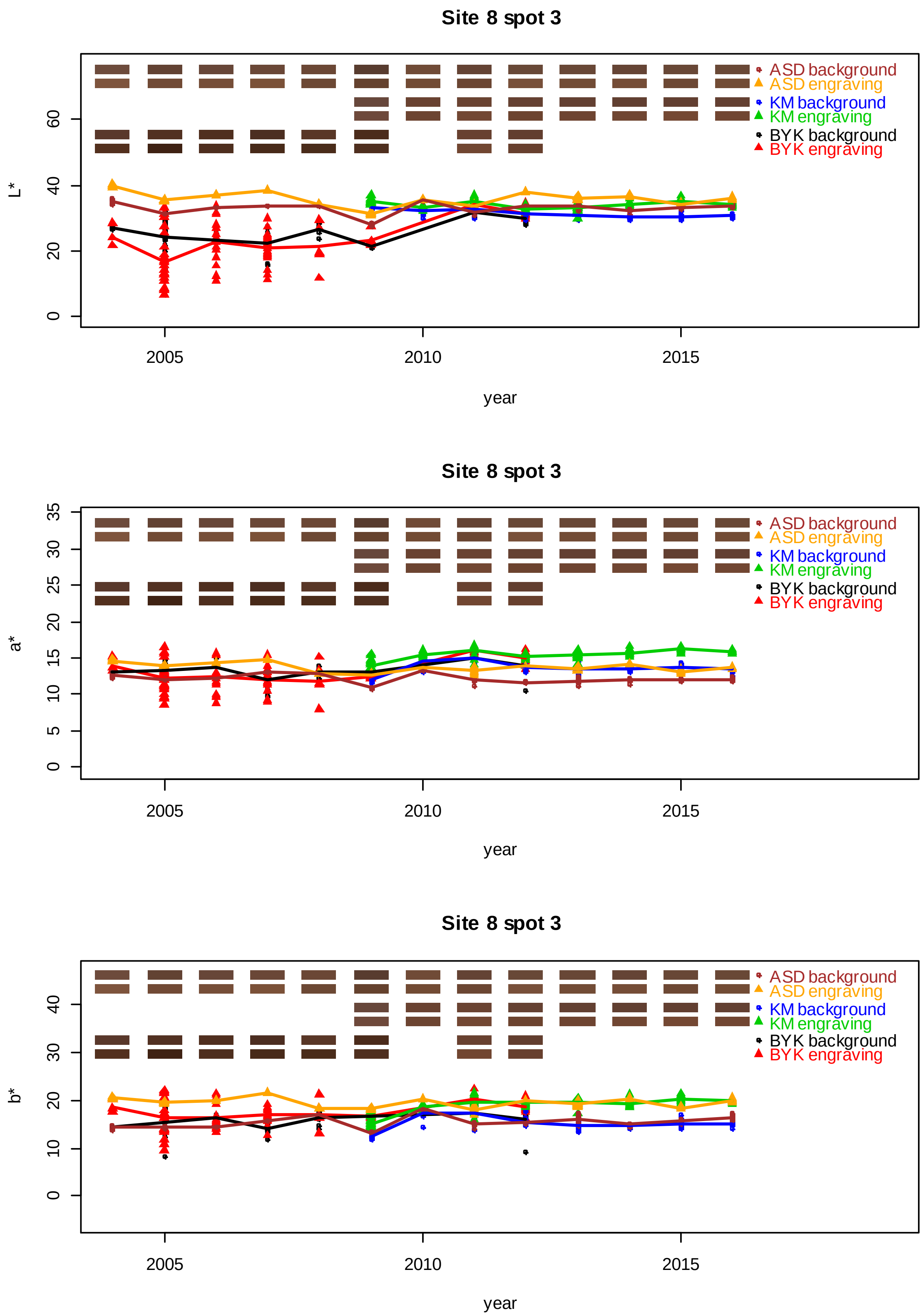


Figure 45. Site 8 spot 3 colour measurements, plotted as in Figure 19.

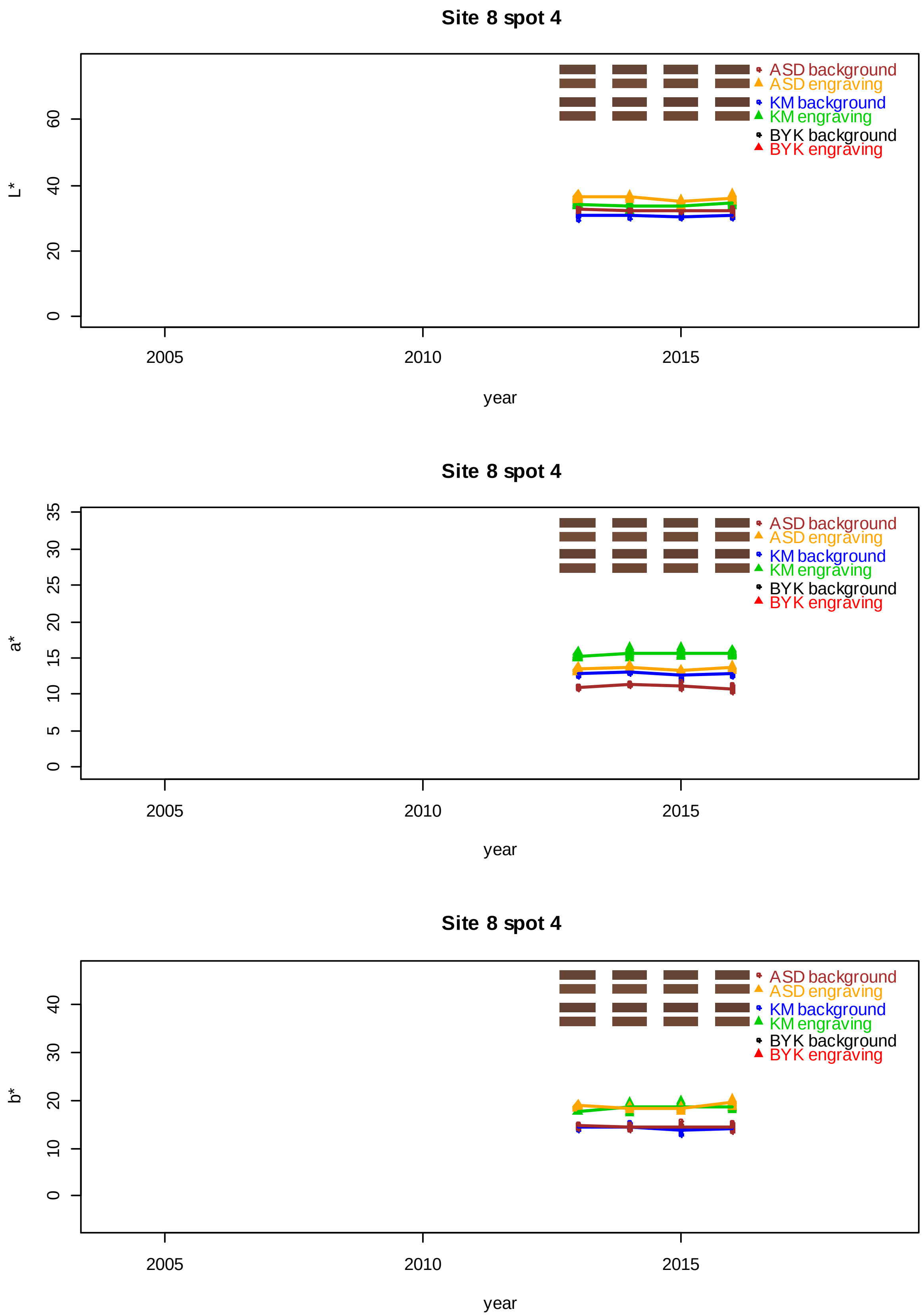


Figure 46. Site 8 spot 4 colour measurements, plotted as in Figure 19.

