Acid Sulfate Soils Centre

Soil patterns on bra fabrics dragged across different soil surfaces using image analyses:

Laboratory dragging experiments

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Cover image

Weighted bra dragged from right to left over soil material during a three second count soil transference experiment. Sections of bra that are not subjected to being dragged over the soil during the experiment remain clean inside a clip-lock plastic bag on top of the weight. The glass Pyrex dish containing soil material and weighted bra is placed on a nonslip mat and a backstop of weights on the left to stop it moving during the transference experiment.

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EXECUTIVE SUMMARY

Key forensic science evidence in a 2012 homicide case included the results of soil examinations. While the soil comparisons that indicated source were not in question, the process of how the soil was deposited on the victim's clothing became a significant factor. It was alleged that the victim was dragged and that this was the mechanism of transfer. However there was no published research available that identified characteristics typical of dragging and the court could not be satisfied that some other mode of transfer had not occurred. The work described in this report was undertaken to provide knowledge that would assist in interpretation of soil transfer in criminal events.

The soil evidence in the homicide case was principally located on the victim's bra. Weighted bras were used in these STEs, to simulate a female victim dragged across a soil surface. Soil transfer to bra shoulder-straps and cups was studied. Shoulder straps were chosen because this area retained the most soil evidence in the aforementioned murder case; while bra cups provided a large area to aid in the initial investigation of soil transfer patterns.

Eighty-four (84) experiments used anthropogenic and natural soils from the Royal Tasmanian Botanical Gardens, Hobart, Tasmania, Australia. Four soil samples used were anthropological [otherwise known as Technosols or human altered/human transported (HAHT)] soils; including one brick sample. One sample was a mixture of HAHT and natural soils, and two samples were natural soil types. Six soils were sampled from 0-10cm depth. One natural soil sample, made from undecomposed leaf matter, was taken from 0-5cm above the soil surface.

Using nylon-elastane bras and either wet or dry soil from seven distinct samples, the soil transfer patterns produced during the experiments were identified in situ by naked eye alone, or with the aid of a microscope. Soil transfer patterns were photographed in situ using a 14 megapixel digital camera and provided an accurate record of the trace soil evidence. Microscopic analysis and photomicrographs of soil transfer patterns followed, with the firmly attached weight preserving the soil transfer patterns through increased stability of the flimsy bra fabric. Once clothing is moved, results indicated that loose soil particles that help define the often very delicate soil transfer patterns are lost; or deposited in the bottom of an evidence bag.

The soil transference experiments identified eight patterns specific to dragging as the method of transfer. These transfer patterns were largely dependent on a wide range of soil features that were measured and identified for each soil tested using X-Ray Diffraction and DNIR analysis. STEs consistently resulted in soil building up on clothing seams, strap edges and to a lesser extent, fluffy seams. Soil 'trails' consistently provided strong evidence of fabric being dragged across a soil surface. A fine dusting of soil appeared on metal bra shoulder-buckles when very dry soil was tested. In contrast, when wet soil was used, the metal buckle was either completely clean or had muddy aggregates adhering to an otherwise wet shiny surface. The dragging method used in these experiments trapped soil in front of the metal buckle and left characteristic 'plough' marks in the soil surface behind. The alignment of elongated particles of soil with the direction of drag was also noted in the laboratory. However, this pattern had to be documented in situ; because the slightest movement of particles or fabric by air-conditioning could destroy the alignment. For this reason, this transfer pattern was the least consistent and should not be relied upon outside of a controlled laboratory environment.

The majority of soil particles transferred in all STEs were very fine silt or clay-sized fragments. The largest fragment transferred was a 5mm x 4mm brick fragment.

Six of the eight soil transference patterns were produced by the transfer method of dragging with 100% consistency in wet and dry soil runs across the seven soil samples; depending on soil moisture content, particle size and mineralogy, some patterns were easier to visually identify than others. Another two patterns that appeared intermittently involved the alignment of elongated particles parallel to the direction of movement and a comparison of the quantity of soil transferred onto fluffy-textured versus smooth finely-woven fabric.

Image processing software analysed digital photographs of soil transference patterns on fabric. All soil objects transferred with a diameter of 2 pixels and above underwent an object-oriented classification. Trace soil from one of seven soil samples were identified using a Munsell colour range with similar diominant and sub-dominant peaks of specific Munsell colours.

Image processing numerical data gathered on the quantity of soil transferred to fabric enabled a relationship to be discovered between soil type, clay (smectite), particle size and soil moisture content. Soil type (e.g. gravelly, sandy, loamy or organic-rich soil), clay (smectite) and soil moisture content were the greatest influencing factors in all the dragging soil transference tests (both visual with the naked eye and measured properties) to explain the eight categories of soil transference patterns.

Key findings and future work

In order to increase our understanding of the universality of soil transfer patterns, which underpin key findings in this research, it was necessary to examine how soil mineralogy, carbon and sulfur content may influence resulting soil transfer patterns. X-ray diffraction (XRD) analysis was used to compare and contrast mineralogy of the original soil samples used in the STEs. Carbon and sulfur content was determined through Nondispersive infrared (NDIR) analysis.

The texture of soil samples ranged from loamy to clayey. NDIR identified carbon levels of up to 3.10% in the gravel-rich HAHT soils, 14% for the Rose garden bed HAHT soil and 22.8% in the natural soil. No Sulfur-bearing species were identified. Further testing of soils from vastly different origins would be required to confirm the universality of the patterns documented in this paper. But initial results are extremely promising that the trace soil patterns that occur when weighted fabric is dragged across a soil surface, would be seen to a greater or lesser extent in all soil types.

Image processing computer analysis of digital photographs taken *in situ* of trace soil transfer patterns on fabric provided an object-oriented image classification of soil objects transferred. Although soil transfer patterns were easily identifiable by naked eye alone, image processing software provided objective numerical data to support our conclusions. Using Trimble eCognition Developer software, all soil objects (both individual grains and aggregates from 2 pixels/≥100microns diameter) were mapped on the fabric surface. Each soil transfer pattern was analysed for its unique range of Munsell soil colours, directionality of soil clumps and stains and quantity of different categories of soil particles. Image processing software thereby enabled the collation of more comprehensive, objective and quantifiable numerical data than could be produced through the interpretation of soil transfer patterns by naked eye alone.

Image processing also provided a more comprehensive Munsell Soil colour analysis to identify and compare trace soil on fabric to other trace soil evidence from the same location. There is tremendous potential for image processing analysis to accurately identify and compare the Munsell soil colour of trace soil evidence on fabric without requiring a spectrophotometer. For example, this robust approach and methodology enables Munsell soil colours and other distinctive characteristics of soil morphology of trace amounts of soils on fabrics to be better interpreted in a court of law.

These new methods of forensic soil investigation provide a direct interpretation of the circumstances behind clothing making contact with a soil surface at a crime scene. Digital photographs taken of trace soil evidence and analysed by image processing software, have the potential to accurately compare trace soil evidence on both victim's and suspect's clothing. These forensic soil analyses do not require expensive equipment or highly trained personnel (e.g. scanning electron microscopy). This initial stage of analysis can potentially be done by Police and Forensic scientists with a very limited knowledge of soil science. Once the soil transfer patterns are recognised and categorised using the image processing software, this information will provide a more quantitative indication of whether trace soil evidence on a victim's clothing is similar or dissimilar to soil evidence on suspects' clothing, Police can decide whether the soil evidence warrants further investigation via more expensive and time-consuming techniques.

1. INTRODUCTION

Summary

This section gives a brief and selective overview of the purpose for conducting soil transference experiments on bra fabrics.

1.1 Overview and purpose

In the Australian Rayney murder case (Martin 2012b, 2012a), there were no fingerprint or DNA evidence or reliable witness testimony to help Police solve this complex murder case. Soil evidence on the victim's bra became vital in discovering and proving the circumstances and location of the initial attack as being the front yard of the victim's home (Fitzpatrick *et al.* 2011; Martin 2012b). Soil evidence on victim's bra remained uncontaminated from other soil sources, despite the victim being buried for eight days at a second location containing a completely different soil type. The CAFSS report and presentations/cross examination in the Perth Supreme court provided a "predictive, soil-regolith model, from microscopic to landscape scale", which established that soil and brick particles/fragments found on the victim's clothing and hair (via two seed pods) originated from the front yard of the victim's home at Como in Perth. The Judge (Justice Martin) agreed with this assessment, as indicated in the following 2 paragraphs of his 369 page report (Martin 2012b, 2012a): "Para 1136 - In broad summary, the soil and artefacts recovered from the deceased and her clothing provide a significant link between the deceased and the home at Como." However, CAFSS were not able to provide evidence during the court hearing on how the brick particles/fragments were transferred to the bra, especially within the elasticised bra-straps. Instead, CAFSS were requested by the Prosecution Council during the trial to provide a supplementary statement on the extraction of the particulate material from the bra (Fitzpatrick and Raven 2012b) for use by State forensic laboratories to conduct soil transference experiments or to provide a statement on possible mechanisms for soil transference to the bra.

The complex circumstances of this murder investigation provided the impetus for conducting a series of systematic soil transference experiments on clothing (bra cups). The prime objective of this study was to develop and conduct more quantitative soil transference experiments based mainly on the methods developed by Pounds and Smalldon (Pounds and Smalldon 1975b, 1975c, 1975a). This will assist forensic examiners to better interpret soil evidence discovered on clothing at crime scenes, especially to establish if a clothed victim has been dragged across a soil surface (Pye 2007; Ruffell and McKinley 2008; Murray 2011). Consequently, the aim of this work was to investigate and develop methods to better quantify soil transfer patterns on a bra using a wide range of representative anthropogenic [otherwise known as human altered/human transported (HAHT) soils or Technosols, which includes brick fragments] and natural soils.

The objectives of this study were to undertake a range of laboratory dragging experiments that involved: (i) testing twenty one (21) weighted bras to evaluate the persistence, size and quantity of soil transferred, (ii) eighty-four (84) soil transference experiments (STE) were run on these bras and (iii) detailed analyses of digital photographs of the resulting soil transfer patterns on the bra cup fabric using image processing software to quantify different trace soil patterns on the fabric that was transferred from different soil locations.

False and/or incomplete criminal reports are a reality for law enforcement officials, waste police, forensic and judicial resources and can lead to possible miscarriage of justice (Taupin 2000; Rumney 2006). Identifying the exact cause or mechanism of soil transference and damage to clothing is difficult, and often the presence of soil and damage to fabrics is the only form of forensic evidence. In the context of soil forensic examinations, the most frequent damage to clothing is likely to be caused by dragging over a range of soil surfaces. A number of factors may influence the “severance morphology” in damaged fabrics such as: (i) the fibre content and fabric structure (e.g. elasticised fabrics) and (ii) soil type. Understanding soil transference and damage to clothing is important to support criminal investigations. Investigating damage and transference to fabrics has traditionally been done using low power microscopy and more recently has also incorporated Scanning Electron Microscopy (SEM) (Pelton 1995, 1998). However, SEM methods have limitations mainly because of: (i) the small size of sample required to be examined in the SEM, (ii) sample pre-treatments are required (i.e. method is partly destructive and (iii) the high cost for SEM analyses. Consequently, the preferred method involved using digital photographs taken *in situ* of the whole bra that was subjected to the dragging experiment followed by selective observations using a low-powered binocular microscope so as to ensure: (i) a “non-destructive soil pattern” on the bra, (ii) rapid and reliable testing, (iii) very little or no sample preparation (iv) and (v) relatively low cost of testing and analyses.

1.2 What is Forensic Soil Science?

The science of soil characterisation for forensic purposes can be significant in helping police solve crime, especially when no fingerprint or DNA evidence is available. The primary aim of forensic soil analysis is to associate a trace soil sample transferred onto an item with a specific location. Items that are routinely examined include clothing, shoes, vehicles and tools including shovels and rakes (Fitzpatrick 2013b; Fitzpatrick and Raven 2013).

When two surfaces come into contact, there is the potential for the mutual transfer of material between them (Locard 1930). It is the task of the forensic scientist to recognize and classify these minute particles of trace evidence.

Soil has been called the ideal trace evidence (Aardahl 2003). It is nearly invisible to the casual observer and the myriad of variables in mineralogy and morphology provide soil with the uniqueness of a human fingerprint. There are more than 50,000 different varieties of soil in the United States alone; and each soil variety will also differ at individual locations due to the soil's parent material, microclimate and unique ecosystem of organisms (Fitzpatrick 2008). The amount of time required for all of these soil-forming properties to create changes can take as little as weeks to thousands of years. Soil does not only alter laterally either. It also alters vertically (Fitzpatrick 2013a). Surface soil is most likely very different to soil occurring at one metre down.

There is an excellent chance that trace soil will be transferred onto any object that comes in contact with it; and that some fine (<2mm) particles will persist as soil evidence. Analysis of this soil evidence can be performed rapidly using inexpensive equipment and non-specialist practitioners (Fitzpatrick *et al.* 2009).

When soil from one location is transferred to a suspect or victim's clothing or belongings, this is referred to as a primary transfer. Secondary transfers, such as when soil from a victim's clothing is transferred to a suspect's clothing whist moving the body, can also provide valuable evidence linking a suspect to a crime scene (Morgan and Bull 2007).

Trace soil evidence found on clothes, shoes, vehicles and property can not only implicate suspects in the execution of a crime, but clear potential suspects and support their alibis (Fitzpatrick and Raven 2012a; Fitzpatrick *et al.* 2012b). Soil evidence has helped Police to solve decade old murders and cleared prime suspects of any involvement; enabling the innocent to mentally resume their lives and the guilty to face a court of law for their crimes (Fitzpatrick *et al.* 2012a).

Natural soil materials include minerals, organic matter and rock fragments, whereas human-made (known as Anthropol/Technosol or HAHT) soils may contain manufactured or exotic materials from different environments, such as glass, brick dust or small particles of concrete (Galbraith 2012). When HAHT material is discovered on clothing at a crime scene, or on the clothing of a suspect, it can provide forensic investigators with unique and distinct comparative evidence. Fine silt and clay-size fractions of soil (<50-100 µm) have the capacity to stick to the surface of fabric for weeks (Morgan and Bull 2007). Small amounts of fine soil evidence have often been missed by offenders who have attempted to destroy evidence that may incriminate them. Geoforensic scientists have located trace soil evidence embedded in clothing and shoes; even after being cleaned in a washing machine or dry cleaners (Bull *et al.* 2006a; Fitzpatrick *et al.* 2009; Fitzpatrick *et al.* 2014).