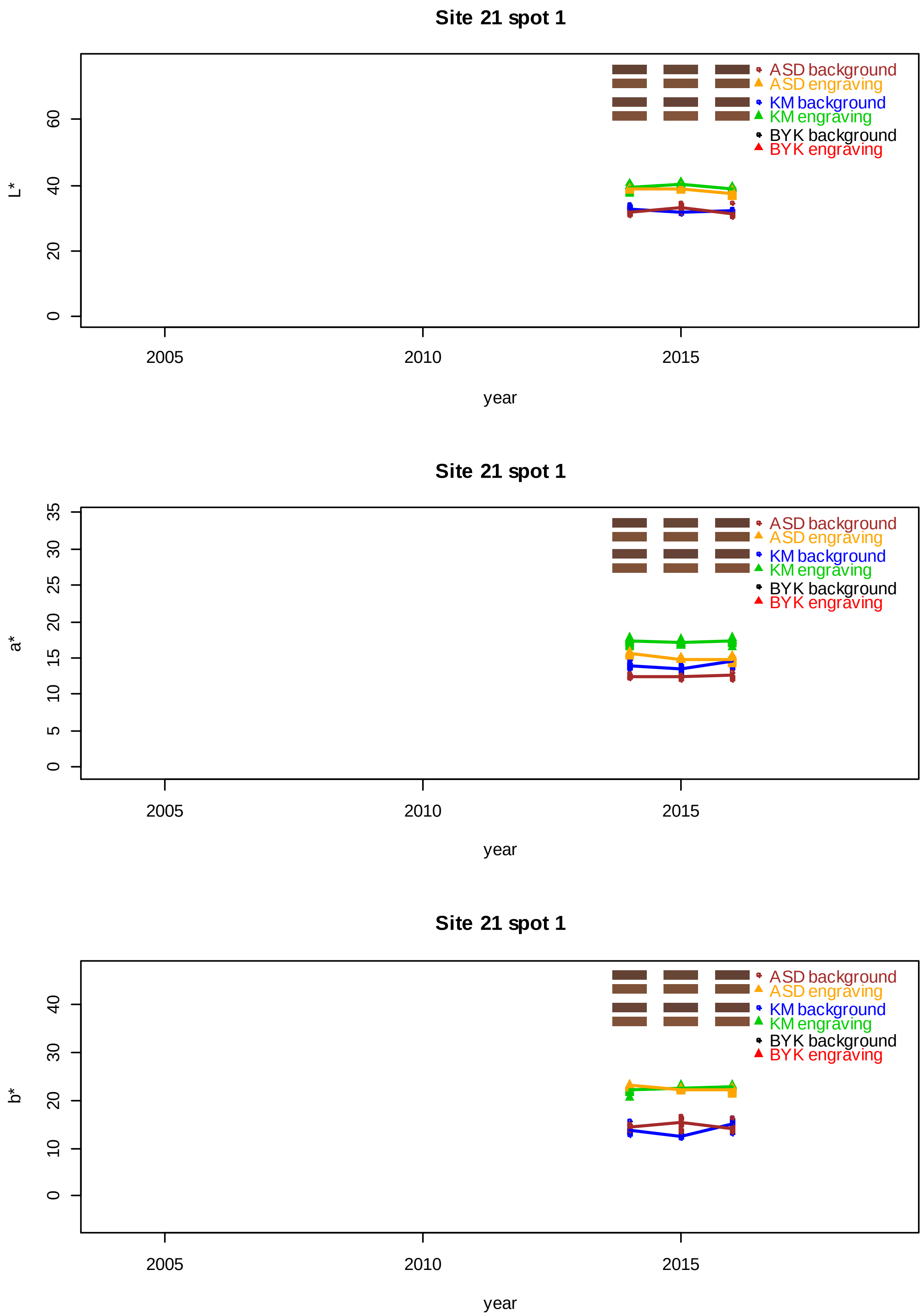
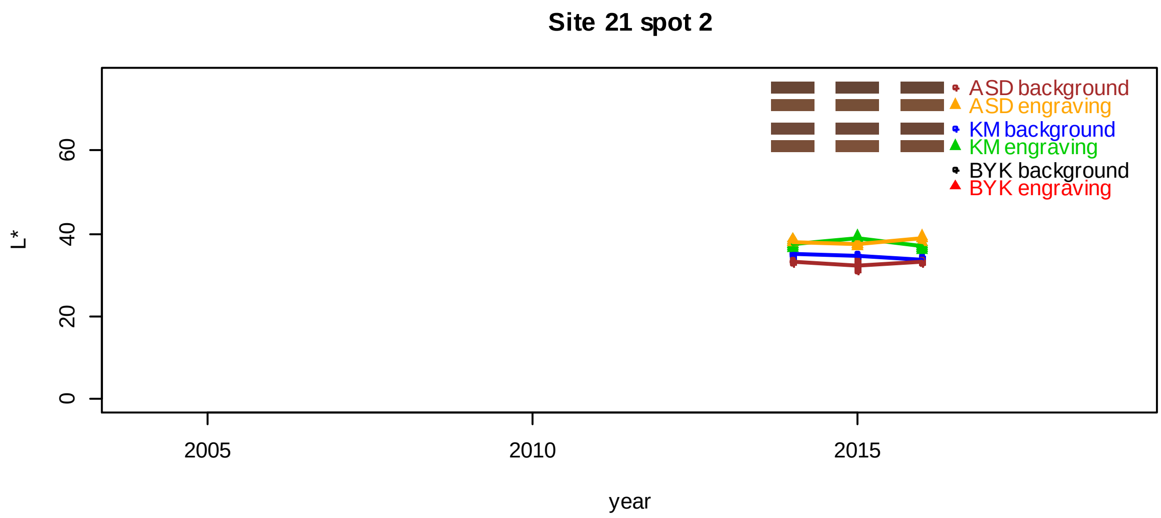
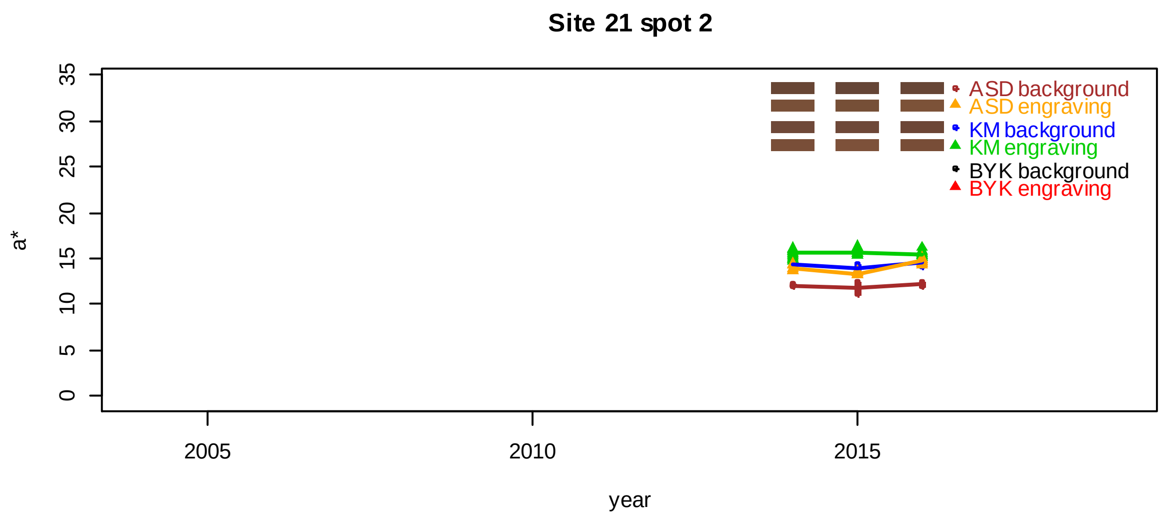


Figure 47. Site 21 spot 1 colour measurements, plotted as in Figure 19.





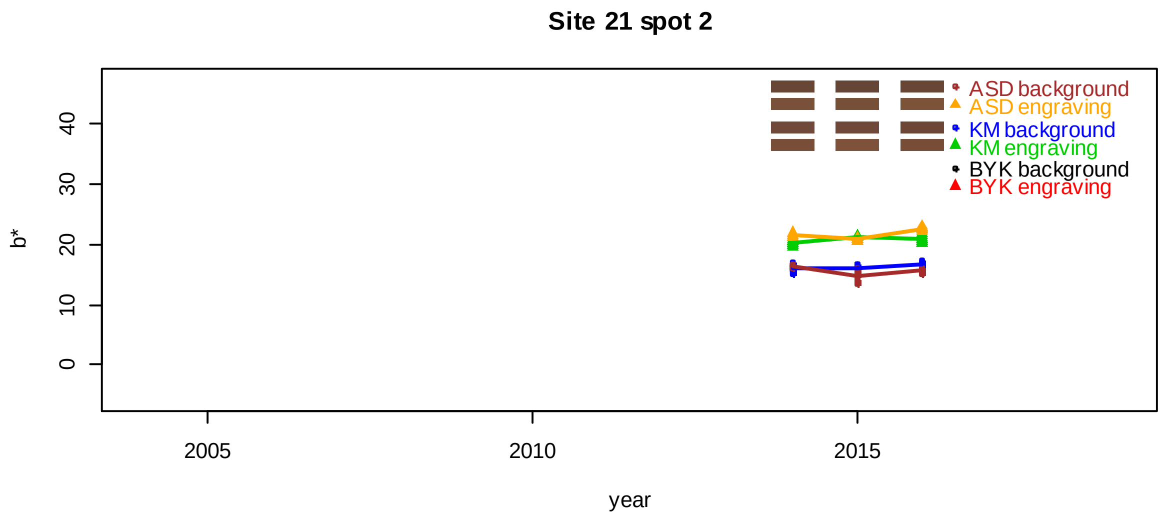
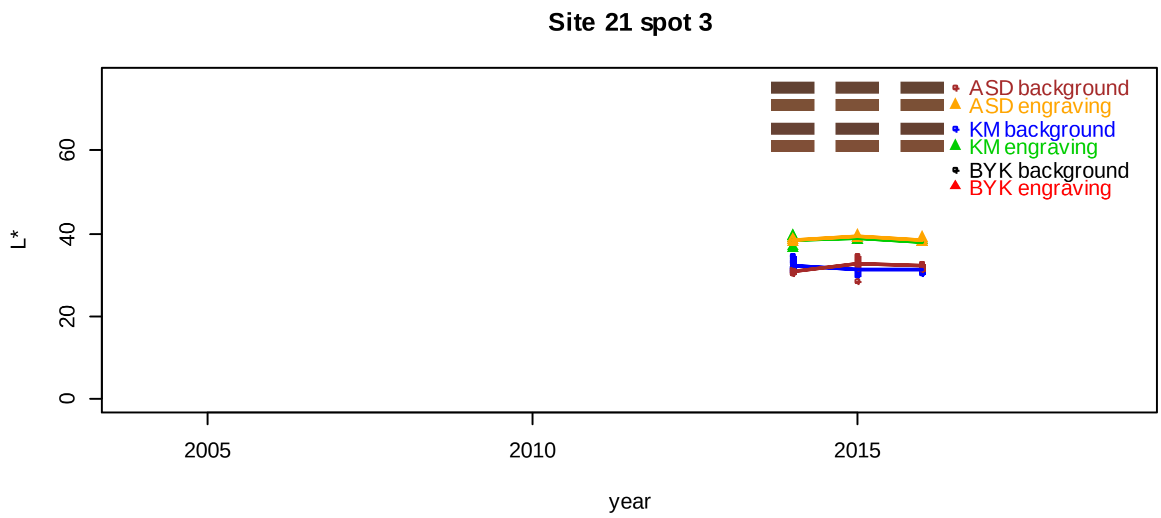
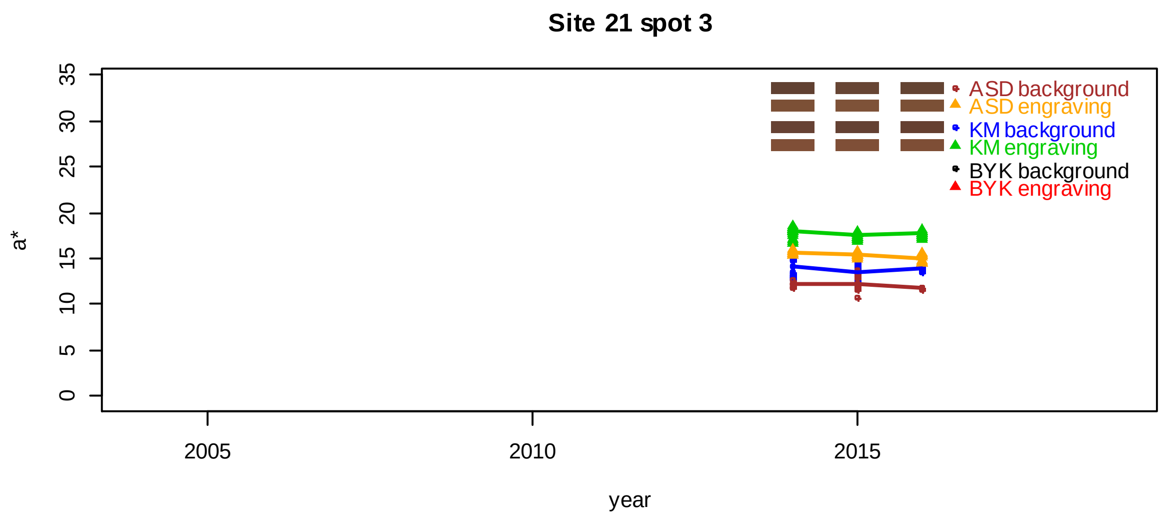


Figure 48. Site 21 spot 2 colour measurements, plotted as in Figure 19.





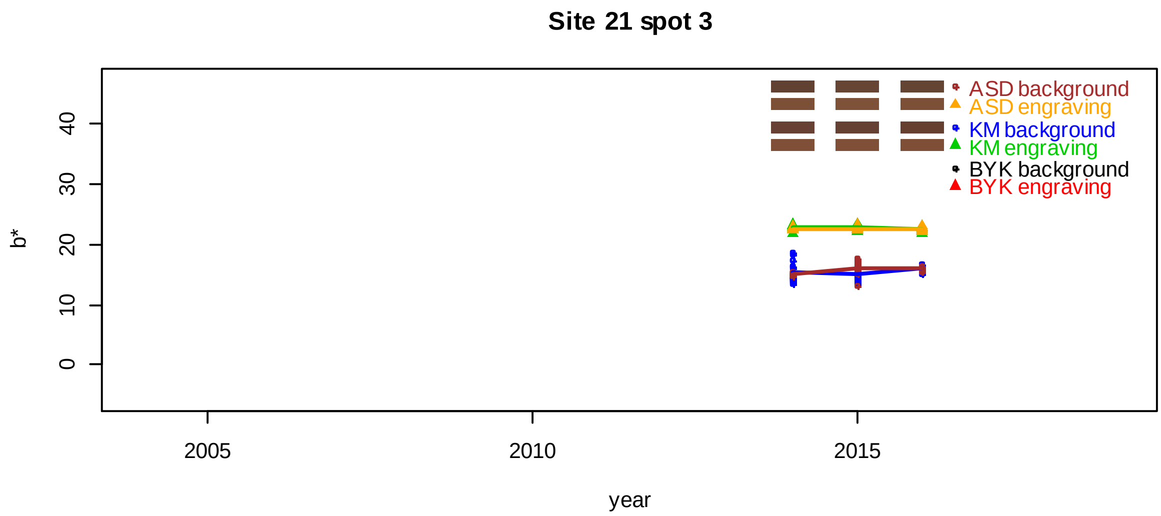


Figure 49. Site 21 spot 3 colour measurements, plotted as in Figure 19.