The current focus of forensic soil analysis is to create an accurate soil description using soil "colour, soil maps, soil minerals, soil biology (plant roots), soil chemical and physical properties, such as pH level or soil magnetism" (Fitzpatrick 2011). A detailed soil morphological characterisation of a sample's mineral and organic composition can be formed using X-ray diffraction (XRD), magnetic susceptibility, heavy mineral and magnetic fractionation (Murray *et al.* 2012). Forensic soil analyses compare and contrast controlled soil samples from a known site (such as a crime scene), questioned soil (unknown site) and alibi soil (suspect indicates a potential alibi location requiring forensic soil analysis) (Fitzpatrick and Raven 2013). As documented by Sugita and Marumo, variations in soil colour provide one of the most distinguishing characteristics of trace soil evidence (Sugita and Marumo 1996).

Rayney Murder Case

During the Rayney murder investigation in Western Australia, HAHT soil evidence pinpointed the location of the initial attack on the victim as occurring in her front yard. The morphology of soil particles adhering to two liquidambar seedpods caught in the victim's hair matched the human-made soil of her suburb of Como. The minus 20 micron fraction of yellow sand found embedded in her bra was consistent mineralogically with soil from the Rayney's front yard near their liquidambar tree. These fine fractions were distinctly different from the natural soil type of Kings Park where the victim's body was buried and subsequently discovered eight days later. The trace soil evidence in her bra was pristine and not contaminated with soil from the gravesite (Fitzpatrick and Raven 2012b).

Thirty-four (34) bricks, lightly coated with dirt, were taken from the Rayney's brick paving as control samples, to compare with the questioned traces of brick dust on the victim's clothing. Using advanced XRD techniques of particle acceleration known as "Synchrotron X-ray diffraction analyses" produced a high X-ray intensity that provided much greater sensitivity and resolution (Fitzpatrick 2012). Mineral particles were better separated in the poorly crystalline soils and bricks than is possible with standard XRD; in order to establish origin.

In his judgement summary, Judge Martin made particular mention of how locating the origin of 'particles of brick, paint and plastic on the deceased and her clothing' in the Rayney front yard convinced him beyond reasonable doubt that the initial attack had occurred there and not at the park where the body was found (Martin 2012b, 2012a). The uniqueness of HAHT trace soil evidence, combined with the last time the victim was seen alive, had narrowed the window of opportunity for committing the crime.

Morgan and Bull noted that a rapid decay rate of transference can quickly obliterate valuable trace evidence on some fabric surfaces (Morgan and Bull 2007). This decay rate is accelerated when the body or clothing is moved. Loose soil particles, including gravel-sized objects, simply fall off.

In investigating major crime, forensic laboratories across Australia, remove soil from clothing for analysis by rigorously shaking soil particles from fabric or even cutting soiled areas from clothing. It is routine procedure to try to extract as much soil as possible from fabric for analysis using such methods as X-Ray Diffraction. Valuable 'patterns' of transfer on fabric that document the circumstances behind soil making contact with the fabric surface are not identified or photographically recorded.

It was noted by Martin that when one forensic expert received the bra for forensic soil analysis, after previous forensic teams had rigorously tested the trace soil and the fabric itself, he declined to examine some areas in detail because "prior sampling and interference with the fabric construction might lead to incorrect conclusions" (Martin 2012b).

The current focus of forensic soil science on creating an accurate soil description, does not include a photographic record of trace soil patterns on the victim's clothing *in situ* before the body is moved or clothing removed. Any trace soil patterns on the victim's clothing that might have proven whether she was dragged or placed on soil surfaces in her back yard were, to our knowledge, never photographically documented and were destroyed during invasive testing processes over a four year period.

In his judgement summary, Judge Martin stated: “I do not accept the State case as to the dragging events. The major problem with the scenario constructed by the State is the absence of any evidence to support it” (Martin 2012a). Trace soil patterns on the victim’s clothing could have indicated the method of soil transfer and therefore, the circumstances during the attack.

Prosecution suggested the soil evidence may have been transferred to her clothing when she was lying on the back seat of her car when her killer drove her to Kings Park. Judge Martin suggested the soil evidence embedded in her bra may have wafted in during the ‘ordinary course of daily affairs’ (Martin 2012b).

Judge Martin also stated that “if the dragging events postulated by the State occurred, some signs of dragging or disturbance, particularly in the moss, would almost certainly have been left” (Martin 2012a).

A forensic soil examination of the Rayney front yard was not undertaken for weeks after the murder. During this time, periods of heavy rain and Police walking through the front yard and across the brick paving could have contaminated or destroyed any potential evidence of dragging soil pattern evidence on the paving or soil surface. This absence of pristine trace soil patterns on the victim’s clothing, combined with the lack of a detailed photographic record of the surrounding soil surfaces in the front yard dating from the time of the attack, became insurmountable weaknesses in the State’s case.

Until a detailed photographic record is routinely made of trace soil patterns on a victim’s clothing *in situ* at a crime scene, potential new forensic soil evidence indicating the circumstances of an attack will be degraded or destroyed. Morgan and Bull stated that ‘it is not only the identification of the components of a soil/sediment sample that enables the use of such evidence; it is of great importance that the interpretation of such analysis and their presentation to the court are accurate and meaningful’ (Morgan and Bull 2007).

With no fingerprint, DNA evidence or reliable witness testimony, these missing pieces of soil evidence became a major factor in the Rayney murder remaining unsolved. By using current methods of forensic soil analysis that begins in the laboratory and not at the crime scene, soil evidence alone could not be used to its true potential.

This reliance on expensive forensic soil testing procedures has further inhibited the use of soil analysis in forensic investigations. For forensic laboratories with all the latest analytical instruments, case volume is a major issue that can limit the scope of soil evidence investigated to major crime.

The need to focus on simple, inexpensive and rapid methods to record and analyse trace soil patterns, created by loose soil as well as soil embedded in fabric, has been an objective of these experiments. Using the methods described in this research, providing a pristine record of soil evidence *in situ* at a crime scene is easily achievable with a digital camera, scale bar and basic training. Therefore, analysis of soil evidence whilst still attached to a body, clothing or property should begin at the crime scene and not after soil evidence has been bagged up for transport to a laboratory or Police evidentiary storeroom. Visual analysis by human eye alone of digital photographs taken at the crime scene of soil evidence on clothing and any disturbed areas on the surrounding soil surface, followed by easily accessible computer image processing of these photographs, has the potential to revolutionise the use and accessibility of soil evidence in forensic investigations.

Morgan and Bull conclude that ‘if we do not learn from mistakes and do not take heed of comments and advice given in the past, then this current resurgence in the use of geoscience applications to forensic problems will once again fail to reach its full potential" (Morgan and Bull 2007). Forensic soil science that adds photographic records of trace soil patterns on clothing, shoes and property, as well as photographing soil surfaces at potential crime scenes, to its arsenal of chemical and morphological analysis, will fill the current void between analytical data and meaningful circumstances. This new vision for forensic soil science will not only help police solve crime, but better convict offenders in a court of law.

1.3 Review of previous research exploring the transfer of different particles onto textile fabrics

During the Rayney Murder investigation, a forensic expert, Mr Edmund Silenieks, began to experiment with the transference of brick dust from a red brick paver from the victim's front paving to 100% nylon knitted white fabric, resembling the fabric and weave of the victim's bra (Martin 2012b). The actual tag showing fabric composition was missing from the victim's bra, so this was an approximation of the actual bra fabric.

To test the transfer method of dragging, Mr Silenieks rubbed the fabric across the length of the paver applying 'firm hand pressure.' He then examined the fabric to discover that although the surface fabric appeared relatively clean, red brick particles had penetrated deep into the fabric, accumulating 'in the gaps between the loops and yarns' (Martin 2012b).

To test the transfer method of placing, Mr Silenieks took another piece of the same fabric and firmly pressed it onto the upper smooth surface of the paver 'using finger pressure for five seconds' (Martin 2012b). Only a few red brick particles were transferred, remaining solely on the upper surface of the individual yards.

These experiments were attacked by the Defendant's council for the following reasons (Martin 2012b):

1. Each experiment was done only once.
2. The force used during the transfer of the soil onto fabric was not measured and therefore not consistent.
3. The material used for the experiments was not close enough in composition and weave to the victim's bra
4. The test was not realistic because during the alleged dragging scenario, the victim was dragged for more than one brick-length.
5. The only other transfer method tested was placing the fabric on the brick surface.
6. These soil transfer experiments did not explore other scenarios that would explain the presence of numerous large coarse sand particles embedded in the victim's bra.

The Defendant's council then suggested that further transfer experiments should focus on dragging the fabric over other surfaces containing deposits of brick dust, such as the backseat of a car, pressing the fabric against a deposit of loose brick dust particles and dropping the fabric onto a deposit of loose brick dust (Martin 2012b).

Judge Martin agreed with Mr Silenieks' conclusion that the transfer method of dragging fabric across the brick surface caused the transfer of more brick particles than when the fabric was merely placed on the brick surface. However, he decided that the criticism made by the Defendant's council of Mr Silenieks' soil transfer experiments was also legitimate (Martin 2012b); leaving the circumstances behind the victim's clothing making contact with soil in her front yard still in doubt.

There has been no recent research focusing on the transfer of soil particles onto textile fabrics since Locard (1930). What follows below is a review of the transfer of mostly human-made particles such as powder, glitter, glass fragments, acrylic and wool fibres (McDermott 2013; Roux and Robertson 2013).

Bull *et al*. (2006b) built on the experiments of Pounds and Smalldon (1975a,b,c) who had originally explored the transfer and persistence of textile fibres. Bull *et al*. (2006b) documented the transfer and persistence of pollen, powder and metal particulates (glitter) on different types of materials; namely acrylic, cotton, denim, nylon, polyester and wool textiles (Bull *et al.* 2006b). A swatch of the textile to be tested was attached to a coat, which was worn indoors and out for seven days. In one experiment, pollen was brushed onto the textile swatch. In a second experiment, fluorescent powder was mixed with wheat flour and evenly distributed to the textile swatch. In a third experiment, lighter flint particles were flicked onto the swatch by striking the flint of a 'Clipper' lighter, Bull *et al*. (2006b) concluded that the fabric weave of the material played a larger part in the transfer and persistence of particulates than did the type particulate. The transference method had an initial effect in the quantity of particles transferred, but the persistence of these particles over time tended to level out. "No discernible difference was identified with any variant of material type, moisture level or grain size with regard to persistence, spreading capability, tenacity, transfer or detection during experimentation" (Bull *et al.* 2006b)

Hicks *et al.* (1996) explored the transfer and persistence of glass fragments on clothing, studying fragments transferred to the clothing of both the breaker standing 50cm away from the window glass and an accomplice standing 80cm away. Using either a hammer a stone or a pendulum, they discovered that up to seven fragments of glass could persist in clothing up to eight hours later. The number of fragments transferred depended upon the number of strikes, the distance between the windowpane and the person standing nearby, the time elapsed before forensic examination of the clothing and the weave of the garment (Hicks *et al.* 1996).

Unknown glitter particles persisting on clothing were compared to four known glitter types using light microscopy (Aardahl *et al.* 2005). They were characterised by end use, colour and shape to ascertain their relative uniqueness (Aardahl 2003). The majority of clothing tested had cosmetic glitter particles persisting, even if the wearer did not use any products containing glitter. The transference and persistence of these particles on human skin was reliant on the body's natural moisture. Adhesion was increased with the addition of petroleum jelly. Numerical data analysis was not attempted in this experiment, due to the large number of unknown variables.

In their ground-breaking experiments involving the transfer of fibres between acrylic and woollen knitted garments and a cotton lab coat, Pounds and Smalldon (1975a) concluded that three processes were involved in causing fibres to be transferred onto recipient garments (Pounds and Smalldon 1975a).

They established that during the first contact pass of transference, the majority of fibres transferred were loose short surface fragments or loose fibres pulled free by the friction of the contact. But during subsequent passes (eight contact passes in total), direct fragmentation of short fibres due to the pressure of the contact became the main cause of fibres being transferred; but at a rate of 50% less fibres than the initial first contact. The persistence of fibres on a garment worn up to thirty-four hours after first contact was not due to the electrostatic nature of the recipient garment fibres, but the strength of bond the remaining transferred fibres had made with the recipient garment (Pounds and Smalldon 1975a). They observed that after the first four hours of transference of fibre evidence to worn knitted garments, only 18% of the transferred fibres remained. After 34 hours, only 3% of transferred fibres remained, signifying the most strongly bonded fibres. On an old, smooth cotton lab coat, transferred evidence was mostly lost within 30 minutes of contact being made, indicating a rapid decay curve (Pounds and Smalldon 1975c).

Natural soil particles may transfer and persist differently on clothing than the human-made particles tested. Fine clay and silt-size fractions have a strong capacity to transfer and persist (Fitzpatrick 2011). Morgan and Bull (2007) noted that fine silt and clay size fractions of soil (<50-100 µm) have the capacity to stick to the surface of fabric for weeks (Morgan and Bull 2007).

Morgan *et al.* (2009) stated that 'in order for trace evidence to have a high evidential value, experimental studies which mimic the forensic reality are of fundamental importance. Such primary level experimentation is crucial to establish a coherent body of theory concerning the generation, transfer and persistence of different forms of trace physical evidence' (Morgan *et al.* 2009).

Using similar methodology to Pounds and Smalldon (1975a,b,c), fibre transference and persistence experiments, analogous experiments were designed to identify which factors influence the transfer, persistence and relative quantity of natural and human-made soil on clothing fabrics. Unlike Pounds and Smalldon, soil and not wool fibre transfer characteristics were tested. These new experiments also differed by focusing specifically on nylon-elastane bras; with the variable element being multiple soil types and not multiple fabric types. Similar to Pounds and Smalldon (1975a,b,c), dragging was the method of transference; but these new experiments were run under both wet and dry conditions.

In order to achieve reproducible and consistent results, the weighted fabric was not pushed by hand across the soil tray. This aspect of Pounds and Smalldon's method could not replicate a similar amount of force for every pass. Aware of this limitation, they experimented using greater and lesser force to ascertain whether this affected the number of fibres transferred. To maximise reproducibility of results in these current experiments, weighted fabric was dragged in timed runs across a soil tray using a drag-line.

Trace evidence on fabric and all bulk soil samples then underwent CAFSS stage 1 classification of soil morphology. Binocular and petrographic microscopy assisted to differentiate each sample and indicate provenance.

Image processing was programmed to analyse digital photographs taken *in situ* of trace soil transfer patterns on fabric. This was aimed to provide objective, quantifiable numerical data to assist or confirm the interpretation of soil transfer patterns as seen by the naked eye. The Trimble eCognition Developer software was also programmed to analyse Munsell Soil colour to identify and match trace soil on fabric to other trace soil evidence from the same location.