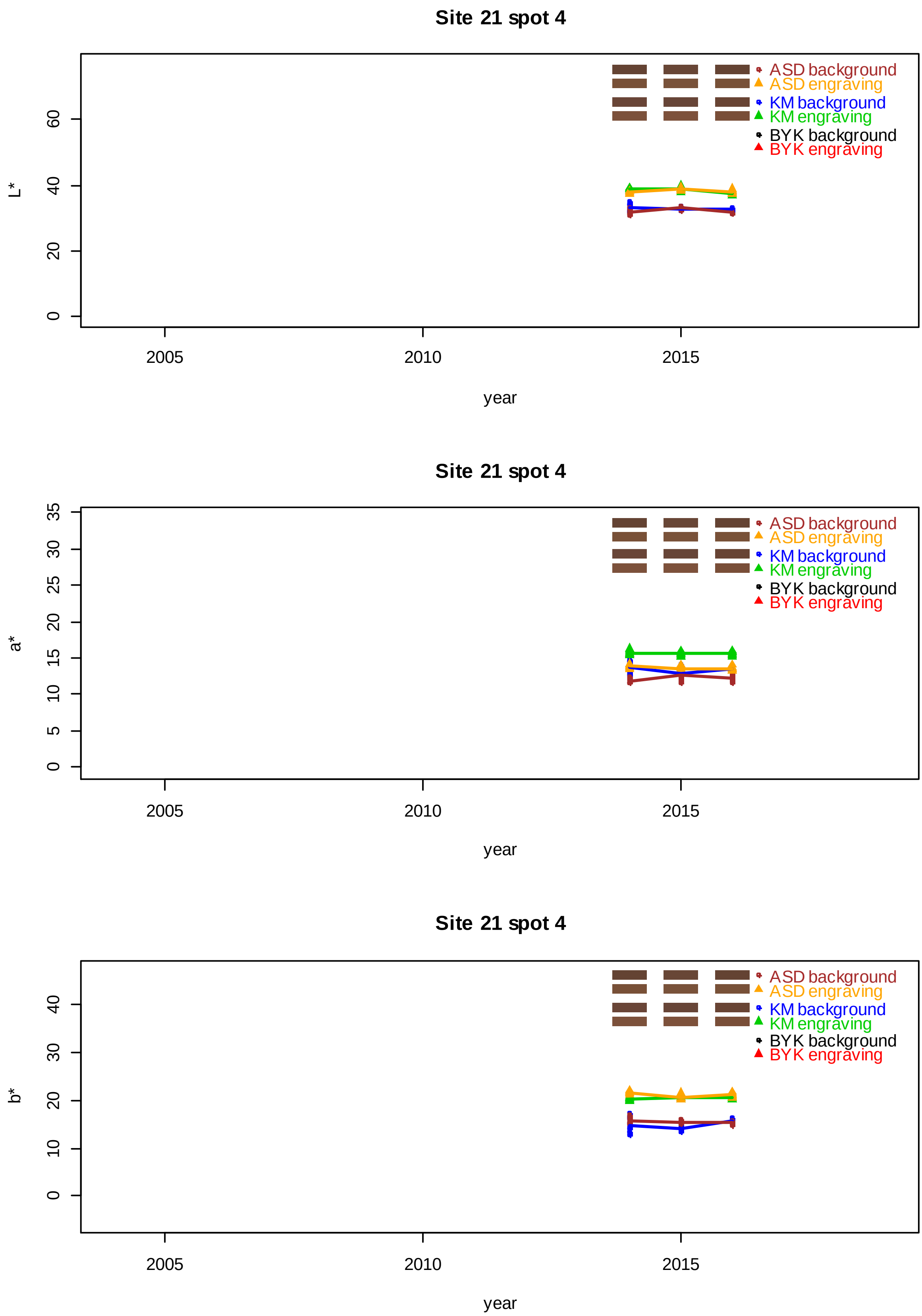


Figure 50. Site 21 spot 4 colour measurements, plotted as in Figure 19.

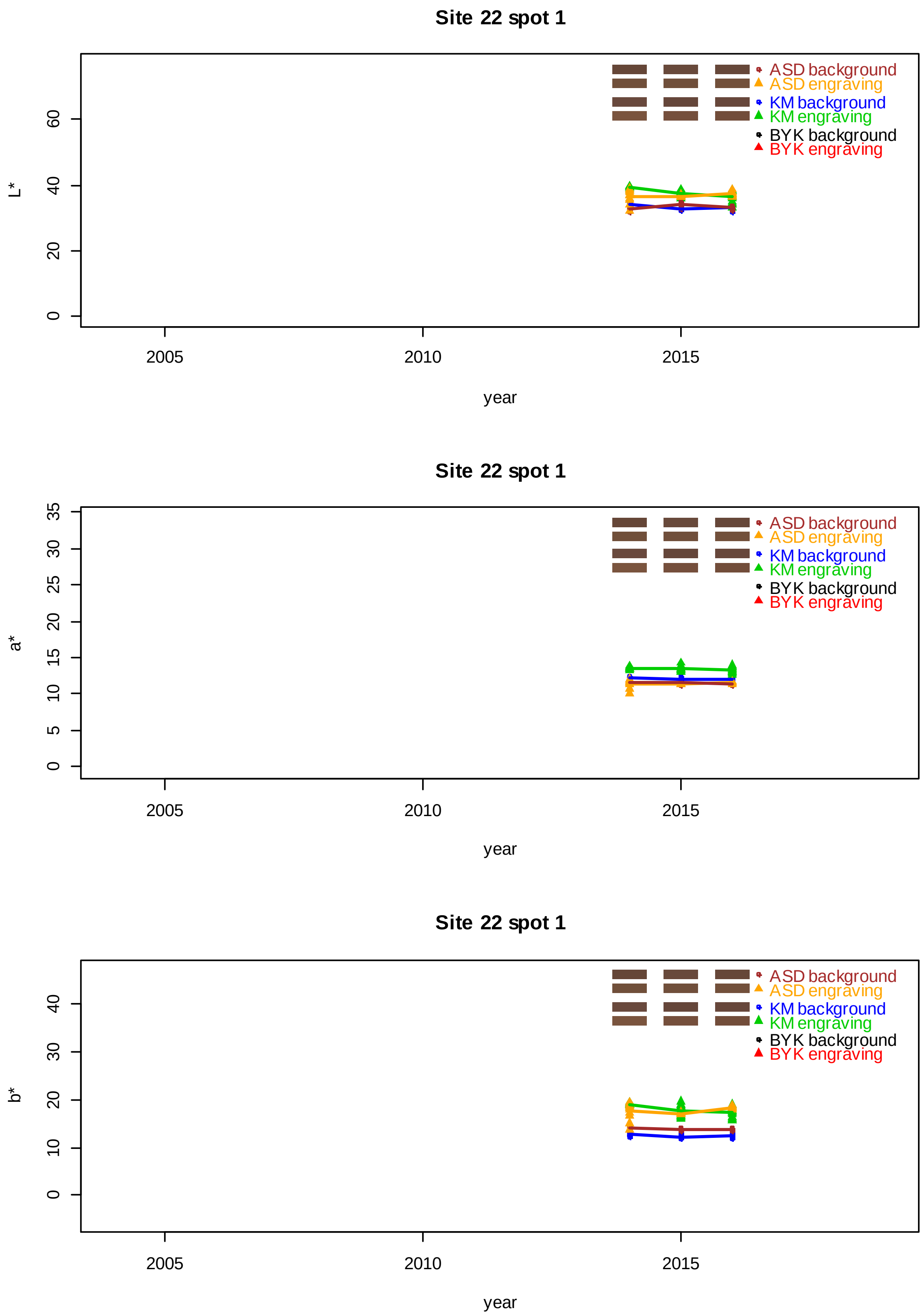


Figure 51. Site 22 spot 1 colour measurements, plotted as in Figure 19.

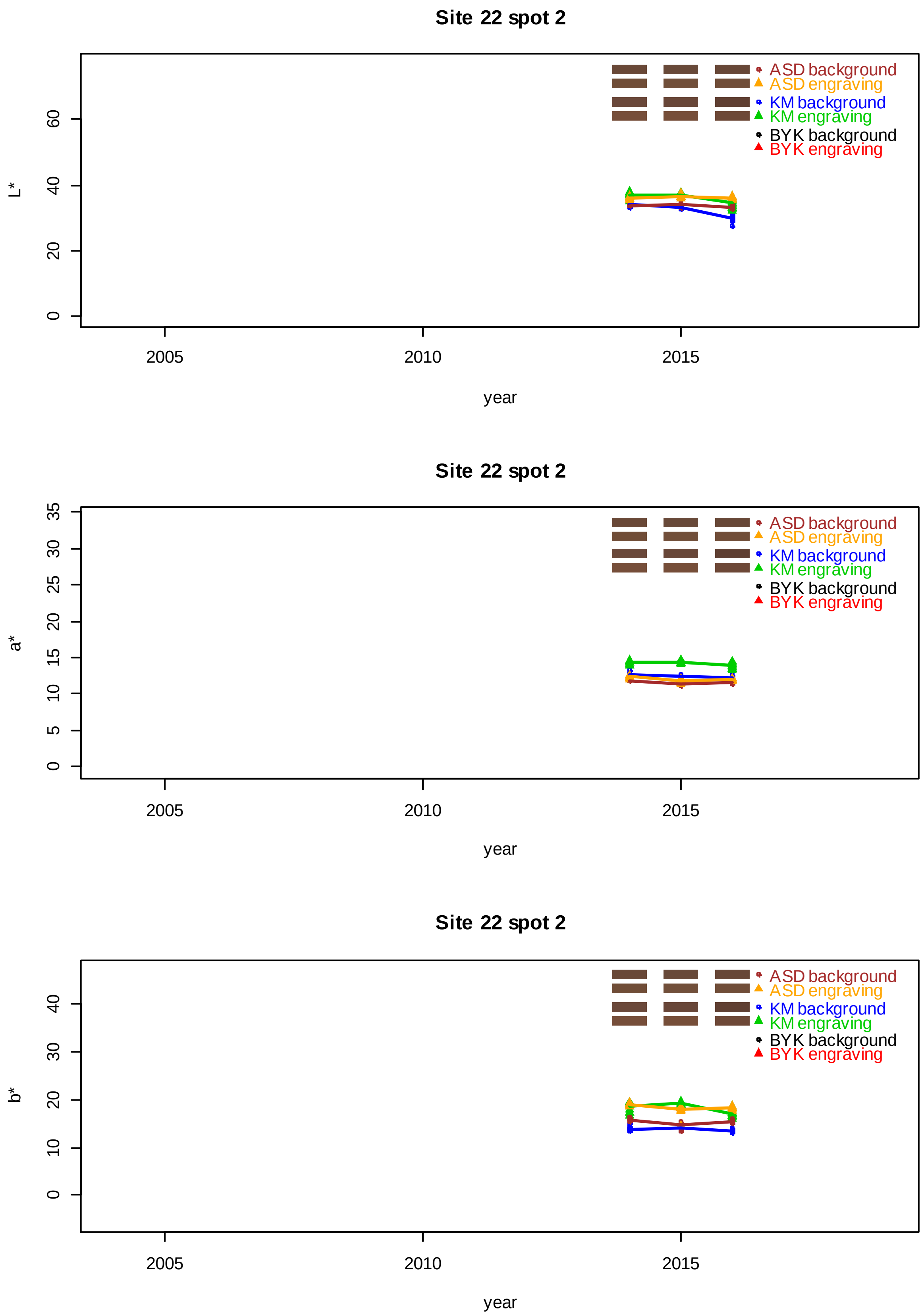


Figure 52. Site22 spot 2 colour measurements, plotted as in Figure 19.