Pounds and Smalldon did not require an analysis of the colour of the wool fibres for their transference and persistence experiments (Pounds and Smalldon 1975b, 1975c, 1975a). They also did not have today's computer technology that enables a higher level of quantitative and objective results. But without their initial groundbreaking experiments, these soil transference experiments may never have come to pass.

1.4 Geology and natural soil of Royal Tasmanian Botanical Gardens, Queens Parade, Tasmania

Hobart is part of the Central Tasmanian Region, with a geological age ranging between the Late Carboniferous to Triassic. Landforms of the Central Tasmanian Region include mountain ranges, dissected plateaus, hills and ridges and undulating plains. Stratigraphy dates from Late Carboniferous to Early Permian sediments (including glacial); overlain unconformably by Permian shallow-marine and deltaic and Triassic lacustrine and fluvial sediments, including Permian and Triassic coal. Tertiary sediments and mafic volcanic are also present (Hergt *et al.* 1989).

The underlying geology of the Royal Tasmanian Botanical Gardens is primarily Jurassic dolerite except at the eastern boundary, where a layer of Triassic sandstone extends into the site.

With the breakup on Gondwana, large volumes of tholeiitic magma, estimated by Hergt *et al.* (1989) to be in the vicinity of 15,000km3, were intruded as dolerite sills in the mostly flat-lying Permo-Triassic rocks of the sedimentary Tasmania Basin. The magma had a basaltic andesite composition, probably formed from a 'primary' tholeiitic magma of similar composition to island arc and interarc basins, derived from a very depleted mantle source (Sun and Nesbitt 1978; Hergt *et al.* 1989). It is moderately enriched in SiO_2 relative to basalts, but slightly depleted in Fe, Mg and Ca and similarly rich in alkalis and P. These compositions can provide good soil fertility. Taking the form of a flattened cone, these doleritic intrusions covered an area of 30,000km^2 (Hergt *et al.* 1989); with limbs forming concordant sills (Leaman 1976).

As indicated in the soil map (Figure 1-1) derived mainly from the Australian Soil Resources Information System (ASRIS (Australian Soil Resources Information System) 2013), Hobart's dominant Australian Soil Classification soil orders (Isbell 2002) before white settlement cover the following soil orders: (i) Dermosols (green-shaded) in Queens Domain and Glebe, (ii) Sodosols (dark tan) in North and West Hobart, (iii) Chromosols (light tan in Hobart, South Hobart, Sandy Bay, Dynnyrne, Battery Point and Mount Stuart. Dermosols have structured B horizons and lack a strong texture contrast between the A and B horizons. Dermosols often have clay skins on ped faces. B2 horizons are often clayey, with free-iron oxide content less than 5% (McKenzie *et al.* 2004).

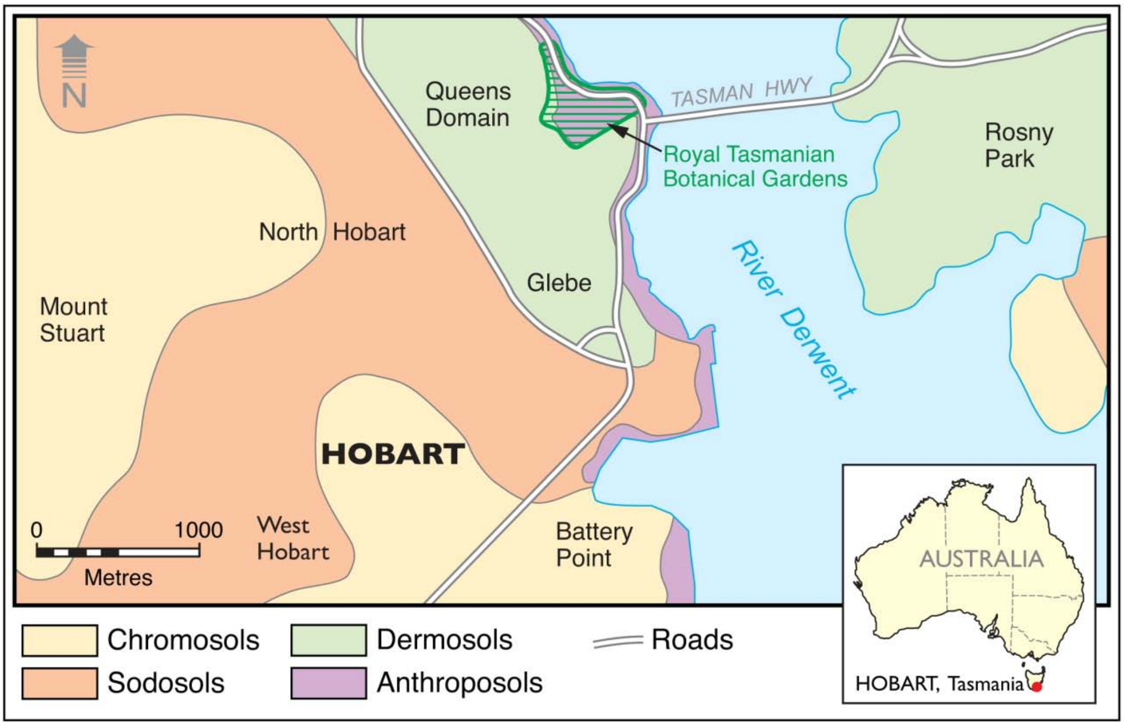


Figure 1-1 Soil map showing purple shaded Anthroposols, which dominate the Royal Tasmanian Botanical Gardens (green cross-hatched area) with minor Dermosols (Modified from ASRIS database) and inset showing the location of Hobart.

1.5 Human-made soils of Royal Tasmanian Botanical Gardens, Queens Parade, Tasmania

The natural Dermosols in the Royal Tasmanian Botanical Gardens (RTBG) in Queens Domain is generally a light clay over heavy black clay but most of the soil has been heavily modified by the introduction of sandy loam (Reid 2012). The majority of these grounds in the RTBG (green cross-hatched area) have been radically modified to create roads, walls, specialty gardens and smooth flat lawn surfaces. As a consequence, the dominant soils in the RTBG and on Hobart's waterfront as shown in Figure 1-1 (shaded a purple colour) comprise:

(i) Anthroposols in accordance with the Australian Soil Classification (Isbell 2002) or

(ii) Technosols in accordance with the World Reference Base (World_Reference_Base 2014) or

(iii) Human-altered and Human-transported material (HAHT) (Galbraith 2012) are defined in Chapter 3 of the 12th Ed. of the Keys to Soil Taxonomy (Soil Survey Staff 2014) and evidence of their existence is provided.

If humans levelled the land to produce terraces, creating artificial landforms, it will qualify as human-transported material. If humans altered the soil on purpose beyond standard agricultural practices (such as adding compost and gravel), it will qualify as human altered material.

All known information concerning the human-made changes to the soil in the RTBG and the human-transported soil, gravel and rocks imported in to transform these gardens was supplied by David Reid, Horticultural Coordinator of RTBG. The construction methods producing HAHT soils tested in STEs, as well as natural soils tested, are detailed in section 2.1.

2. FIELD AND LABORATORY METHODS

Summary

This section outlines the methods used to sample and analyse representative natural and human made soil samples from soil profiles.

2.1 Study area and materials

The diversity and heterogeneity of naturally occurring soils (eg. crystalline minerals, organic matter) and anthropogenic soils that often contain trace amounts of manufactured materials such as brick fragments and road gravel, enable forensic soil examiners to differentiate between soils.

The seven soil samples were sourced from the Royal Tasmanian Botanical Gardens (RTBG), Lower Domain Rd, Hobart, Tasmania, Australia (Figure 1-1). Five samples were anthropological (HAHT) soils (110.7.1, 110.5.1, 6.1, 8.1); including one brick sample (110.6.2). Six soils were sampled from between 0-10cm depth. At the natural soil site on the SE boundary, a horizon comprised of undecomposed leaf matter, was taken from 5-0cm above the soil surface (110.9.1). Underlying mineral soil (110.9.2) was also sampled at 0-10cm depth.

Sample site location coordinates were obtained using a GPS, using the WGS 84 Datum: Zone 54 South (Eastings and Northings). Photographs were taken of the soil profile sites and soil profiles. In the field, each soil profile was photographed with a scale and horizons were sub-sampled. Soil material was described and physical properties such as colour, consistency, structure and texture follow McDonald and Isbell (McDonald and Isbell 2009). Representative sub-samples were also collected in chip trays for: (i) soil morphological study/ description.

Table 2-1 Summary table of soil morphology and selected chemical properties

Locality	Sample no.	Matrix colour Dry	Moist	Texture	Gravel >2mm%	Quartz	Structure	Efferv. Class	Roots	WR	pH distill H20	pH CaCl2
Rose Garden Path	110.5.1	7.5YR 5/2 Brown	7.5YR 3/2 Dark brown	LS	90	R - S	Granular to single grain	NE	0	R	7.03	6.16
Rose Garden path near wall	110.6.1	7.5YR 5/2 Brown	7.5YR 3/2 Dark brown	S	90	R	Granular to single grain	NE	0	N	7.71	7.05
Brick fragments	110.6.2	2.5YR 7/8 Light red	2.5YR 5/8 Red	Brick	90	R - UT	Brick fragments & br. Dust	NE	0	N to R	N/A brick	N/A brick
Rose Garden bed	110.7.1	7.5YR 2.5/1 Black	10YR 2/1 Black	LS	15	R	Massive	NE	1	R	6.49	5.81
Japanese Garden	110.8.1	2.5YR 6/1 Reddish gray	2.5YR 3/1 Dark reddish gray	LS	90	R - A	Granular to single grain	NE	0	R	6.27	5.53
Natural soil (leaf litter)	110.9.1	leaves	leaves	Undecom-posed leaves	2	N/A	Undecom-posed leaves	NE	0	R	N/A leaves	N/A leaves
Natural Soil	110.9.2	7.5YR 2.5/2 Very dark brown	10YR 2/2 Very dark brown	LS	2	R - S	Massive	NE	0	R	6.86	6.54

Texture: S, Sand; LS, Loamy Sand; obtained by the "feel" method in accordance with McDonald and Isbell (McDonald and Isbell 2009).
Quartz = Quartz particles shape (Roundness and Sphericity): R = Rounded; S = Subrounded; UT = Subrounded tabular; A = Angular (McDonald and Isbell 2009).
Effervescence Class (H4) (Reaction to 6N HCl): NE = Non effervescent; (Schoeneberger *et al.* 2002).
Water Repellence (WR): N = Non water repellent; R = water repellent (McDonald and Isbell 2009).
Roots: 0 = None; 1 = few (1-10 fine roots) in sample area 100mm² (McDonald and Isbell, 2009; p.199).

Soil samples were sourced from three main sites at RTBG (Figure 2-1): the Rose Garden, bordered by a heritage-listed, convict-built brick wall (110.5.1 to 7.1), the Japanese Garden (110.8.1) and a natural soil site opposite the Japanese Garden by the Southern fence, Eastern section (110.9.1 and 9.2).

The textures of all soil samples are representative of the soil particles remaining after each sample was passed through a <2mm sieve. The loamy-sand texture recorded for soil from the Rose garden bed (110.7.1) is representative of the 10% very fine soil particles that remained after the >2mm quartz-rich gravel was removed.

Likewise, the loamy-sand texture of soil from the Rose garden path (110.5.1) is indicative of the texture of fine (<2mm) soil matrix, excluding the sandstone and quartz gravel making up 90% of this sample. The coarser sand texture of the fine (<2mm) particles of the same gravel path near the Eardley Wilmot brick wall, may indicate the presence of fine sand particles eroding off this 170 year old brick wall.

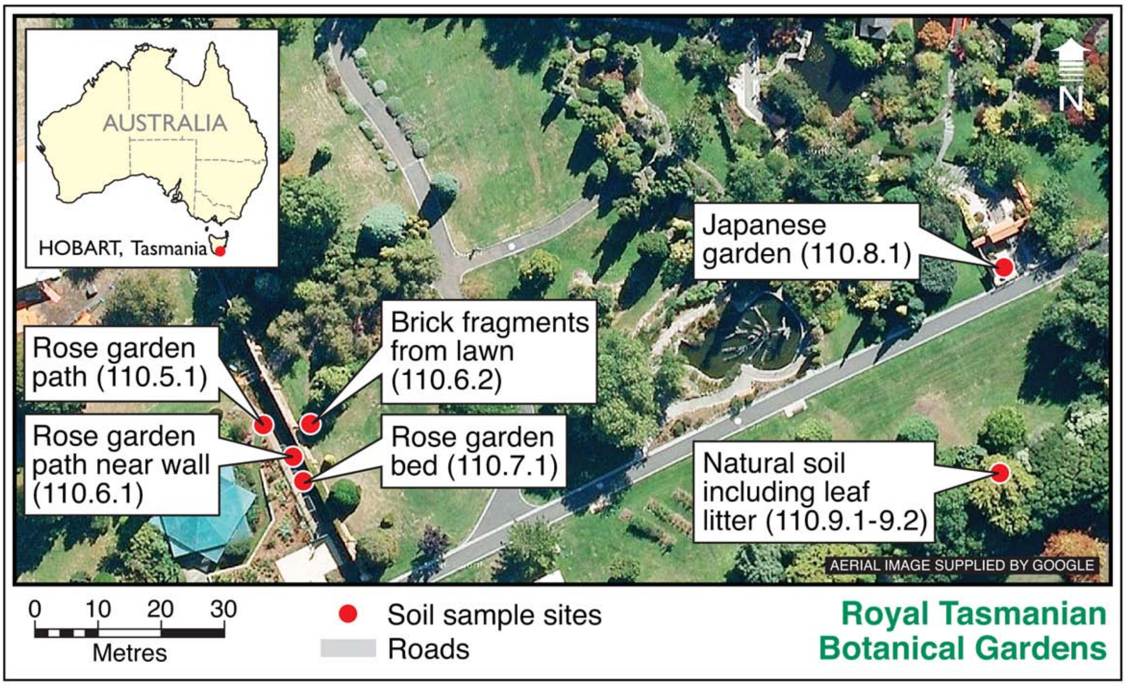


Figure 2-1 Map showing the distribution of seven soil samples used in STEs, taken from RTBG, Lower Domain Rd, Queens Domain, Hobart. (i) Rose Garden path (110.5.1 to 6.1); (ii) Lawn at base of Rose Garden Wall (110.6.2); (iii) Rose Garden bed (110.7.1) (iv) Japanese Garden (110.8.1); (v) Southern fence, Eastern section (110.9.1 to 9.2).