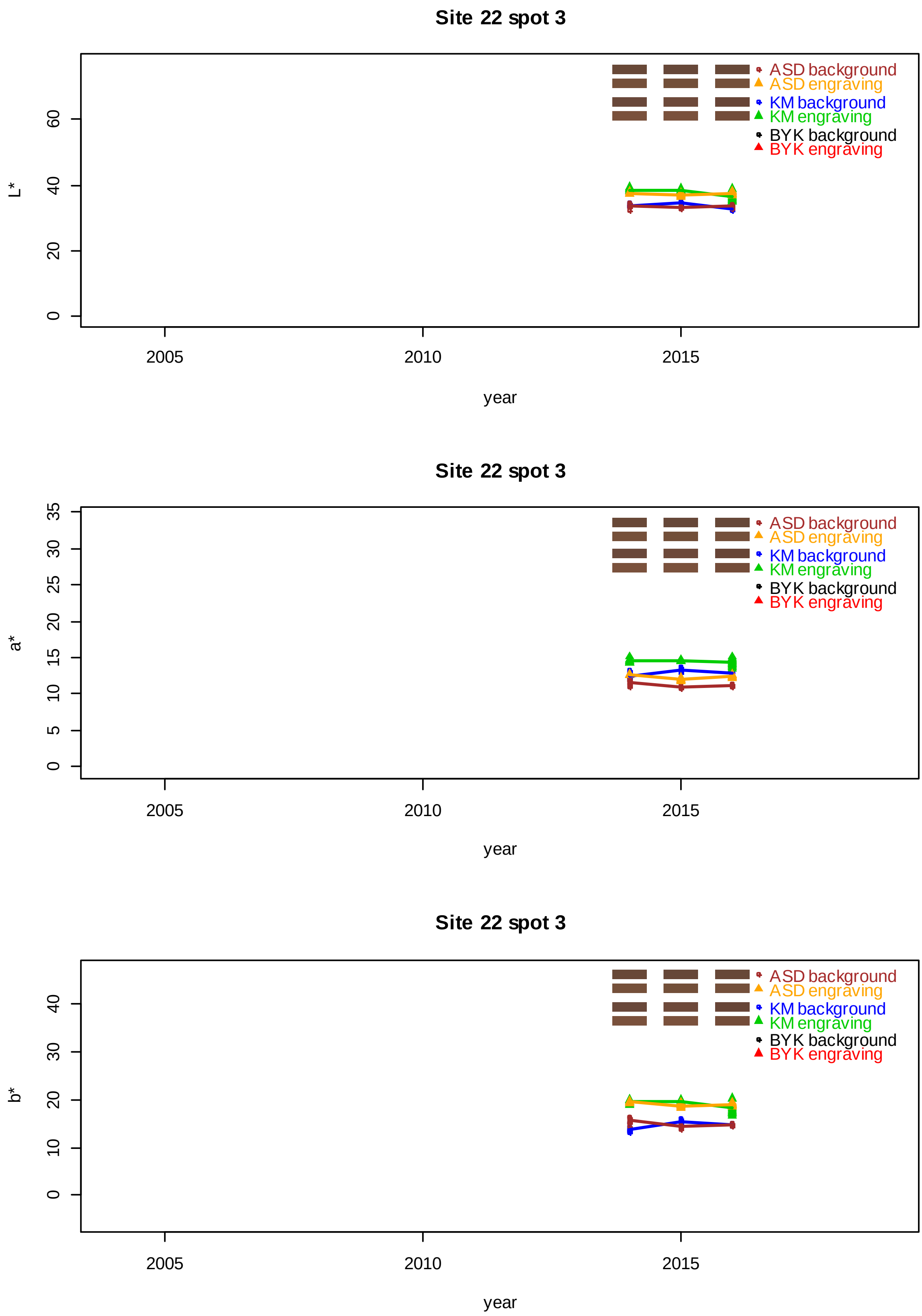


Figure 53. Site 22 spot 3 colour measurements, plotted as in Figure 19.

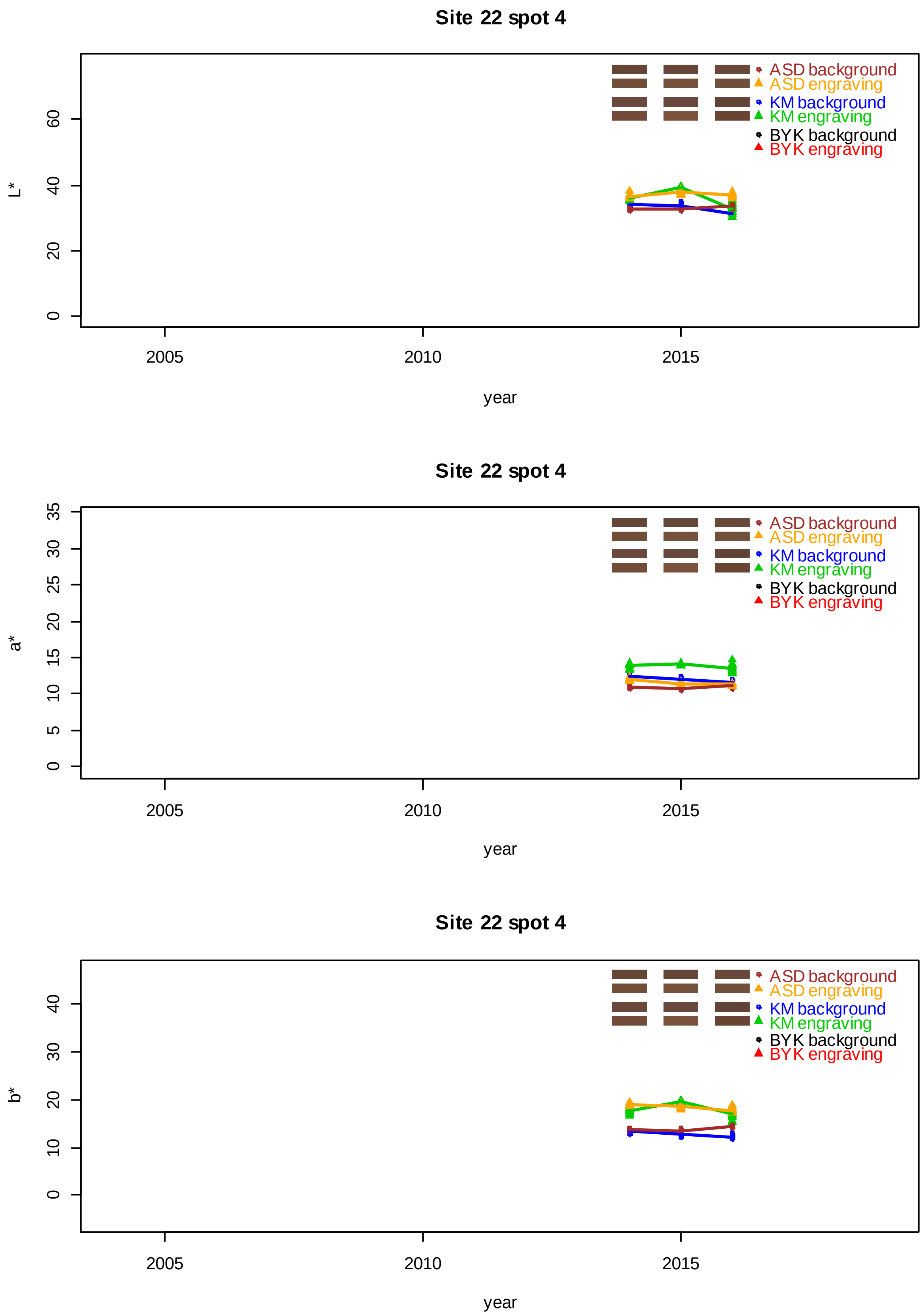


Figure 54. Site22 spot 4 colour measurements, plotted as in Figure 19.