For the Rose Garden paths, the original natural soil was excavated and removed before adding 70-80mm of road base followed by a gravel surface layer 40-50mm thick (Reid 2012) (Figure 2-2 and Figure 2-3). The gravel is a mix of arkosic sandstone and andesitic-to-weathered mafic igneous rock.

Figure 2-2 Photograph of Rose Garden path (110.5.1) in RTBG. See also Figure 2-3 for soil on the Rose Garden path near the Eardley Wilmot brick wall (110.6.1).

The Rose Garden beds were constructed by excavating original soil to 300-400mm depth and backfilling with a mixture of 3 parts RTBG compost, 3 parts composted pine bark and 1 part coarse river sand (Reid 2012) (Figure 2-3).

Figure 2-3 Photograph of rose garden bed organic-rich soil covered with thick straw mulch (110.7.1) bordered by the Eardley Wilmot brick wall. Note also that sample 110.6.1 was taken from the Rose Garden path in close proximity to this wall.

The heritage-listed convict-built “Eardley Wilmot” brick wall running alongside the rose garden was constructed in 1843 from an unknown brick source (Reid 2012) (Figure 2-4).

Figure 2-4 Photograph of “Eardley Wilmot” brick wall running alongside the rose garden.

Because of its heritage listing, brick fragments could not be collected from the wall itself. Built in 1843, small brick fragments have continually eroded over the past 170 years. These small (0.5cm - 4cm) loose decomposing brick fragments, fossicked from the lawn area along the length of the wall, were collected to create the brick sample (110.6.2). Because these brick fragments were mostly half-buried in the lawn that runs alongside the wall (Figure 2-5), this sample also contained a small amount of natural soil that had coated some of the brick particles.

Figure 2-5 Photograph of “Eardley Wilmot” brick wall fragments (110.6.2) used for soil transfer experiments were fossicked from the lawn side of the wall. (See also Figure 2-1 and Figure 2-3 for views of the extensive lawn bordering one side of the wall).

The Japanese garden also had the original native soil removed. The area was then covered with compacted road base to a depth of 100mm depth before loose quartz-rich gravel was spread to 50mm depth (Reid 2012) (Figure 2-6). The quartz gravel is well-rounded to angular; appearing to come from several sources. A smaller percentage of the gravel is made from sub-rounded to angular dolerite, quartzite and iron-rich sandstone. In addition, the area also comprises a small quantity of ironstone gravel, which contains microscopic inclusions of quartz nodules.

Figure 2-6 Photograph of quartz-rich gravel soil surface of Japanese Garden at RTBG, with Director of RTBG and Prof Fitzpatrick.

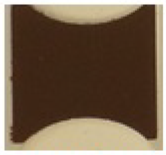
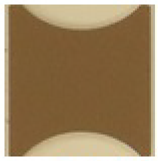
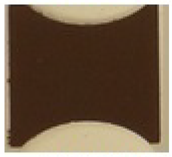
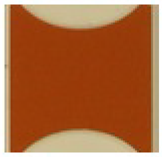
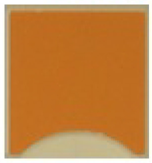
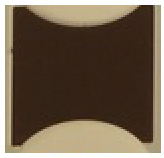
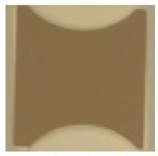
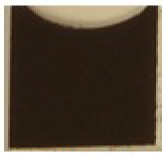
Two natural soil materials were collected from a soil profile under deciduous trees located on the south eastern boundary of the RTBG. The soil profile is covered by a thick layer of dry fallen leaves (sample 110.9.1), which overlies a dark organic-rich layer (sample 110.9.2) (Figure 2-7).

Figure 2-7 Photograph of natural soil under deciduous trees (110.9.1-2) near south eastern boundary of RTBG.

Detailed morphological descriptions of the seven soils sampled are provided in Table 2-1. The fine (<2mm) fraction of all soil samples (except the brick and undecomposed leaf samples) have either a sand or loamy-sand texture. Three of the HAHT or Technosol samples came from paths; with gravel >2mm making up 90% of the main constituents.

Munsell soil colour was recorded for the fine (<2mm) fraction of each colour in natural daylight (Table 2-1). From twenty-one soil samples initially tested from various locations throughout Tasmania, the colours registered for both dry and moist samples were later used in image processing (Table 2-2), to provide computer software with a basis for matching ‘Red Green Blue’ values with the standard Munsell soil colour scheme (Munsell Color Company 2009).

Table 2-2 Munsell colour of moist and dry fine (<2mm) fractions of soil samples. (Please refer to (Munsell Color Company 2009) for true colour of soil colour chips).

Soil sample **Location**	**Munsell Fine <2mm (Moist)** Fine (dry)	**Munsell colour Fine <2mm (Moist)** Fine (dry)	**Moist**	Dry
110.5.1 RTBG, Rose Garden path	**7.5YR 3/2** 7.5YR 5/2	**Dark brown** Brown	 **7.5YR 3/2**	 7.5YR 5/2
110.6.1 RTBG, Rose Garden path near brick wall	**7.5YR 3/2** 7.5YR 5/2	**Dark brown** Brown	 **7.5YR 3/2**	 7.5YR 5/2
110.6.2 RTBG, Brick fragments near wall	**2.5YR 5/8** 2.5YR 7/8	**Red** Light red	 **2.5YR 5/8**	 2.5YR 7/8
110.7.1 RTBG, Rose Garden bed	**10YR 2/1** 7.5YR 2.5/1	**Black** Black	 **10YR 2/1**	 7.5YR 2.5/1
110.8.1 RTBG, Japanese Garden	**2.5YR 3/1** 2.5YR 6/1	**Dark reddish gray** Reddish gray	 **2.5YR 3/1**	 2.5YR 6/1
110.9.1 RTBG, Natural soil site	LEAVES	N/A	N/A	N/A
110.9.2 RTBG, Natural soil site	**10YR 2/2** 7.5YR 2.5/2	**Very dark brown** Very dark brown	 **10YR 2/2**	 7.5YR 2.5/2

2.2 Laboratory soil analysis methods

The aim of this research was to visually identify patterns produced by the transfer method of dragging weighted clothing (specifically a bra) across a soil surface. Bulk soil samples underwent eighty-four (84) soil transference experiments (STE) in the lab, using both wet and dry sediment.

It was originally anticipated that XRD analysis would be heavily relied upon in order to decipher any soil transference patterns discovered. But when soil transfer patterns were being routinely identified and categorised by naked eye alone across all seven soil samples tested, knowing the exact mineral composition of the soil via XRD became a secondary consideration. Simple light microscopy and photomicrographs were also taken of all soil transfer patterns on fabric. However, digital photographs of STEs taken *in situ*, proved to be of greater scientific merit; creating a pristine record of the entire fabric surface of the STE. The apparent universality of these patterns produced six of the documented soil transference patterns with 100% consistency in natural soil, HAHT soil, a mix of HAHT and natural soil; even in a natural soil sample made entirely of undecomposed leaves.

2.3 Image processing computer analysis of digital photographs

Image processing computer analysis of digital photographs of trace soil patterns, taken in the laboratory immediately after each STE, provided numerical data of every soil transfer pattern produced on fabric. Despite the ease in which the human eye can identify these soil transfer patterns, image processing was undertaken to: (i) confirm patterns observed visually by human eye (ii) provide standardised numerical data of the colour and shape of soil objects >100 microns/2 pixels and (iii) allow statistical comparison of observed soil patterns. This included quantity and directionality of soil transferred, percentage of individual soil objects and aggregates and Munsell soil colour range. In a court of law, image processing analysis of trace soil evidence on fabric could be treated with the same respect as XRD analysis of a soil's mineralogy.

Image processing software from University of Tasmania's School of Earth Sciences provided an object-oriented image classification of soil patterns on fabric. Image processing was carried out using Trimble eCognition Developer software (version 8) to analyse digital photographs and classify objects transferred during soil transference experiments (STE) conducted in the laboratory at Mineral Resources Tasmania.

The images were RGB files with the red band analyses as Image layer 1, green as image layer 2 and blue as image layer 3. The classification was strongly dependent on colour both in raw measurements in each colour band and as colour ratios. Colour ratios were corrected for the gamma correction carried out by the camera.

The original digital photos were taken at a fixed distance above the 12.5cm diameter fabric round used in each soil transference experiment, under controlled artificial lighting conditions in the laboratory. During image preparation, non-relevant parts of the image were masked.

Often it is desirable to present orientation data to emphasise distribution of orientations independently of the geographic location of data. The types of diagrams most frequently used to present such information are histograms, rose diagrams and spherical projections (Allaby and Allaby 1999).

Using the image processing directional or orientation data, rose diagrams were applied to map the orientation of thousands of dry or moist soil particles displayed as≥2 pixels diameter transferred onto fabric. Rose diagram plots were created using GEOrient version 9.5.0 (Holcombe 2011) to provide a simplified computer image, illustrating the directionality of soil on fabric. Quantitative numerical data on directionality, produced by Trimble eCognition Developer software (version 8), were inputted into GEOrient. The resulting rose diagrams provided a quick and vivid method of comparing STE results from different soil samples.

2.4 Total carbon and sulfur

The carbon and sulfur content of the soil samples were determined using Nondispersive infrared (NDIR) analysis.

The carbon and sulfur contents of the soil samples were determined by Nondispersive infrared (NDIR) analysis using a Bruker G4 Icarus analyser, in the MRT laboratories, Rosny Park. The following standards were run during analyses to check calibration: AR4005 (C=1.42%, S=1.41%), AR4013 (C=2.93%, S=0.020%), AR4014 (C=5.87%, S=0.029%), AR4007 (C=7.27%, S=3.26%) and AR4024 (C=11.72%, S=0.418%).

2.5 Mineralogical analyses by x-ray diffraction

XRD analysis was undertaken to compare and contrast the mineralogy of the seven soils involved. If the soils used in the experiments were very similar in mineral composition, further STEs on soils vastly different in composition would be required before it could be concluded that soil transfer patterns documented in this paper were universal across all soil types.

Homogenous samples of each soil type (incorporating bulk and <2µm fractions) were hand ground to <20 microns in an agate mortar and pestle. The resulting fine powders were either gently back pressed into aluminium sample holders for X-ray diffraction analysis (XRD) analysis. XRD patterns of samples were collected with an automated Philips X-Ray diffractometer system: PW 1729 generator, PW 1050 goniometer and PW 1710 microprocessor with nickel-filtered copper radiation at 35kV/25mA, a graphite monochromator (PW1752), sample spinner and a proportional detector (sealed gas filled PW1711). The diffraction patterns were recorded in steps of 0.02° 2 theta with a standard scanning speed of 0.02 second counting time per step.

Analysis of the XRD patterns were performed using CSIRO XRD software: "VisualXRD", "PW1710 for Windows" and "XPLOT for Windows". Mineralogical phase identification were made by manually comparing the measured XRD patterns with a series of similarly-prepared standards of the more common minerals to enable some semi-quantitative analysis. Quartz, if present, is used as an internal standard. If quartz is not present, it is routinely added to the sample for a supplementary scan. The semi-quantitative results are calculated using single-peak calibration factors derived from scans of known mixtures of minerals. This follows the methods of Maniar and Cooke (Maniar and Cooke 1987) and Chung (Chung 1975); which are variants of the internal standard and matrix flushing method of Klug and Alexander (Klug and Alexander 1954).

2.6 Sports bra

The unpadded, underwire, sports bra used in all these experiment has three hook-and-eye back fasteners, underwires rising high between the cleavage, unpadded cups, and sliding shoulder-straps with metal buckles. The bra's fabric is nylon-elastane. A DD-cup size provided a large fabric area for experiments and the white fabric made it easier to locate and identify trace soil transferred.

2.7 Soil transference experiments to test the transfer method of dragging weighted clothing across soil surfaces

In order to identify patterns of soil transference created when weighted clothing (simulating a clothed human body) is dragged across a soil surface, an experiment was undertaken in the laboratory based on Pounds and Smalldon's (1975a,b,c) particle transfer experiments. Originally designed to test methods of transference and persistence of wool and acrylic fibres onto clothing, their method for fibre transference was adapted to transfer soil particles onto a bra.

Experimental design

A 2kg weight was enclosed in a plastic bag to enable easy cleaning between each STE. The side that was to be dragged across the soil bed was made as flat as possible, by cutting a plastic lid to the exact size and using duct tape to secure it to the weight. The drag line, made from packing tape, was wrapped firmly around the weight before also being secured by duct tape. The plastic bag was made firm and flat against the weight using duct tape also (Figure 2-8). A glass Pyrex 3 quart/2.8L dish was filled with a minimum of 3cm with bulk soil. This was placed on a non-slip mat, with heavy weights on one side to ensure the dish didn't move during the experiment.

Figure 2-8 Flat underside of 2kg weight, enclosed in plastic bag to enable easy cleaning between each STE. Weight placed in glass Pyrex dish used for all STEs, with yellow drag line kept low to maximise the 2kg weight's contact with the soil surface. Note non-slip mat under glass dish and heavy weights at front of the dish to ensure it doesn't move during the experiments.

The soil to be tested was then tipped into the glass dish and roughly made level, without compaction. The section of bra to be tested was then firmly attached to the weight, using a thick rubber-band (Figure 2-9). The sections of bra to be tested later were kept clean in a plastic cliplock bag. Each bra had the two cups and two shoulder-straps tested individually. As each test took place, the bra was photographed, microphotographed, and then placed in an individual cliplock bag, which was duct taped to minimise cross-contamination.

Figure 2-9 Bra cup is secured to 2kg weight using thick rubber-band. b) The remaining clean sections of bra are kept clean inside a cliplock bag on top. Note the bra is placed on clean paper whilst it is being attached to the weight, to avoid sediment being accidentally transferred to the fabric surface.