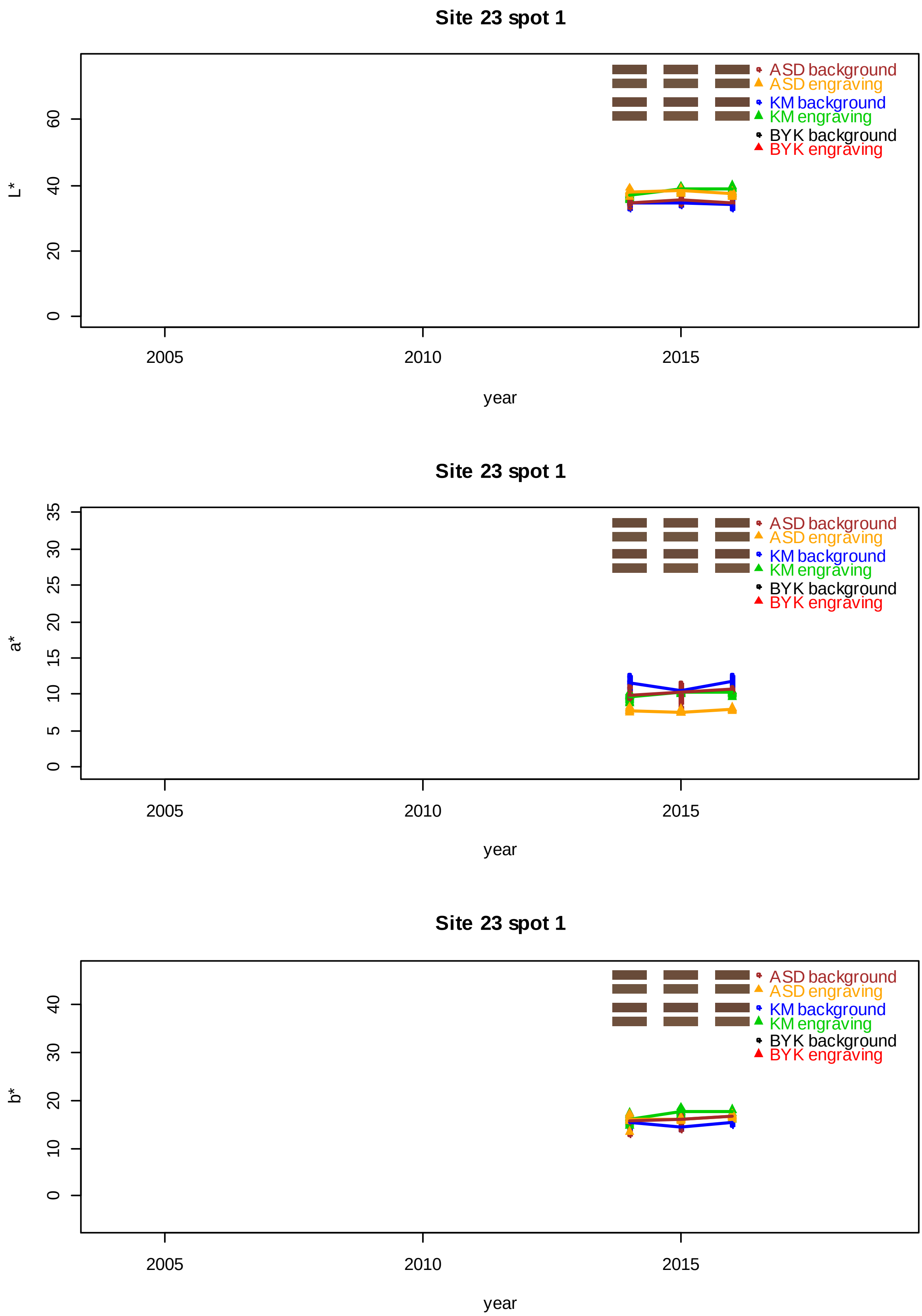
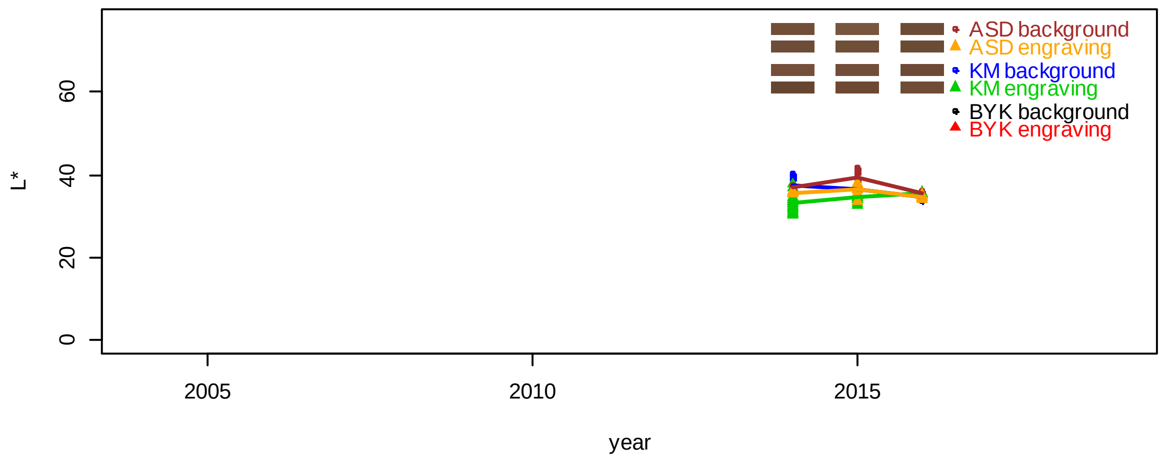
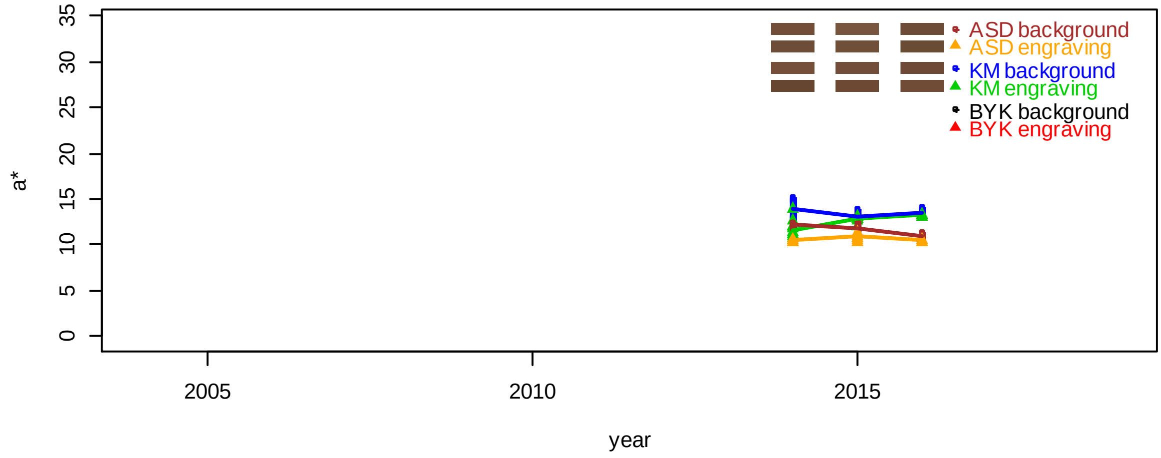


Figure 55. Site 23 spot 1 colour measurements, plotted as in Figure 19.

Site 23 spot 2



Site 23 spot 2



Site 23 spot 2

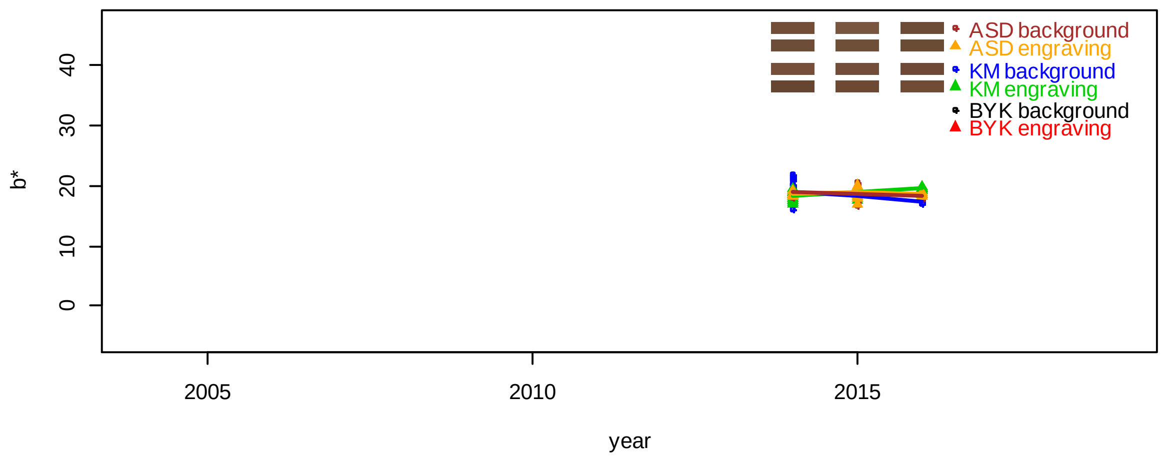


Figure 56. Site 23 spot 2 colour measurements, plotted as in Figure 19.

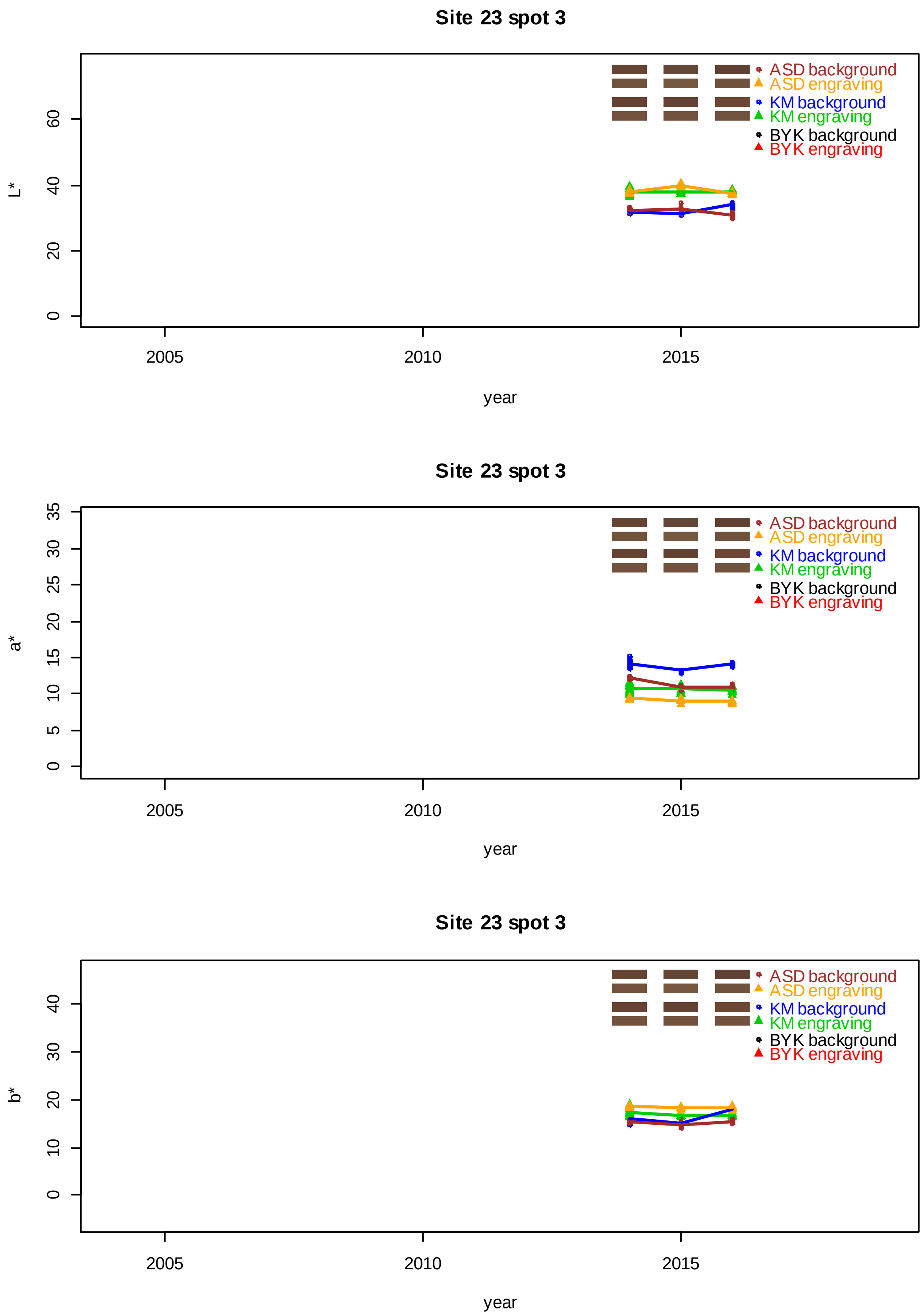


Figure 57. Site 23 spot 3 colour measurements, plotted as in Figure 19.