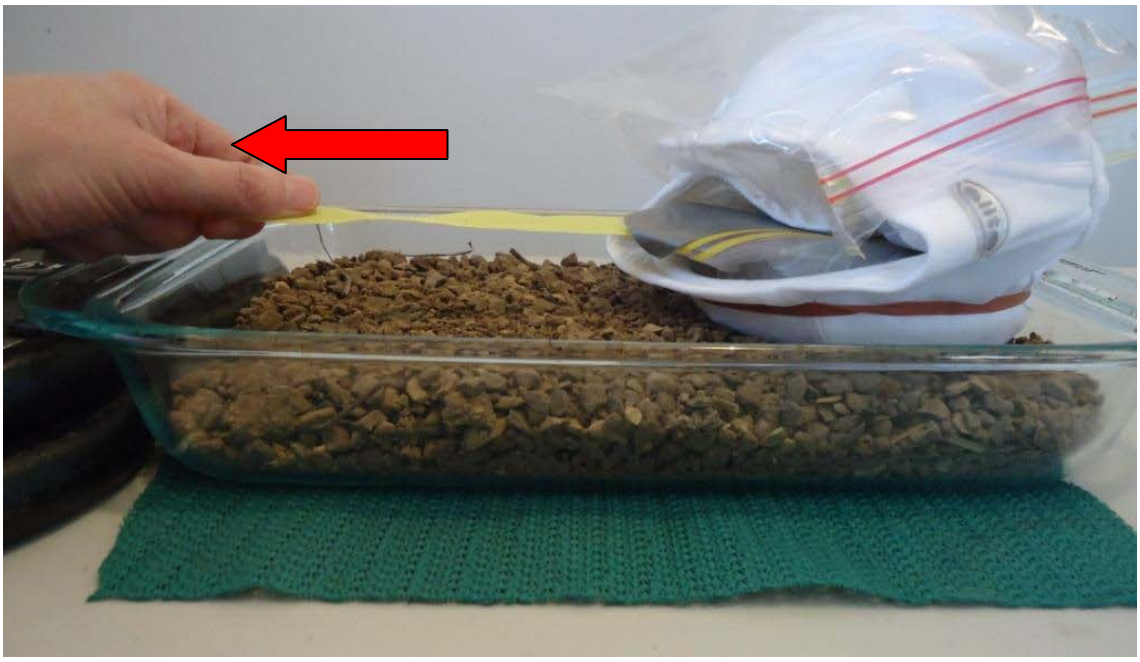
With a bra cup or shoulder-strap wrapped securely around the 2kg weight and the metronome set to 1 beat/second, the test run commenced. The weighted bra was gently placed at one end of the soil dish for a 3 second count, moved smoothly and continuously for 3 seconds to the other end of the soil dish and then left in place for 3 seconds (being lifted on the 3rd count) (Figure 2-10). The yellow drag line is kept low and parallel with the soil to ensure the weighted bra has constant and full contact with the soil surface.

The weighted bra was then gently turned right-side up, to maximise the quantity of soil particles remaining or persisting on the bra fabric in their original positions. The bra's target area was then photographed to document the trace soil patterns; before undergoing detailed microscopic analysis and photomicrography. Patterns resulting in the soil bed were also photographed.

The 2kg weight keeping the transferred sediment flat and stable was then removed and cleaned of soil with dry paper-towel. The bra was then placed flat in a labelled double-cliplock plastic bag. In the middle section of bra between the cups, the cliplock bag was taped on both sides with gaffer-tape. This prevented any loose sediment from either falling out of the bag or rolling into the middle section of the bra.

When dry bulk soil samples were first emptied into the glass dish, there were usually very fine clay-sized soil particles in the bottom of the bag that came out last; settling like fine 'dust' on the soil surface. This caused the first dry run of every new soil sample to consistently have more very fine soil transferred to bra fabric than in subsequent runs.

In summary, a smooth-surfaced 2kg weight with a diameter of 13cm/5", had either a bra-strap or cup secured with a red 10mm-thick rubber-band. This restricted potential movement or loosening of the strap/cup during the experiment; as well as simulating the effect of the weight of a human body on soil transfer patterns produced. Using a yellow 'drag line', each bra was then dragged in timed runs through a soil dish containing either wet or dry bulk soil. The drag line was kept parallel to ensure full contact of the weighted bra with the soil bed at all times.



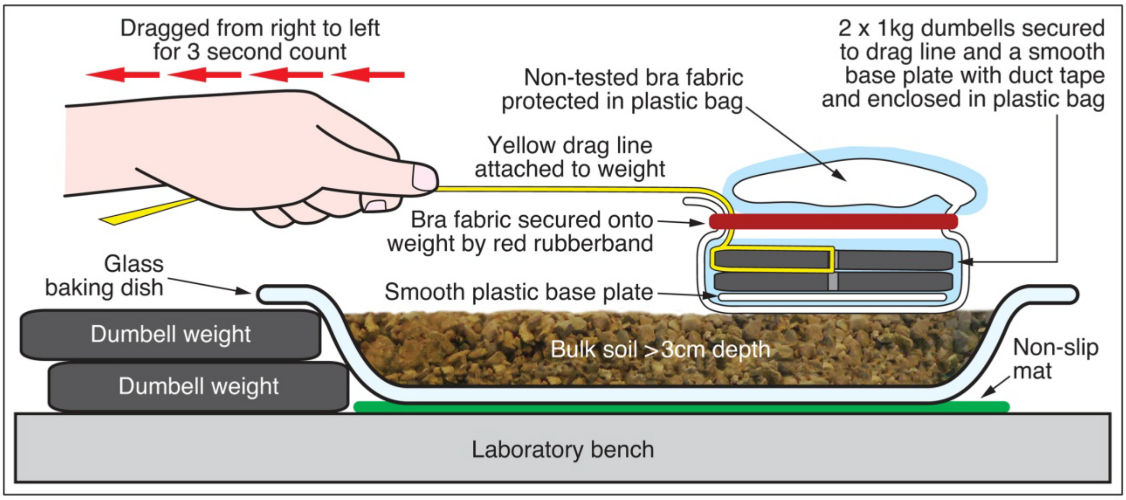


Figure 2-10 Photograph (above) and cross-section of weighted bra dragged from right to left over soil material during a three second count soil transference experiment. Sections of bra that are not subjected to being dragged over the soil during the experiment remain clean inside a cliplock plastic bag on top of the weight. Note the end of the glass Pyrex dish containing soil material and weighted bra is placed on a nonslip mat and a backstop of weights on the left to stop it moving during the transference experiment.

All bras were washed twice on a heavy-duty wash cycle, using 80ml of ‘Earth’s Choice’ liquid laundry detergent per wash, in a top-loading washing machine. Before the bras were washed, the washing machine was thoroughly cleaned. All filters were cleaned; in this case, the filters in each hose-fitting on both taps. The machine’s inside drum and central column were then cleaned with a sponge and hot water. In a final step to ensure the bras couldn’t pick up any sediment during the wash cycle, a cup of white vinegar was added to a hot water heavy-duty wash on a high-water setting, as recommended by a washing machine technician. Only then was the washing machine deemed clean enough for the bras to be washed.

The back-fasteners of each bra were joined together to prevent any hooks from snagging on and damaging another bra's fabric.

Bulk soil samples were air-dried before a small amount was sieved to separate a <2mm component for further analysis.

The brick sample (110.6.2) was placed in a clip-lock bag and roughly crushed with a geological hammer, to promote results consistent with the other soil samples collected. Particle size ranged from a fine powder to 1cm fragments.

The results of all STEs were photographed in situ with a Sony Cyber-shot DSC-W530 14.1 megapixel camera.

Low-powered binocular microscopy using a WILD Heerbrug M5-53707 microscope was undertaken on the seven control samples taken from the RTBG and on eighty-four (84) trace soil samples from 21 bras in the STEs. Digital photomicrographs were taken using the Leica DFC-425 and the Leica Application Suite, Version 3.6.0.

Every STE was individually photographed and photomicrographed whilst the 2kg weight holding the fabric flat remained in situ.

In preparation for the wet runs, soil in the dish was sprayed with distilled water until the soil colour changed evenly and water beaded. If the surface became dry and crusty between wet runs, the surface was jostled and rewetted.

Between each run, the soil surface would be gently levelled by hand without compacting the soil surface.

In the first test, a shoulder-strap was stretched tightly across the weight and secured. Each bra-strap was aligned with a yellow drag-line attached to the weight, to minimise fabric movement and ensure consistency of results with every run.

In the second test, a bra cup was stretched firmly and smoothly over the weight and secured. Every bra cup was positioned identically in proximity to the yellow drag-line, to keep results consistent regarding seam-lines and the cut of material. During each test, the yellow drag-line was kept low to the soil surface, ensuring the entire surface of the weight was kept in full contact with the soil.

The chosen section of bra was then dragged in timed runs through bulk soil samples. The right-hand (as if worn) bra cup and shoulder-strap underwent one dry run each and the left-hand bra cup and strap underwent one wet run each. In total, 84 soil transference experiments were run on 21 bras. Sections of bra not being tested were protected from accidental soil transfer in plastic clip-lock bags. Because bras were needed for future experiments, they couldn't be cut up.

3. MINERALOGY, CARBON AND SULFUR ANALYSES

Summary of mineral, carbon and sulfur analyses of all soil samples used in dragging STEs in the laboratory; to further investigate the universality of transference patterns across all soils.

3.1 Mineralogy

In order to ascertain how each soil's unique mineralogy (in particular clay), carbon and sulfur content affected subsequent soil transfer patterns, mineralogy, carbon and sulphur analyses were undertaken. Thirteen (13) minerals typical of loamy-to-clayey Tasmanian soils were identified.

The semi-quantitative determination of minerals in the whole soil by X-ray diffraction (XRD) is presented in Table 3-1. Quartz is the major mineral in these soils. Smectite is of secondary importance in the Rose garden and soil on the SE boundary. X-ray diffraction (XRD) diagrams are presented in Appendix 5.

Table 3-1 contains the results of XRD analysis of soil samples from the Royal Tasmanian Botanical Gardens that were prepared, examined and analysed The sample composed entirely of undecomposed leaf litter (110.9.1) was omitted from XRD analysis because it lacked any mineral content.

Table 3-1. Results of X-Ray Diffraction (XRD) analysis and organic carbon on soil samples from the Royal Tasmanian Botanical Gardens (approximate weight %)

Sample	110.5.1	110.6.1	110.6.2	110.7.1	110.8.1	110.9.2
Location	Rose Garden Path	Rose Garden Path near brick wall	Brick fragments from lawn area near brick wall	Rose Garden Bed	Japanese Garden	Natural Soil near SE boundary
Quartz	40±4	41±4	high Quartz content	69±5	83±5	32±3
Organic		2±1	possible amorphous material inorganic	24±2	5±1	38±2
Plagioclase	19±3	21±3	probable remains of inadequately-fired clays	3±1	4±1	7±2
Smectite	19±3	15±2	trace of Mullite	2±1	2±1	20±3
K-Feldspar	1±0.5	2±1		2±1	1±0.5	3±1
Halloysite	3±1	2±1	Calcite and Rutile			
Clinopyroxene	3±1	2±1			3±1	
Mica					1±0.5	
Hematite	8±2	9±2	Hematite			
Ilmenite	1±0.5	2±1				
Laumontite	4±1	4±1				
Kaolinite					2±1	
Stilbite	1±0.5	1±0.5				
Apatite	1±0.5	1±0.5				

A range of results was given for each mineral detected, to compensate for a possible 'peak overlap' that may interfere with identifications and quantitative calculations; such as can occur between Potassium Feldspar and Clinopyroxene.

Amorphous material and trace amounts of minerals not detected are shown as blanks.

3.2 Organic carbon and sulfur

Table 3-2 contains the results of NDIR analysis of soils undertaken at MRT. Organic content of soil samples was calculated using NDIR measurements. No sulphur-containing minerals were identified in any sample. Due to its lack of mineral content, the soil sample composed entirely of undecomposed leaf litter (110.9.1) was omitted from NDIR analysis.

The Carbon contents were converted to approximate Total organic matter, by multiplying the total organic carbon content by 1.7, a standard figure (Howard, 1965).

Small Sulfur contents were noted in most samples but no Sulfur-bearing species were identified; appearing to correlate with organic matter.

Table 3-2. Nondispersive Infrared Analysis (NDIR) of Carbon and Sulfur Content of soils from the Royal Tasmanian Botanical Gardens.

Sample	Location	Carbon (%)	Sulfur (%)	Analyses
110.5.1	**Rose Garden Path**	0.70	0.09	2
110.6.1	**Rose Garden Path near wall**	1.21	0.08	2
110.6.2	**Brick fragments from lawn area near brick wall**	0.29	0.06	2
110.7.1	**Rose Garden bed**	14.0	0.33	4
110.8.1	**Japanese Garden**	3.10	0.12	3
110.9.2	**Natural soil near SE boundary**	22.8	0.54	3

Standards run during analyses to check calibration: AR4005 (C=1.42%, S=1.41%), AR4013 (C=2.93%, S=0.020%), AR4014 (C=5.87%, S=0.029%), AR4007 (C=7.27%, S=3.26%) and AR4024 (C=11.72%, S=0.418%)

4. CLASSIFICATION OF SOIL MATERIALS

Summary

This section summarizes the classification of all soil materials used in the laboratory dragging experiments in accordance with The World Reference Base (WRB) and Australian Soil Classification (ASC).

Sufficient descriptive, chemical and mineralogical (XRD) data was acquired on the 7 soil samples collected to characterise properties and classify the soil materials. Based on soil morphology (Table 2-1) and mineralogical data (Table 3-1), classification of the 7 soil materials was made according to The World Reference Base for soil resources (World_Reference_Base 2014) and the Australian Soil Classification (Isbell 2002). The classification of each soil material is presented.

The soil morphological descriptors of five soil materials and mineralogical data indicate two distinct groups, which are reflected in their soil classification as indicated in Table 4-1. These two groups of soil materials classify as: (i) natural soil materials or (ii) artefacts[1] or artefact materials (i.e. created or substantially modified by humans as part of an industrial or artisanal manufacturing process to manufacture “roads” e.g. road metal) and classify as Anthroposols or “man made materials” [Urbic Technosols (Ekranic-like)] or Spolic Technosol materials (World_Reference_Base 2014) or Anthroposol materials (Isbell 2002).

Summary description of Technosols (World_Reference_Base 2014): Connotation: Soils dominated or strongly influenced by human-made material; from Greek technikos, skilfully made.

[1]Artefacts Definition (World_Reference_Base 2014): Artefacts (from Latin ars, art, and facere, to make) are solid or liquid substances that are:

1. one or both of the following:
    a. created or substantially modified by humans as part of an industrial or artisanal manufacturing process; ***or***
    b. brought to the surface by human activity from a depth where they were not influenced by surface processes, with properties substantially different from the environment where they are placed; ***and***
2. have substantially the same properties as when first manufactured, modified or excavated.

Technosols Definition (World_Reference_Base 2014):Other soils having :

- 20 percent or more (by volume, by weighted average) artefacts in the upper 100 cm from the soil surface or to continuous rock or a cemented or indurated layer, whichever is shallower; or
- a continuous, very slowly permeable to impermeable, constructed geomembrane of any thickness starting within 100 cm of the soil surface; or
- technic hard rock starting within 5 cm of the soil surface and covering 95 percent or more of the horizontal extent of the soil.