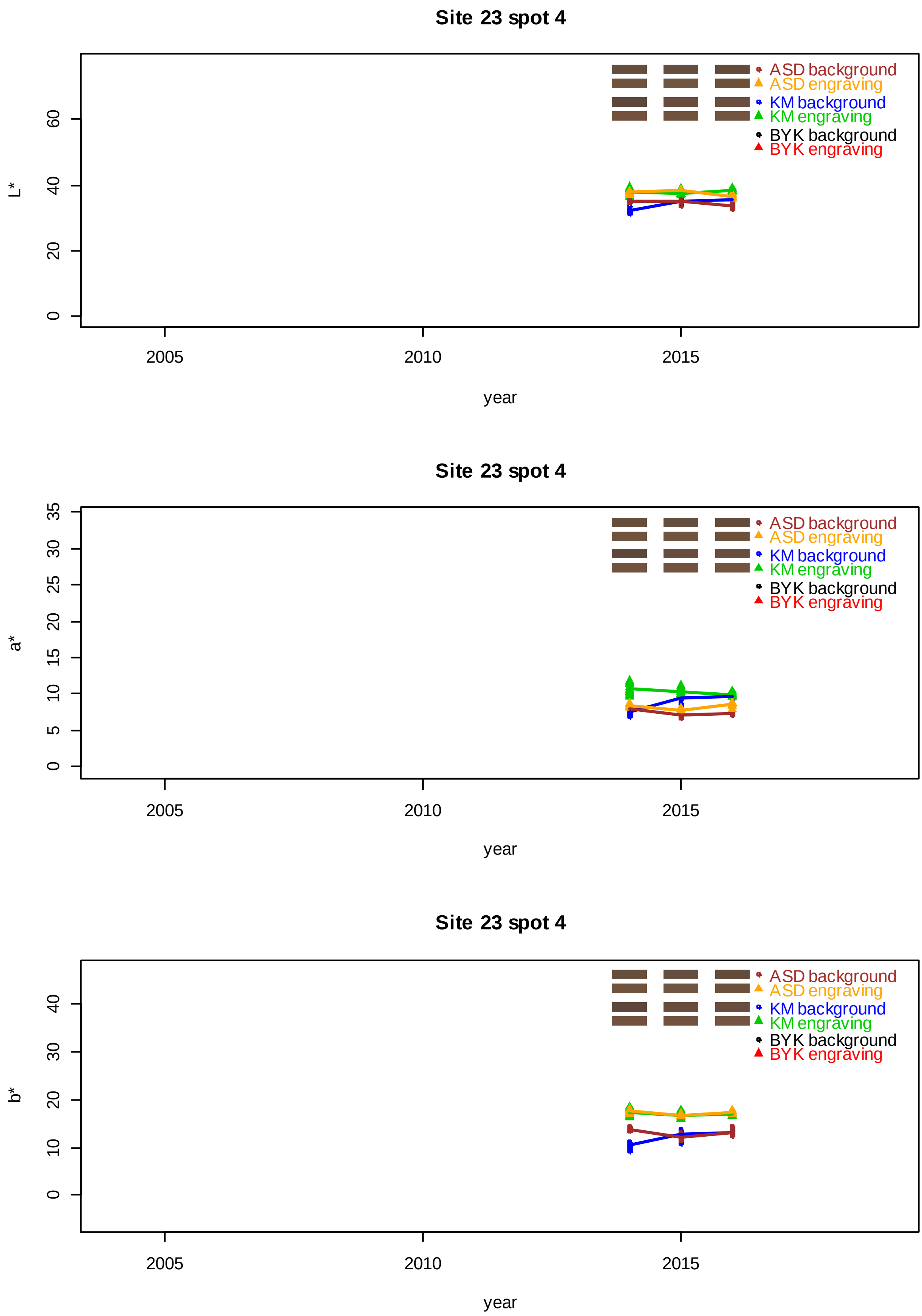


Figure 58. Site 23 spot 4 colour measurements, plotted as in Figure 19.

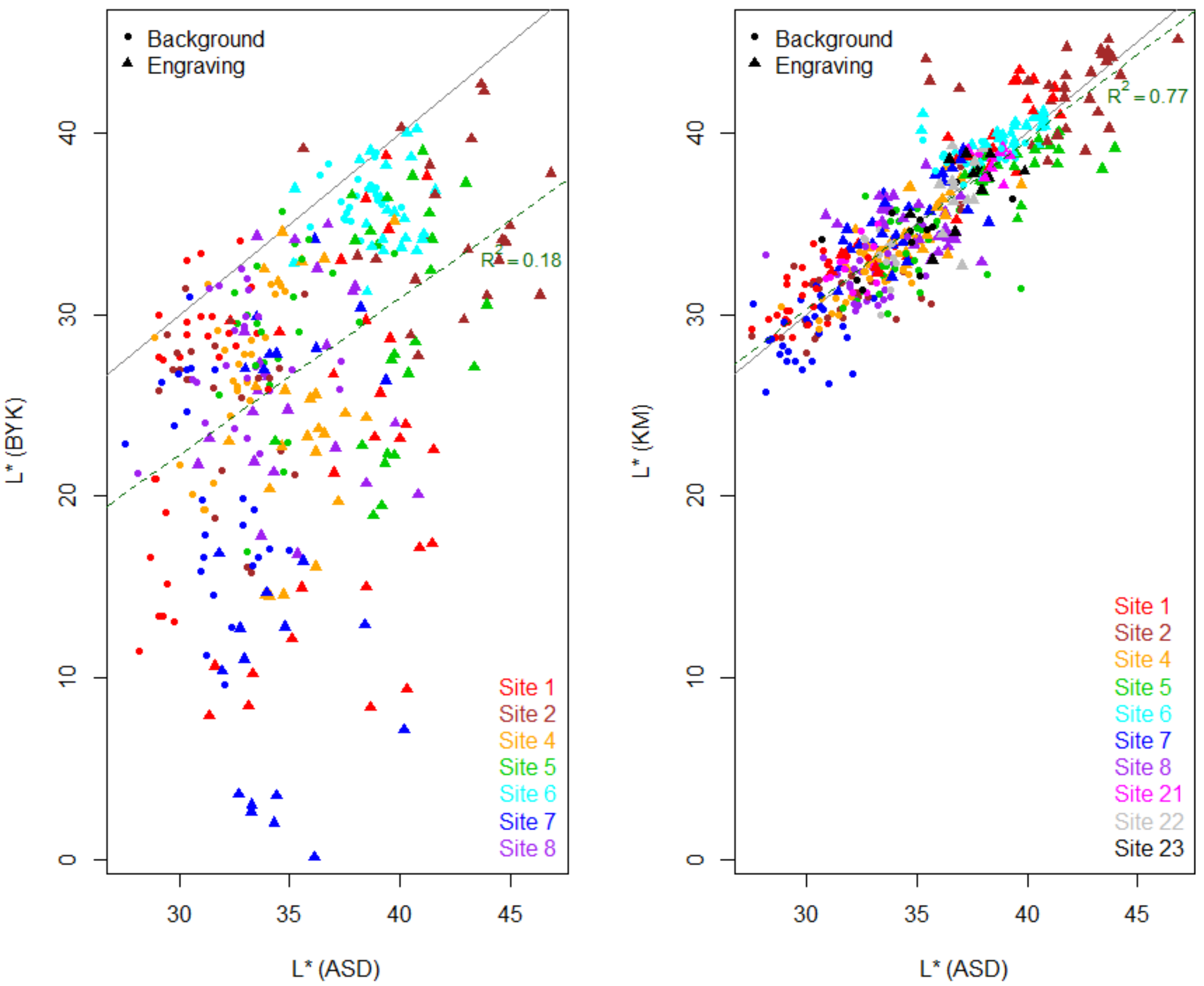


Figure 59. Average L* values from BYK and KM photospectrometers, compared with average L* values calculated from ASD spectra for background and engraving across all years, sites and spots. The horizontal axis in each case is the L* measurement calculated from ASD spectra, and the vertical axis is the L* measured value on the BYK instrument (left plot) or the KM instrument (right plot). The solid line shows where measurements would lie if they corresponded perfectly. Dashed regression lines indicate the average difference between the instruments, and the labelled value of R^2 for the regression indicates the level of agreement. The site colour coding shows that some sites have higher lightness than others do, but also that some sites show greater variation in BYK measurement. Triangles indicate measurements of the background, and circles of the engraving; note that the larger outliers on the BYK photospectrometer were made on the engraving.

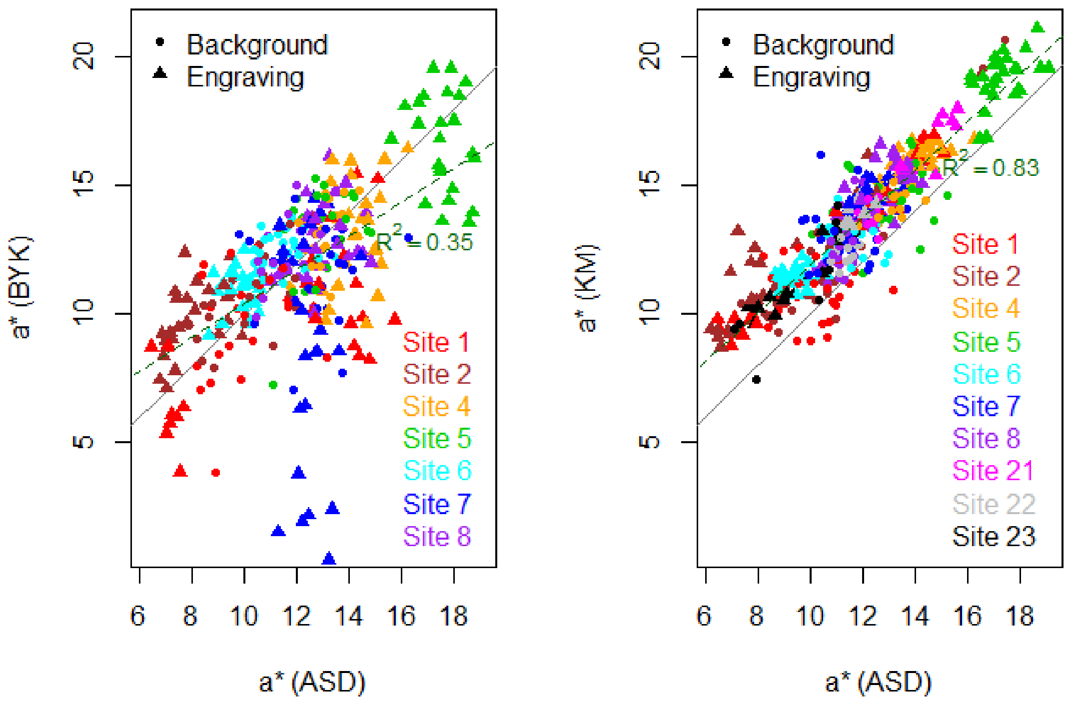


Figure 60. Average a* values from BYK and KM photospectrometers, compared with average a* values calculated from ASD spectra for background and engraving across all years, sites and spots. The plots are generated as in Figure 59.

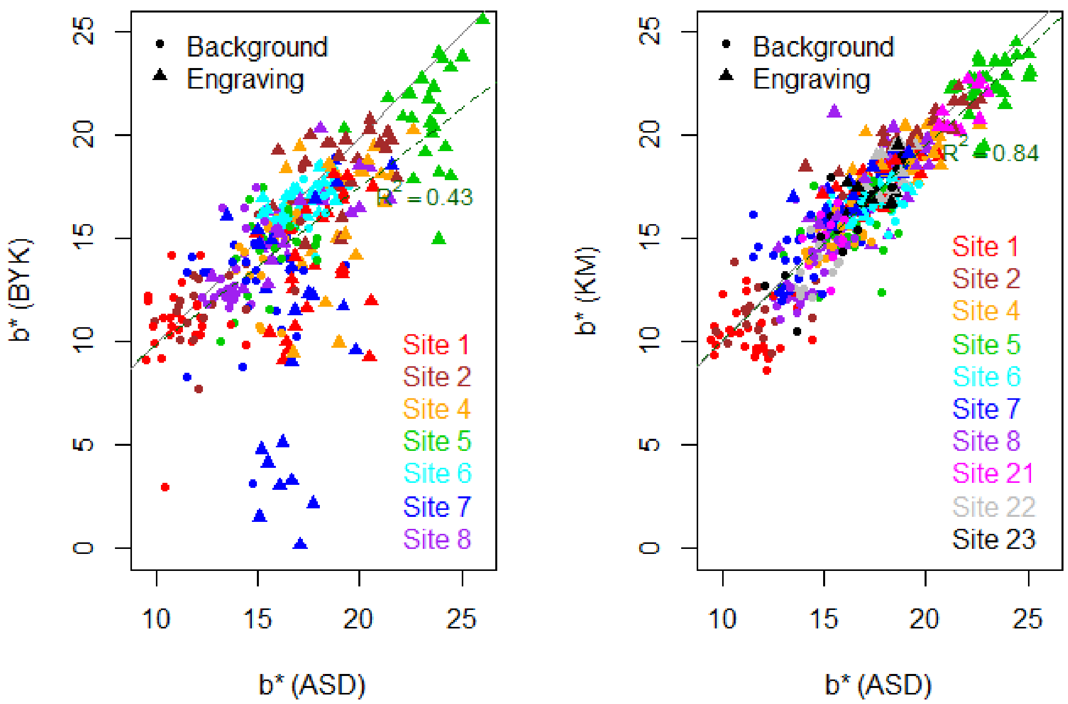


Figure 61. Average b* values from BYK and KM photospectrometers, compared with average b* values calculated from ASD spectra for background and engraving across all years, sites and spots. The plots are generated as in Figure 59.