Human-transported material and human-altered material are defined in Chapter 3 of the 12th Ed. of the Keys to Soil Taxonomy, and evidence of their existence provided (Soil Survey Staff 2014). If humans levelled the land to produce terraces, creating artificial landforms, it will qualify as human-transported material. If humans altered the soil on purpose beyond standard agricultural practices (such as adding lime), it may qualify as human altered material.

Table 4-1. Soil type and morphology, Australian Soil Classification of soil materials (Isbell 2002) and the approximate corresponding World Reference Base for Soil resources class (World_Reference_Base 2014).

Locality (Depth cm)	**CAFSS Code1[1,2]**	**[3]Munsell Soil Colour Fine <2mm (moist)** (dry)	**Soil type[4]**	**Brief Description**	**The Australian Soil Classification (Isbell 1996)**	**The World Reference Base for soil resources (WRB) (WRB;**
Rose garden path (0-10cm)	110.5.1 Rose-path-Anth	**Dark brown 7.5YR 3/2** Brown 7.5YR 5/2	Anthropogenic gravelly sandy loam soil	Gravel (90%; arkosic sandstone and andesitic-to-weathered mafic igneous rock) loamy sand, water repellent, 0.7% Carbon (C).	Spolic Anthroposol; very gravelly, sandy, very shallow	[5]Spolic Technosol (Densic)
Rose garden path near wall (0-10)	110.6.1 Rose-path-wall Anth	**Dark brown 7.5YR 3/2** Brown 7.5YR 5/2	Anthropogenic gravelly sandy loam soil	Gravel (90%; as above)), sand, non water repellent, 5% brick fragments, 1.2% C.	Spolic Anthroposol; very gravelly, sandy, very shallow	[5]Spolic Technosol (Densic, Transportic)
Brick fragments (0-2)	110.6.2 Brick-Anth	**Red 2.5YR 5/8** Light red 2.5YR 7/8	Anthropogenic brick fragment-rich soil	Gravel (90%), sandy, water repellent, weathered brick fragments (0.5-4 cm) ,1.2% C.	Urbic Anthroposol; very gravelly, sandy, very shallow	[5]Urbic Ekranic Technosol (Transportic)
Rose garden bed (0-10)	110.7.1 Rose-bed-Anth	**Black 10YR 2/1** Black 7.5YR 2.5/1	Anthropogenic, organic-rich sandy loam soil	Gravel (15% coarse river sand), loamy sand (25%) , water repellent, 30% fine compost, 30% composted pine bark, 14 % C.	Hortic Anthroposol; non-gravelly, sandy, shallow	[6]Hortic Anthrosol (Escalic)
Japanese garden bed (0-10)	110.8.1 Japan-bed-Anth	**Dark reddish gray 2.5YR 3/1** Reddish gray 2.5YR 6/1	Anthropogenic, quartz-rich, gravelly, sandy soil	Gravel (90%: ~80% rounded quartz, 10% sub-rounded to angular dolerite;5% ironstone), loamy sand, water repellent, 3 % C.	Spolic Anthroposol; very gravelly, sandy, very shallow	[5]Spolic Technosol (Grossartefactic, Transportic)
South eastern boundary (5-0) (0-10)	110.9.1 Sth-E-bound-Nat 110.9.2	**Very dark brown 10YR 2/2** Very dark brown 7.5YR 2.5/2	Natural organic-rich soil Natural loamy soil	Undecomposed Leaves (60%) and decomposed (40%) Gravel (2%), loamy sand, water repellent, 23 % C.	Humose, Mesotrophic, Brown Dermosol; non-gravelly, sandy, deep	[7]Eutric Cambisol (Humic)

Where: [1]Anth: Anthroposol (Isbell 2002); [2]Nat: Natural soil; [3]Munsell Soil Colour: measured on the fine earth fraction (<2mm);

[4] Special-purpose technical soil classification system, which uses plain English language places strong emphasis on being either an Anthropogenic soil or Natural soil, soil texture (e.g. gravelly, sandy, sandy loam) and presence of high amounts of organic carbon (>10%; organic-rich)

[5]Classification of Technosols (World_Reference_Base 2014): Connotation: Soils dominated or strongly influenced by human-made material; from Greek *technikos*, skilfully made. They contain a significant amount of *artefacts*.

[6]Classification of Anthrosol (World_Reference_Base 2014): Connotation: Soils with prominent characteristics that result from human activities; from Greek *anthropos*, human being (e.g. such as addition of organic material and cultivation).

[7]Classification of natural soils : Connotation: Soils with substantial soil formation such as Dermosols (Isbell 2002) or Cambisols (World_Reference_Base 2014)

5. RESULTS OF SOIL TRANSFERENCE EXPERIMENTS (STE)

Summary
This section presents the results of 84 soil transference experiments.

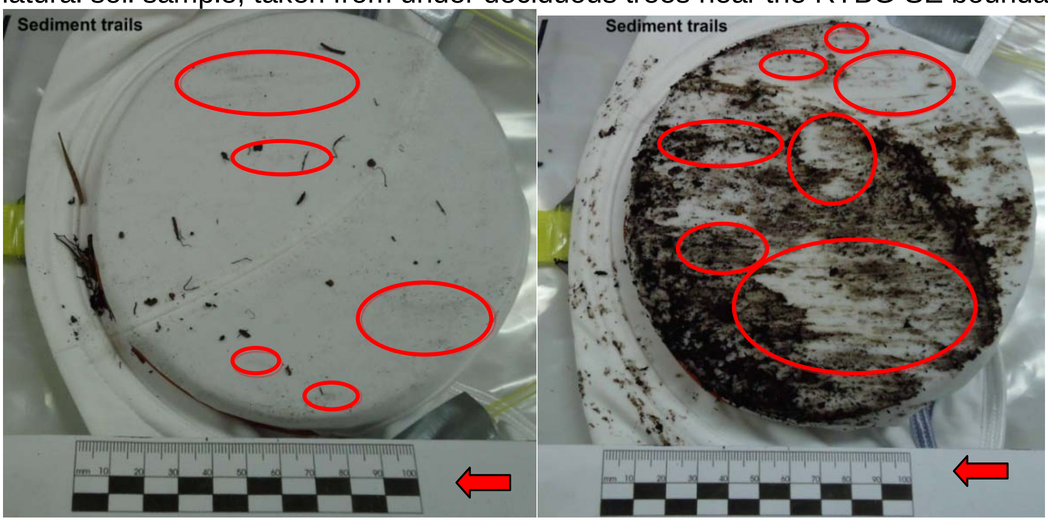
5.1 The transfer and persistence of both anthropogenic/HAHT and natural soil samples onto a nylon/elastane bra; through the transfer method of dragging weighted clothing across a soil surface

Image processing numerical data quantifying the quantity of soil transferred to bra cup fabric, the percentage of individual soil objects and aggregates, the range of Munsell soil colours detected and Rose diagrams displaying directionality of soil transferred is discussed in depth in the image processing sections of this paper.

5.1.1 Soil 'trails' on bra cups and bra straps

Soil 'trails' on the fabric, evidence of the transportation of soil parallel to the direction of movement, could be seen with the naked eye on all dry and wet soil runs in every sample. First recognised during the wet runs due to the darker colour and higher quantity of wet soil transferred, soil 'trails' stood out strongly against the white colour of the bra. A closer visual examination of the dry runs (sometimes requiring light microscopy), confirmed the same patterns.

Note that the two bra cups shown in Figure 5-1 are displayed smaller than actual size; and yet soil trails can still be identified. These STEs were produced from the same natural soil sample, taken from under deciduous trees near the RTBG SE boundary.



a) DRY RUN b) WET RUN

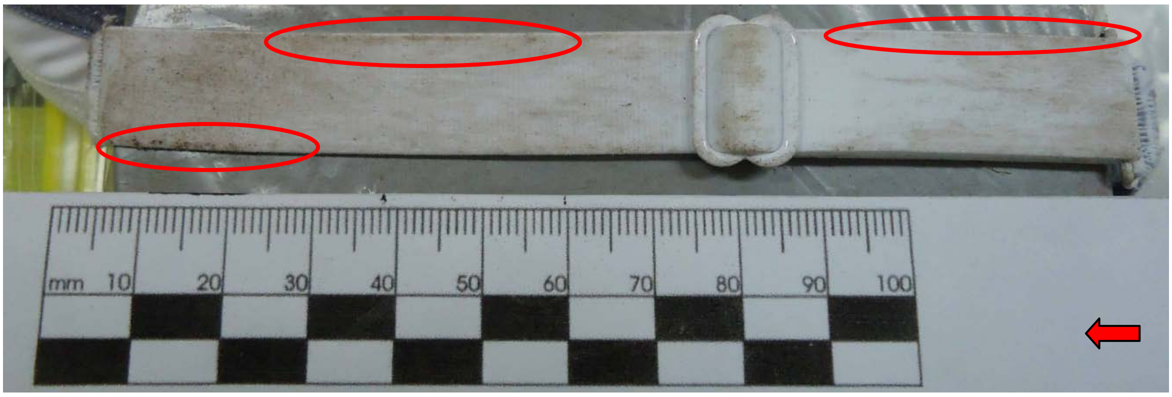
Figure 5-1 Soil trails on fabric, aligned with direction of movement right to left. The dramatic difference that can occur when soil from the same soil sample is transferred during a dry soil run (a) and wet soil run (b) is shown using natural soil sample (110.9.2). Notice also the massive build-up of soil over the raised middle seam and the minimal amount of soil transferred directly behind it.

Another example of this transportation of soil is seen in HAHT soil sample from the Rose Garden path (Figure 5-2). During a wet soil run, a muddy fragment (<2mm) has been transported over the metal buckle (confirmed by the soil trail left behind it on the buckle-bar). It is persisting on the very edge of this buckle-bar; and from the shadow cast, is not touching the fabric underneath for support.

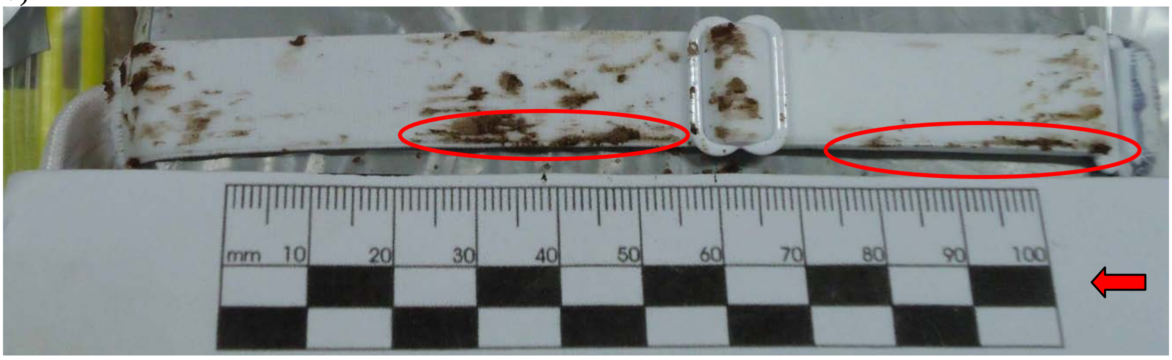
Figure 5-2 Photomicrograph of muddy fragments from a STE wet run using HAHT soil sample (110.5.1) from the Rose Garden path. Note the soil trails coming over the fabric on top of the buckle (Microscope magnification = 6X). Direction of movement = up.

5.1.2 Areas of soil accumulation on bra-straps after weighted fabric was dragged across a soil surface

Soil also accumulated intermittently along one or both fabric edges of all shoulder-straps in both wet and dry soil runs (Figure 5-3). This provided evidence not only that the fabric was dragged, but that the direction of movement was parallel to the bra-strap during transfer.



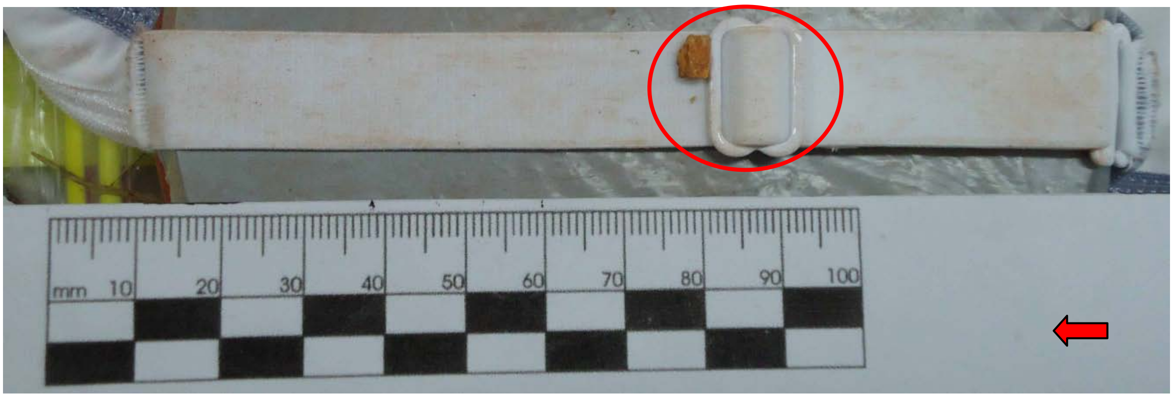
a)



b)

Figure 5-3 Soil accumulation along the edges of bra-straps in HAHT soil sample (110.5.1) from the Rose garden path (Direction of movement = right to left). In dry run a) note the fine (1mm) elongated aligned fragment on the bra-strap above the 50mm mark on the scale-bar. Fine soil trails are also evident near the 100mm mark. In wet run of the same sample (110.5.1) b), the soil trails are much more evident.

On the bra-strap, one of the best areas to differentiate not only dragging as the method of transfer, but also soil trails indicating direction of movement, was the fabric crossing over the metal buckle; as well as soil distribution around the buckle itself. As shown in brick fragment sample (110.6.2) (Figure 5-4), the accumulation of soil in front of the leading edge of the buckle in all samples indicated it was scraping and collecting soil onto the fabric in front. This pattern strongly indicated not only that the fabric was dragged across soil, but also the direction of movement.



a)

b)

Figure 5-4 Using brick fragments from near the brick wall (110.6.2), soil trails over fabric in middle of buckle and accumulation of soil on the bra-strap fabric in front of the metal buckle in both dry (a) and wet (b) runs. Note the large brick fragment (4mmx5mm) that persisted on the fabric in dry run (a) even when the weight was turned upright; and the lack of soil on fabric behind the buckle in both examples. Note also the distinct soil trails across the fabric in the middle of the buckle in wet run b). (Direction of movement = right to left).