6.3 Analysis of colour measurements from KM and ASD spectrometers

6.3.1 FACTORS AFFECTING COLOUR MEASUREMENTS

Models of the data must account for various fixed and random effects. The physical situation evidently suggests there should be expected to be random variation between sites (which vary in their age, location, degree of exposure to weather, etc.), and between the various spots on each site, and between the measurements taken each year. Variation between years could be caused for example by:

- weather events, which may affect each site differently and may be each spot differently as the spots on some sites are quite distant from each other;
- microbiological activity, which would clearly fluctuate randomly across all sites;
- animal activity, the engraving at a spot was once covered by a bird dropping;
- slight variation in the targeted alignment of the photospectrometer as the chosen spot is identified by photos and by the memory of the instrument operator. Some variation here is inevitable, since the rocks cannot be marked to standardise the position of the instrument each year.

Before 2015, multiple measurements were taken with the ASD spectrometer without replacing the instrument on the rock surface, providing also a measure of internal instrument variability.

Fixed effects to be tested for in each model include differences between the background and engraving; differences between the northern and southern sites; linear trends over time; and interactions between these effects. These effects apply equally across all measurements, though they could also vary randomly with the other factors described above; for example, the engravings at different sites may achieve differing contrast with the background owing to differences in age, or in the engraver; the effects of weather or other events may differ between rocks of slightly different composition, or between background and engraving; etc. Figure 19 to Figure 58 make it clear that the northern and southern sites chosen are different, but the study seeks to test whether the rate of colour change also differs at the two separate locations. If industry affects rock colour, this would be expected to influence southern sites more than northern sites; sites 1 and 2 were chosen to be far from industry in order to serve as controls.

It would be possible to test also for curvilinear colour change in the rocks, rather than linear trends; but plots of the data in Figure 19 to Figure 58 give no indication of such curvature, and the number of years of data is still relatively low, making models of more than linear colour change harder to justify. (Sites 21-23 have only been measured on three occasions; fitting a curved trend to this data would leave no estimate of error in the fit.) In addition, for the purpose of monitoring, steady changes of colour in a particular direction are of principle interest.

Note that the effect that must be tested for is not simply whether or not L*, a* and b* measurements change over time; such changes are expected, due to a variety of random effects including those described above. Random fluctuation of each colour measurement over time is amply demonstrated in Figures 29-68. Rather, interest centres on

- whether each measurement has an overall trend in one direction over time; and, most importantly,
- whether that trend differs between the northern control sites and the others.

It is also of interest to know whether such trends affect the background and engraving differently, though this is not the basic aim of the study. (For example, it would still be a concern if the southern sites were changing rapidly, but at the same rate on both background and engraving – even though the background/engraving contrast would then be constant at all sites.)

6.3.2 RANDOM VARIATION: OVERVIEW

The strongest evidence for change in the KM data occurs in the L* measurements. Even here, though, the evidence is not overwhelming; plots of the KM data in Figure 19 to Figure 58 give little visual impression of a general trend over time in all the L* measurements. Figure 62 overlays all the L* measurements from the KM spectrophotometer on a larger scale.

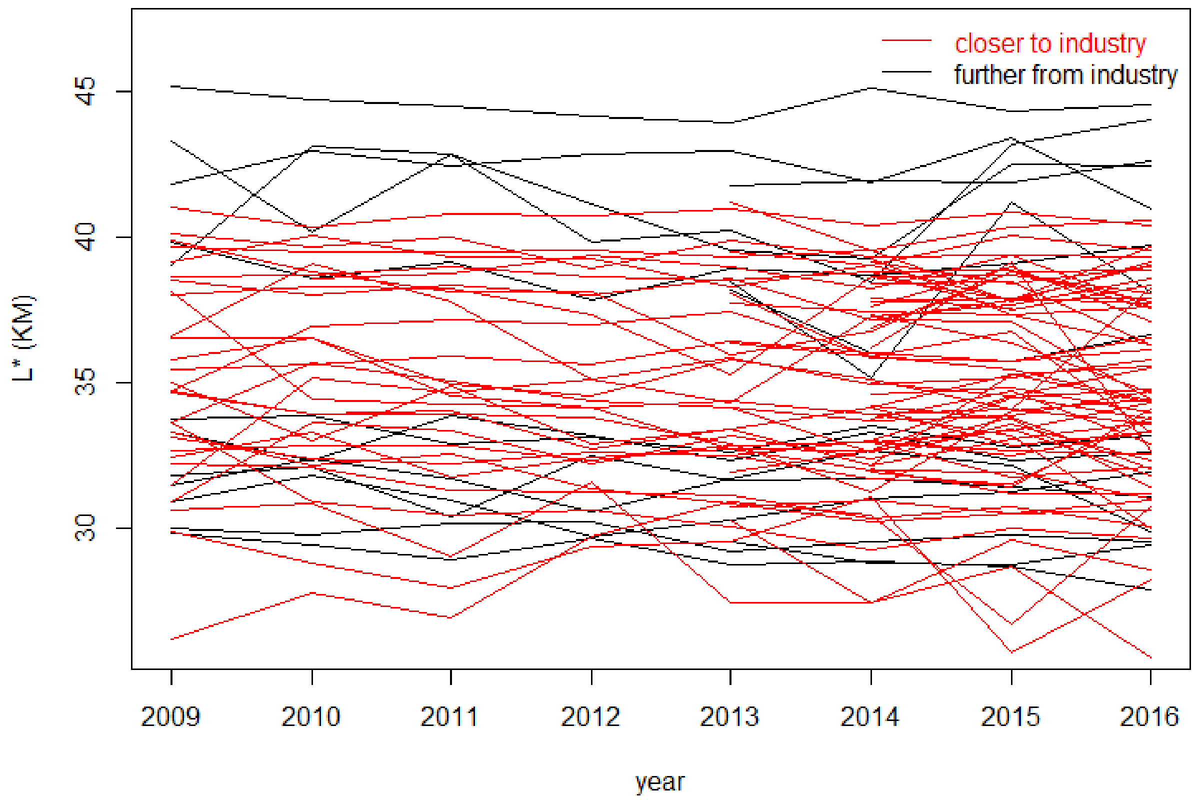


Figure 62. Variation over time in average L* measurements on the KM spectrophotometer for background and engraving of all spots on all sites.

Figure 62 shows that the measured L* values in the KM data vary widely across the entire experiment, but have no clear trends over time. Most, but not all, of the engravings are lighter than the backgrounds (see Figure 19 to Figure 58); and the lightest engravings belonged to control sites 1-2, as Figure 62 depicts. But neither these control sites nor the others show any obvious sign of a continuing trend over time toward either greater or lower lightness; and the slopes of the black lines do not obviously differ from those of the red.

There is no spot where either background or engraving lightness was always recorded either to increase or decrease. Each of the backgrounds or engravings for which measurements have been made since 2009 'changed direction' (from increasing L* to decreasing, or vice versa) at least twice over that period. Note also that the ups and downs of each site are asynchronous; there is no time point where all L* readings changed in the same direction. Rather, the magnitude of different sources of variation appear to differ for each site, spot and type (background or engraving). A clear directional trend would have manifested itself in consistent increases or decreases at the same spot each year, or perhaps in simultaneous increases or decreases across many sites during the same year; but the data illustrates neither of these scenarios.

A formal profile analysis (Desjardins and Bulut, 2015) confirms that the changes over time at the background and engraving of spots on each site are not parallel; random variation affects each one differently. This suggests caution in drawing conclusions from the analysis that follows, as inferences about these trend models are based on the assumption that each series of measurements is subject to the same sources of random variation. If the causes of random variation at each spot are different (for example, if some are more subject to particular environmental events than others, or if it is harder to correctly place the spectrometer on some than others) then the assumption that each has the same variation may well be invalid, and a true comparison between the various sites and spots will not be possible.

Similar analysis applies to other measurements taken with the KM spectrophotometer, and to L*, a* and b* values calculated from measurements on the ASD spectrometer.

6.3.3 LINEAR MIXED EFFECTS MODEL

Simple averages of the level of annual change in L*, a* and b* measurements are given in Table 17. (The actual variation at background and engraving of each site and spot are plotted in Figure 19 to Figure 58, but Table 17 gives a convenient high-level summary.)

Note again that the BYK photospectrometer differs markedly from the others, recording increases in all variables, whereas the other measurements decreased on average in the case of L* and of a*; and recording much greater change for each variable. Issues with the reliability of data from the BYK spectrophotometer have been discussed above.

Table 17. Averages of the increases per year of L*, a* and b* measurements across each combination of site, spot and type (background or engraving) for each instrument. (Negative numbers indicate an average decrease over time).

	L*	a*	b*
BYK	1.456	0.253	0.144
KM	-0.161	-0.005	0.010
ASD	-0.132	-0.048	0.007

Table 17 again reflects good agreement between results from the KM and ASD instruments. The level of change in L* recorded on these spectrometers, while lower, is still high enough that colour change would eventually be visually detectable at some sites (the scales of L*, a* and b* are designed so that a change of about 2 in any of these variables would be just noticeable to the human eye). The question is whether the recorded changes are actually indicative of real colour change on the rocks, or whether these measured values could have arisen, through random variation as described above, on rocks where no colour change has actually occurred.

The lmer function in the lme4 package of R (Bates et al.) was used to fit linear mixed effects models to each of L*, a* and b*. The BYK data shows very clear trends that are modelled as significant no matter what particular model of random variation is used. However, the KM and ASD data is much less clear-cut; different conclusions could be drawn depending on how the random variation is modelled. The models summarised below include all the sources of variation described in Section 6.3.1 above, including random variation on background and engraving of each site and spot each year. This factor is modelled to have a high variance in all models investigated (in the case of L*, it is never less than 1.8 units, which is large considering a change of around 2 units would be visible to the naked eye). Including with this effect all lower order combinations of these factors is a standard choice.

The R code thus includes random terms (type | yearF) + (type | site) + (type | spot) + (type | yearF:site) + (type | yearF:spot), where type is an indicator variable identifying background and engraving; and site, spot and yearF are factors indicating site, spot (coded to distinguish between identically numbered spots on each site) and year respectively. ASD models also include a (1 | place) term to allow for variation within repeat measurements made before replacing the spectrometer on the rock.

The contrast between background and engraving differs between northern and southern sites, as Figures 29-68 demonstrate, so this fixed effect is included in all models. A comparison can then be made between a basic model and others including a trend over time; different trends in northern and southern sites; and different trends on background and engraving at northern and southern sites. Results are summarised in Table 1.1.

Table 18 p values for successively adding to models for L*, a* and b* measured with KM and ASD spectrometers: a trend over time (first row); different trends on northern and southern sites (second row); and different trends also on background and engraving (third row).

	KM			ASD		
	L*	a*	b*	L*	a*	b*
year	0.004	0.28	0.60	0.029	0.012	0.46
control * year	0.33	0.45	0.89	0.94	1.00	0.93
control * year * type	0.71	0.84	0.84	0.77	0.13	0.94

Most of the p values in Table 18 are fairly high; in most cases, it would not be unlikely for purely random variation to produce evidence for time trends as strong as the evidence of the observed data. However, the models for L* measured on the KM instrument, and for L* and a* measured on the ASD instrument, indicate a continuing trend over time. (Table 1.1 does not indicate that trends in any of the colour measurements, or in contrast between background and engraving, differ significantly at northern and southern sites.)