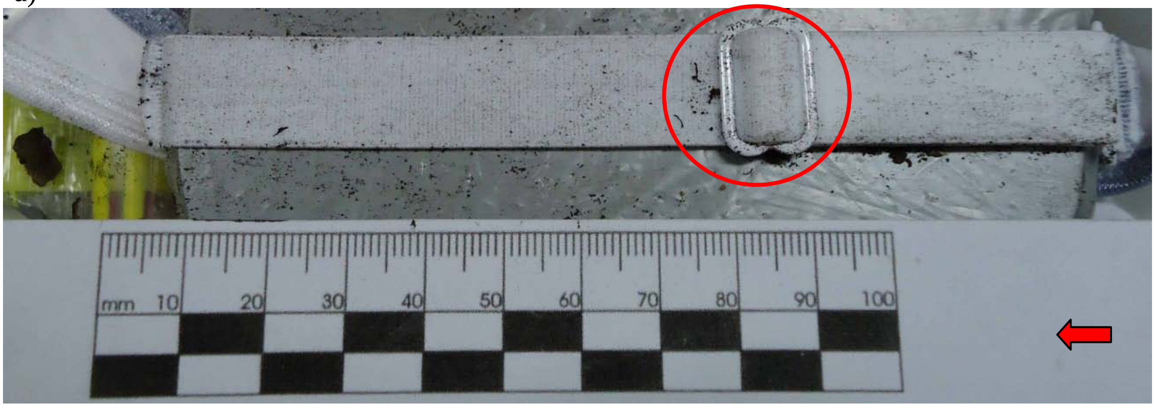
This observation was also confirmed from soil patterns left in the soil bed after every STE. There was a marked difference in the pattern of transfer left in the soil bed when a bra-cup or a strap was tested. When a bra-cup was dragged over a soil surface, it tended to drag a large amount of soil to the left side of the soil dish (Figure 5-5). However, when a bra-strap was tested, the metal bars of the raised bra-buckle caused a deeper and more distinct pattern to emerge in the soil bed than did the smooth, wide and flat expanse of bra-cup. The metal buckle protruding from the raised section of strap appeared to have ploughed into the soil surface due to the weight above; in a pattern aligned with the direction of drag. In Figure 5-5 b), the deep gouging out of soil stops exactly where the metal buckle has come to rest in the soil dish. To the left of this, the narrow shape of the strap is clearly visible.

Figure 5-5 Drag patterns left on the soil surface of HAHT soil sample from the Rose Garden path (110.5.1) after a STE, testing the transfer method of drag on dry soil, has been run. In a), a weighted bra cup has pushed the soil surface up to one end of the tray in the direction of movement (right to left). In b) a weighted bra-strap has carved a narrow line through the soil surface, leaving the remainder of sample generally level in the dish (see line of soil surface at top of photo).

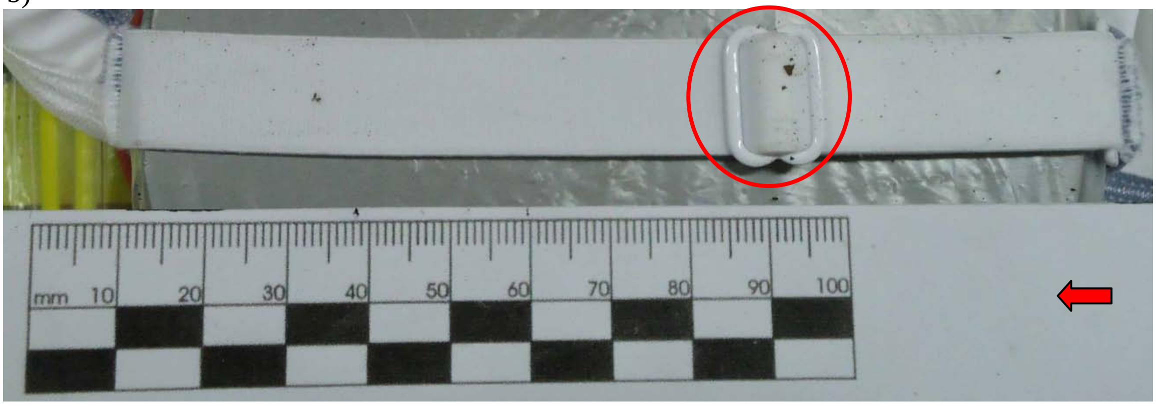
5.1.3 ‘Dusting’ of very fine soil particles on metal buckles when very dry soil samples were tested

In all 21 dry soil runs using a weighted bra-strap in all seven soil samples, a ‘dusting’ of fine clay-sized particles would be deposited evenly over the entire metal buckle (Figure 5-6). This ‘speckling’ only occurred when soil was dry. Digital photos reveal this fine transfer pattern can be seen by naked eye. The STE result from natural soil (110.9.1) is included (Figure 5-6 c) to show that even in a sample made entirely of leaves, this transfer pattern is evident (albeit harder to identify without light microscopy).

a)



b)



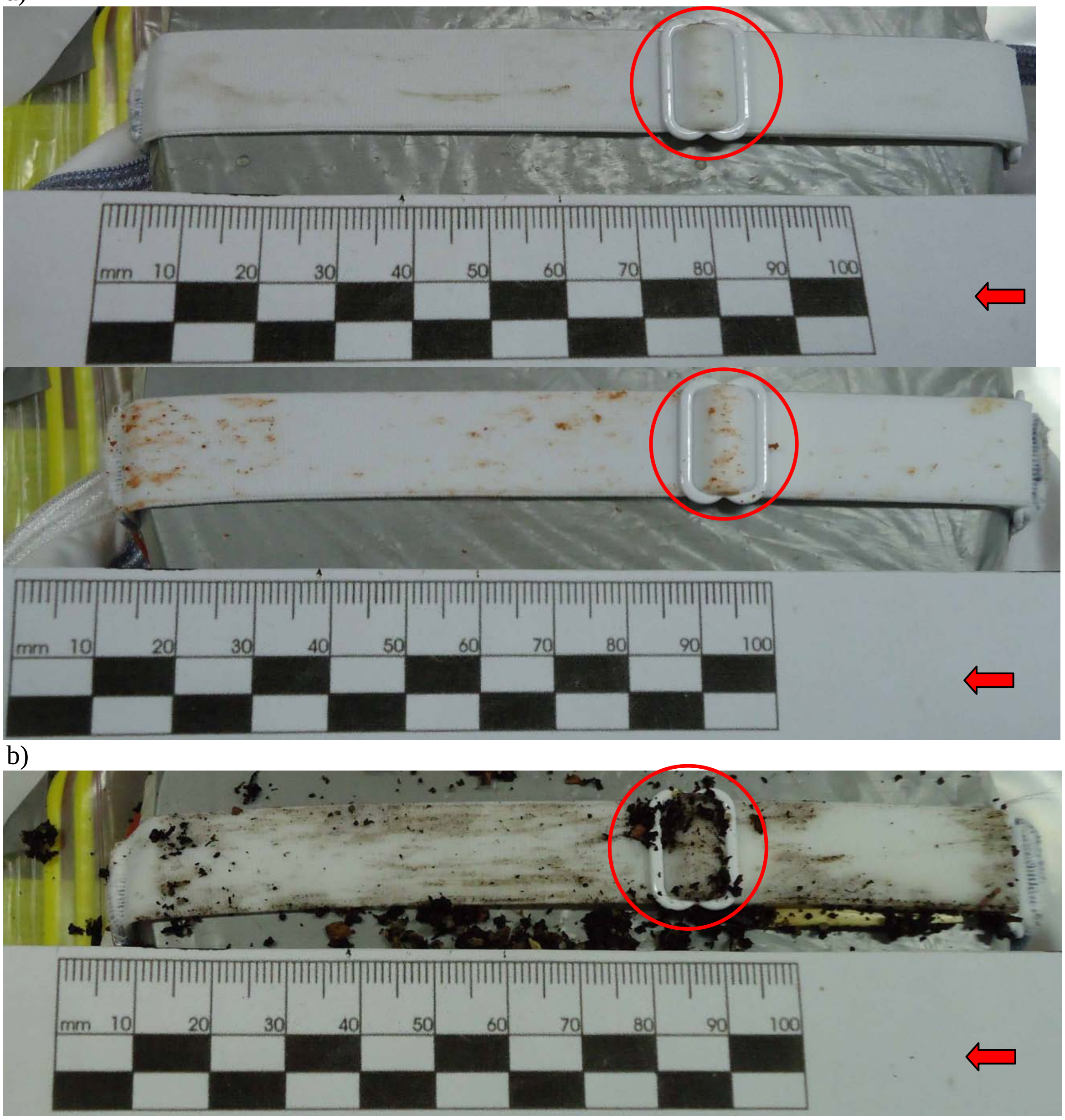
c)

Figure 5-6 ‘Dusting’ of fine clay-sized particles that were transferred evenly over the metal buckle in all 42 STE dry runs in all seven soil samples tested. Dry run a) is from HAHT soil sample from the Rose Garden Path near the brick wall (110.6.1). Dry run b) is from natural soil sample from the SE fence (110.9.2). Dry run c) is from natural soil sample composed entirely of undecomposed leaves (110.9.1). (Direction of movement = right to left).

5.1.4 Very moist soil left metal buckles shiny with small soil aggregates or microscopic trace soil in water droplets

In all 21 wet soil runs dragging a weighted bra-strap across seven different soils, trace soil was transferred to the metal buckles in small to microscopic amounts. After dragging through moist soil, all buckles appeared shiny clean by naked eye; except for a few 1-2mm muddy clumps persisting on five of the seven soils tested (Figure 5-7). This contrasted with dry soil runs, where the speckled surface produced an all-over matt appearance on the metal buckle.

a)



b)

c)

Figure 5-7 Metal buckle is mostly shiny clean, except for 1-2mm muddy clumps of soil. Wet run a) is from HAHT soil sample from the Japanese Garden path (110.8.1). Wet run b) is from HAHT brick fragments from lawn bordering the heritage-listed brick wall (110.6.2). Wet run c) is a mixture of HAHT and natural soils from the Rose Garden Bed (110.7.1). Note that areas without clumps of soil are shiny clean and do not have an evenly fine dusting of soil covering them. (Direction of movement = right to left).

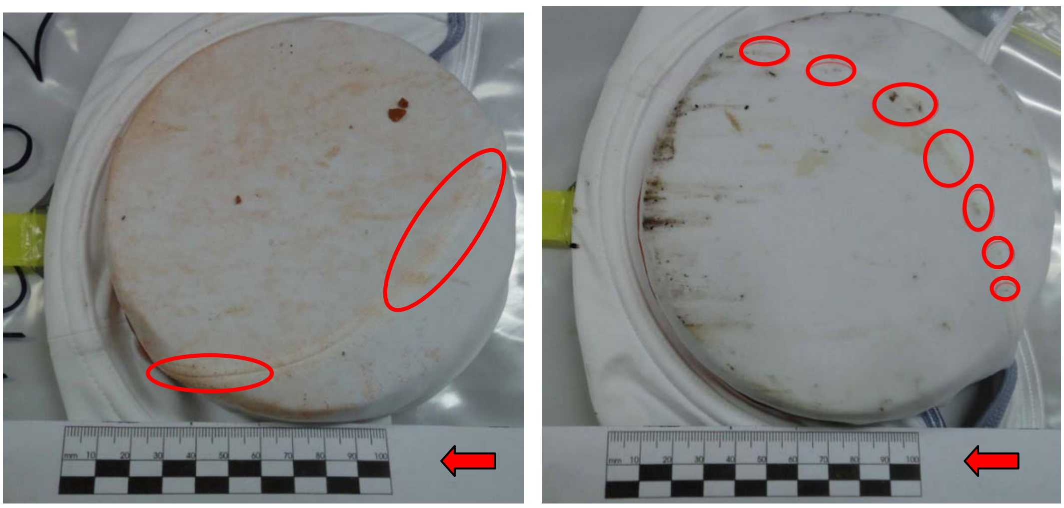
Two soils tested had negligible clay content, namely anthroposol Japanese garden soil consisting of 90% gravel and the top horizon of natural soil on SE boundary consisting of undecomposed leaves (Table 3-1). Metal bra-strap buckles dragged across these two moist soils appeared by naked eye as shiny clean and devoid of any trace soil transferred. However using light microscopy, water droplets on the otherwise clean buckles contained extremely fine soil particles (Figure 5-8). These two soil transfer patterns only occurred when soil was wet.

(a) MOIST Japanese Garden soil (110.8.1) **(b) MOIST SE boundary natural soil (110.9.1)**

Figure 5-8 Photomicrographs of trace soil patterns using the transfer method of dragging weighted fabric for a three second count across a soil bed containing moist soil. The only soil persisting on the metal buckles is contained in water droplets.

5.1.5 Soil accumulates in front and on top of raised seams in both wet and dry soils

In all 42 STEs using either wet or dry soil, soil accumulated in front and on top of raised middle seams in all bra cups. It was also noted that soil was minimal directly behind the raised seam; indicating that the seam was at an angle to the direction of motion (Figure 5-9. Also refer back to Figure 5-1). Even with minimal soil transferred from undecomposed leaf litter (110.9.1), very fine soil has still been transferred onto this raised middle seam.