A p value less than 0.05 is usually considered 'statistically significant', as the probability of such an event occurring by chance is less than 1 in 20. In a situation where multiple comparisons are conducted, however, it is usual to require a lower p value in order to be certain that the result is not merely one of random chance. In a series of 20 tests on completely random data, one test would be expected to have a p value of 0.05 or less simply by chance. In the first row of Table 1.1, tests have been conducted on L*, a* and b* values from two instruments; the probability of at least one of these tests obtaining a p value as small as that obtained from L* analysis on the KM instrument is 0.024, which is still low, indicating that this effect is more than a statistical anomaly. However, the probability of at least one of the remaining five tests obtaining a p value as small as that for the a* analysis on the ASD spectrometer is 0.06, which is less remarkable. The observed evidence for trends in data from the ASD spectrometer does not appear so convincing if such a correction is applied. Nonetheless, further investigation is warranted – particularly in the case of the L* data measured on the KM spectrophotometer. This trend in the lightness of the rocks is supported by the similar (though less statistically impressive) result from data recorded on the ASD spectrometer.

In summary, the KM data show a trend over time in the L* measurements, but not in a* or b* measurements. Data from the ASD spectrometer indicates change over time in the L* and a* data, but not the b* data, though this is less clear. None of the instruments demonstrates a difference in the rate of change between northern and southern sites.

The modelled change in measured lightness in the KM data is a decrease of 0.31 units per year, across both background and engraving of all spots on all sites. A 95 % confidence interval for this decrease in lightness is (0.11, 0.52) units per year.

The section is concluded with plots relevant to some of the models mentioned above. Changes in L* and a* values calculated from spectra recorded on the ASD spectrometer are plotted in Figures 63 and Figure 64. There is again little visual indication of any trend in this data.

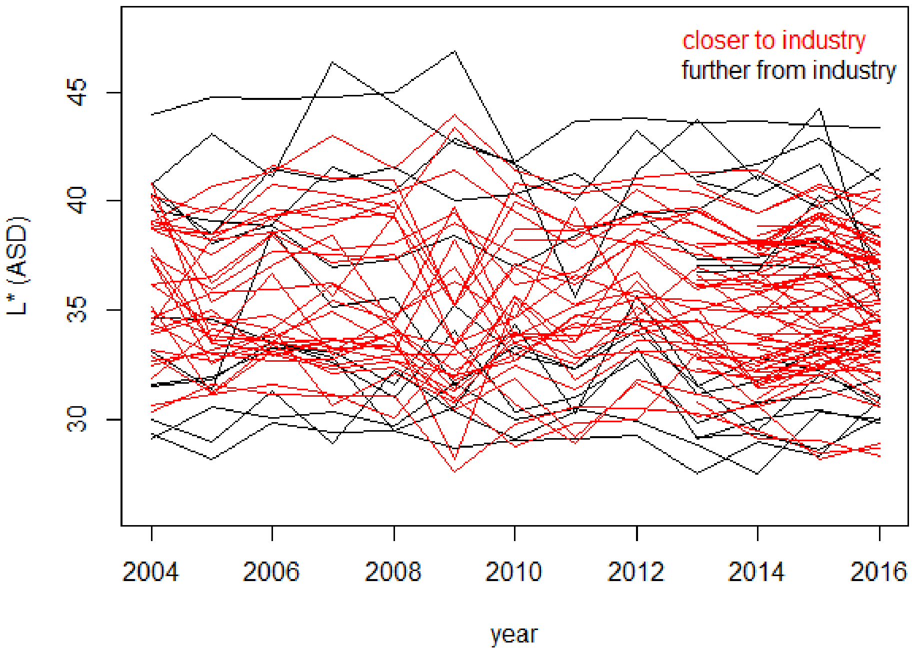


Figure 63 Variation over time in average L* measurements calculated from spectra recorded on the ASD spectrometer for background and engraving of all spots on all sites. Data from sites 1-2 is drawn in black; all other data in red

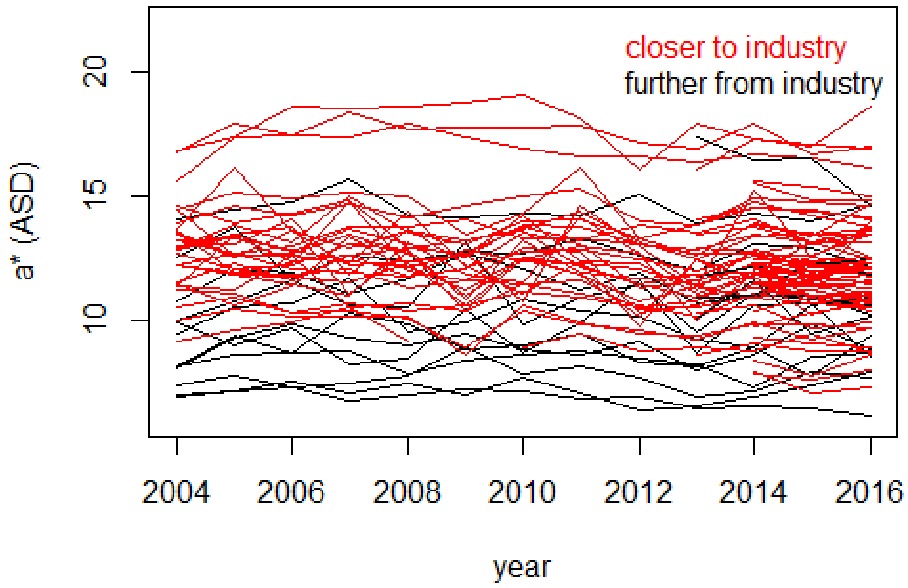


Figure 64. Variation over time in average a* measurements calculated from spectra recorded on the ASD spectrometer for background and engraving of all spots on all sites. Data from sites 1-2 is drawn in black; all other data in red.

Figure 65 plots the residuals in the model for L* measured on the KM spectrophotometer, including a linear trend over time. There are just a few large residuals that could suggest heteroscedasticity however not enough to reject the model on this account.

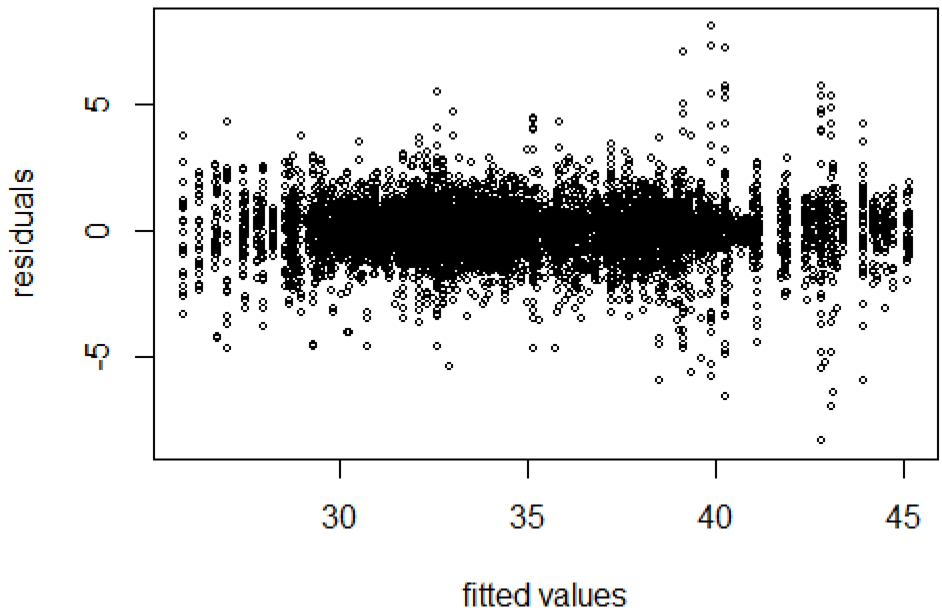


Figure 65. Residuals and fitted values of the model for L* data calculated from spectra recorded on the KM spectrophotometer for background and engraving of all spots at all sites. The level of variation in the residuals is fairly constant across all fitted values.

7. Conclusion of 2004-2016 study

The petroglyphs at seven sites in the Burrup Peninsula were measured annually from 2004 to 2016. Three new sites close to the new Yara construction plant were also added from 2013 bringing the total to 10 sites. The same engravings and background rocks were measured *in situ*. Measurement of the annual colour changes utilised three instruments, the ASD and the BYK and KM. An examination of the colour measurements as a function of time, as well as a comparison of the two measurement techniques, has been conducted.

For both the KM and the ASD instruments, three-dimensional L*a*b* colour space (L* - degree of lightness, a* - degree of red/green, b* - degree of yellow/blue), identifying a tristimulus value (L*a*b*) for each sample point have been calculated.

Data from the KM spectrophotometer shows a trend over time in the L* measurements. The lightness (L) decreasing at a modelled average rate of 0.31 units per year (a total decrease of about 2 units on this scale is just noticeable to the human eye). However no trend is indicated in either a* (degree of red/green) or b* (degree of yellow/blue).

Data from the ASD spectrometer shows trends indicated in L* (degree of lightness) and a* (degree of red/green) but not on b* (degree of yellow/blue), though the evidence is not as strong as seen with the KM instrument.

The conclusion of colour change would be clearer if it was detected across all dimensions of colour (it would be natural for colour change to be evident in all dimensions, L*, a* and b*, not only in one or two of them). The results are not fully conclusive and if the measurements do reflect real colour change, as the data suggest, then continued observations would continue to mark out the trend more clearly; and if not, observations will likely continue to fluctuate over time, making the randomness of the recorded variation more apparent. Sites 21-23 have currently only three years of observations; additional observations will be particularly helpful at these sites. Nonetheless, the indication of significant colour change is important, and warrants closer attention. None of the instruments demonstrates a difference in the rate of change between the northern control sites and the southern sites closer to industry.

It should be noted that data from the BYK spectrophotometer appears unreliable for drawing conclusions on colour change in the rock art and, as such the cross calibration issues with the BYK portable photospectrometer and the KM photospectrometer will no longer be undertaken.

All the photospectrometer data (KM, BYK and ASD) have been provided in an easily readable format to WA DER for safekeeping.

It should be noted that the results of this report supersede all results previously published.

8. Recommendations

For future work, it is recommended that:

- A complete statistical analysis is done on the full spectrum of each individual ASD spectrum (not just the visible part i.e. L*, a* and b*)
- A study be conducted to assess how many new sites and how many new engravings and backgrounds should be added to the current locations to increase the quality of the monitoring in the Burrup Peninsula. In particular, new control sites with similar rock types should be added to the current ones (for instance Depuch Island). It should also be noted that by increasing the number of independent measurement on each spot (in doing so improving statistical analysis) could also have an adverse effect on the petroglyphs and it was demonstrated in 2015 and 2016 by coloured spectrometers heads, signs that instruments measurements might be affecting the measured spots. A balance should be found between statistical endeavour and petroglyph protection.
- One (1) rock sample be collected at each site (old and new), a total of 10 samples, and brought to CSIRO in Perth to be stored in a container where humidity is 0% (no water) and in an argon atmosphere (no oxygen and no oxidation) and placed in a dark area. This will allow a comparison between the control sites, where natural weathering occurs and these reference samples.

It is also recommended that the colour and mineralogical monitoring be complemented in the future with atmospheric and microbiological monitoring studies.

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