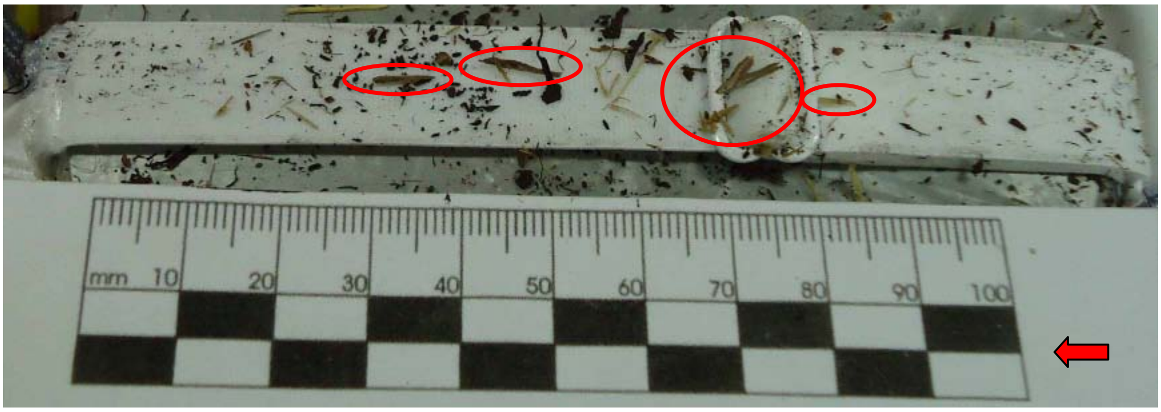


a) b)

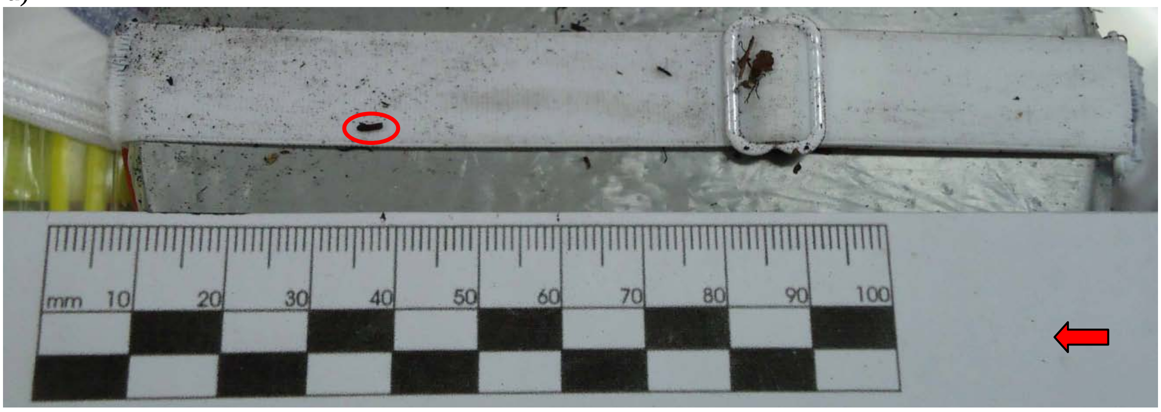
Figure 5-9 Soil accumulates in front of and on top of the raised middle seam of the bra-cup. In dry run a) taken from HAHT brick fragments (110.6.2), there is not only soil accumulating in front of and on top of the raised seam, but a definite change in colour behind the seam; due to the lack of soil transferred directly behind it. In wet run b) taken from natural soil sample made entirely of undecomposed leaves (110.9.1), very fine soil still accumulates in small patches on the raised seam. Notice also the striking soil trails aligned with the direction of movement, near the western edge of the bra cup. As in Figure 9b, there is more soil/mm in front of this raised seam than behind it. (Direction of movement = right to left).

5.1.6 Elongated particles of soil align on the fabric parallel with the direction of movement

Elongated particles of soil (such as grass seeds, dry grass and wood debris ≥2mm), aligned parallel with the direction of movement. Although all seven soil samples produced this pattern, it only occurred in approximately 65% of STEs (Figure 5-10 and Appendix 1). This transfer pattern proved a much less reliable visual method to establish the direction of movement than the more persistent and very distinctive soil trails; and was inconsistently produced amongst the elongate particles transferred to fabric. Outside of a controlled laboratory environment, this pattern could not be relied upon to infer that a victim had been dragged, unless elongate soil particles, such as grass seeds or twigs were actually embedded or pushed under the fabric.



a)



b)

Figure 5-10 Elongated particles of soil aligned parallel with the direction of movement (right to left). In dry run a) from the mix of HAHT and natural soil from the Rose Garden bed (110.7.1), elongated organic particles on top of the buckle and on both sides of the strap, have aligned with the direction of movement. However, there are still many elongated particles that have not aligned. In dry run b) from natural soil near the SE fence (110.9.2), several elongated particles have aligned along the bra-strap (but not on the buckle) in the direction of movement. Notice also the soil trails on both sides of this strap.

In Figure 5-11, elongated soil particles (3-5mm dry grass and wood fibres) from dry Rose Garden bed soil (110.7.1) are persisting on the fluffy seam at the back end of the strap. They are clearly aligned with the direction of movement, from right to left. Note the faint sediment trails running along the entire strap length; whilst the majority of loose particles are persisting on the strap in front of the metal buckle.

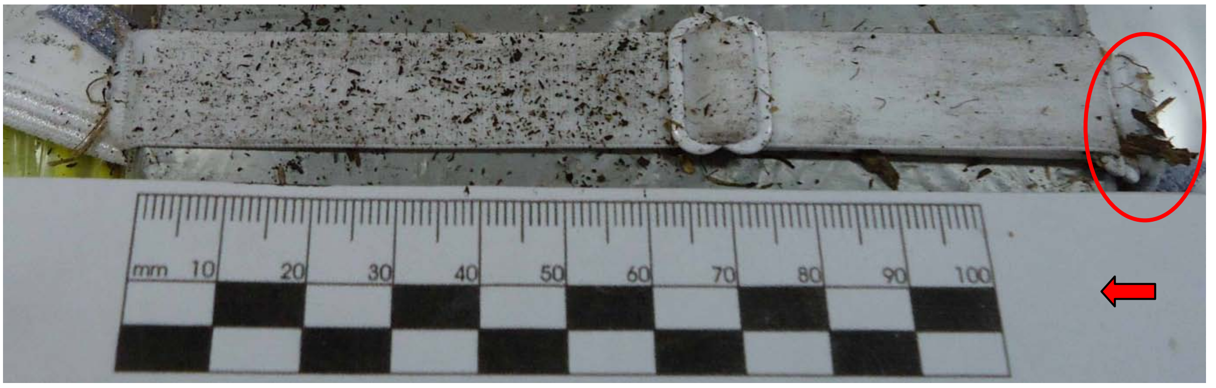


Figure 5-11 STE dry run using the soil sample from the Rose Garden bed (110.7.1); which is a mixture of natural and HAHT soil. (Direction of movement = right to left).

5.1.7 The persistence of fine trace soil transferred by dragging synthetic nylon-elastane fabric across a soil surface

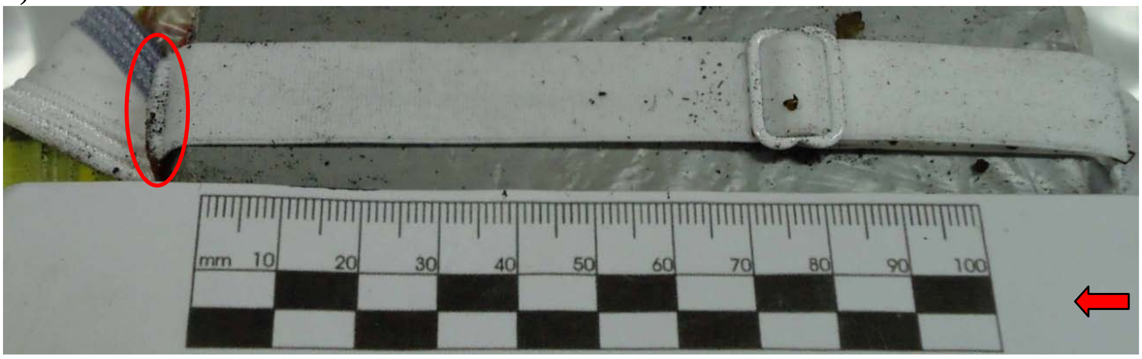
Evidence of the delicate and transitory nature of loose particles of trace soil on fabric was documented in the laboratory. Light-weight organic elongated particles (fine roots between 1mm-2mm in length) could be blown out of their original position on fabric by air-conditioning within seconds. This was less of a problem with smaller or heavier elongated particles. But in the field, wind and rain (notwithstanding the body being moved or clothing removed), could degrade the pristine record that trace soil patterns can provide forensic investigations. Rose garden bed soil (110.7.1) contained many fine roots and other elongated organic particles. When the bra was removed from the 2kg weight, simulating clothing being removed from a female victim, static electricity produced by the nylon-elastane fabric being dragged for 3 seconds through the soil dish (over 20 minutes earlier), caused light-weight organic elongated particles to stand up on end and even shoot off at great speed (Figure 5-12).

Figure 5-12 After a STE dry run using Rose Garden bed soil (110.7.1), elongate fragments stand up on end due to static electricity after the nylon-elastane fabric of the bra has been dragged for three seconds across the soil surface.

5.1.8 Fluffy-textured raised seam accumulates trace soil at ends of bra-straps

The fluffy raised seam at the top and bottom of the bra-strap could accumulate soil in both wet and dry soil runs (Figure 5-13). It was anticipated that this fluffy surface would collect more soil that the finely-woven bra strap. But this hypothesis was proven inconclusive by the STE results. This transfer pattern was the least reliable; only occurring in 47.6% of dry runs and 28.6% of wet runs on average over all seven samples (Appendix 1).

a)



b)

c)

Figure 5-13 Soil accumulating in the fluffy seam at the front of the bra strap. Dry run a) is taken from HAHT brick sample (110.6.2). Note also the accumulation of soil in front of the buckle. Dry run b) is taken from natural soil (110.9.2). Wet run c) is taken from natural soil made up of undecomposed leaves (110.9.1). Even in a sample with minimal soil transference, familiar patterns indicating the transfer method of drag are still evident: a build-up of soil over the buckle fabric in fine soil trails and also intermittently along both strap edges. (Direction of movement = right to left).

In summary, eight transfer patterns were seen across all seven soils tested; but only the first six occurred with 100% consistency (Appendix 1).

(1) Soil 'trails' were observed by naked eye on the bra-straps and cups as a result of soil transported across the fabric parallel to the direction of movement. The darker colour of wet soil contrasted more strongly against the white fabric compared to dry soil; and a greater quantity of wet soil was transferred than dry.
(2) Soil accumulated intermittently along the edges of shoulder-straps in all STEs. This indicated not only that fabric was dragged, but that direction of movement was parallel to the bra-strap during transfer.
(3) Soil objects accumulated in front and on top of raised middle seams in all bra cups, at an angle to the direction of motion; regardless of soil moisture content. Soil transference was minimal directly behind the raised seam; indicating direction of movement.
(4) Likewise, soil accumulated on the metal bra-strap buckle and on strap fabric in front of the leading edge of the metal bra-strap buckle, when the strap was dragged across soil. This provided an indicator of direction. This soil could be seen by naked eye alone, except when moist soil had minimal clay content; as occurred with 90% quartz gravel (Japan-bed-Anth) and natural soil composed of undecomposed leaves (Sth-E-bound-Nat-leaves). These exceptions are discussed in greater detail in pattern (6) below.
(5) When the weighted bra was dragged across dry soil, very dry clay-sized particles 'dusted' or speckled the metal bra-strap buckle evenly like icing sugar.
(6) Moist soil left metal bra-strap buckles wet and shiny, often with 1-2mm muddy clumps transferred onto an otherwise shiny clean surface; to an extent dependent on soil type. This contrasted with dry soil runs, where the speckled surface produced an all-over matt appearance on the metal buckle. Occasionally, these tiny clumps had their own microscopic soil 'trails'. Metal buckles dragged through soil with negligible clay-sized content (Japan-bed-Anth and Sth-E-bound-Nat-leaves) appeared shiny clean with a few water droplets remaining. However, using light microscopy, water droplets were clouded with extremely fine soil particles.
(7) Regardless of moisture content, elongated particles of soil material such as grass seeds, dry grass or wood debris≥2mm), aligned parallel with dire ction of movement. This pattern was not consistent throughout all STEs, occurring on average 65% using seven soils tested.
(8) Soil accumulated in fluffy raised seams at the ends of bra straps. This occurred in only 47% of dry soil STE's and 28% of wet soil STEs.

6. IMAGE PROCESSING CONDUCTED ON DIGITAL PHOTOGRAPHS TAKEN OF SOIL TRANSFER PATTERNS

Summary of image processing analyses conducted on digital photos recording the soil transfer patterns on fabric after STEs were conducted in the laboratory

Image processing software analysed digital photos taken of every soil transfer experiment (STE). Quantifiable numerical data was collected regarding the quantity of soil transferred, percentage of individual soil objects and aggregates, Munsell soil colour range and directionality of soil transferred. This data was then combined by soil sample, method of transfer and whether soil was moist or dry when the test was run; producing the following graphs and Rose diagrams.

Photographs were categorized by soil sample and further classified by wet or dry moisture content experiments. Image processing enabled quantifiable numerical data to be collected on the following key areas:

1. The quantity of different categories of soil particles (pale smears, brown smears and organic particles) were collated as a percentage of the total soiled fabric area in pixels and then compared with areas of clean fabric. The objects include solid clumps of soil, bark and plant fragments. There are also areas of stained fabric (“pale smears”) probably due to the presence of dispersed clay and oxide in grains that are individually too small to recognise in these images. Visual inspection suggests the objects reported are very rarely single mineral grains. Some of the plant material is distinctly green and this is reported separately as “organic particles”. However most of the plant material and especially bark was not distinguished from aggregates composed of soil minerals (“brown smears”).
2. The approximate composition of individual soil objects and aggregates of soil objects (both greater than 2 pixels) making up this soiled fabric area were compared for each soil sample, which was further divided by wet or dry soil moisture content.
3. Directionality of soil clumps and stains, sorted by length/width >2 pixels, revealed the dominant direction in degrees that soil was transferred to the fabric when dragged from right to left across a soil surface. This numerical data was illustrated using rose diagrams created in GeoOrient. Three Soil Transference Experiments (STE) recorded in each category were combined into one rose diagram.
4. Standard Munsell colour hues, values and chromas were matched to the image processing software’s ‘Red Blue Green’ (RGB) colour values. A ‘colour standard’ was created by analysing the average ratio of RGB values of the white colour of the scale bar incorporated into all original photographs. The colour ratios of 25 Munsell colour chips, originally allocated to one or more soil samples in optimum daylight conditions, were then analysed using digital photos of Munsell colours taken under the same lighting conditions in the laboratory. (Only seven soil samples were eventually chosen for these experiments). Any discrepancies in RGB values in individual photographs could then be adjusted for approximate brightness and colour differences using the ‘colour standard’ white scale bar. A range of dominant Munsell colours for each

soil sample, further separated by wet or dry moisture content, were recorded as a number of pixels (Appendix 3).

5. The smallest object in digital photographs that is consistently recognised by image processing classification is 2 pixels in area. From the scale bar in the images the typical pixel size was 40-60 microns; so the dimensions of the smallest objects recognised are 100 by 50 microns.

6.1 Quantity of soiled areas on fabric compared to clean areas of fabric

Soil objects recognised by image processing software as areas in pixels were categorised as pale smears, brown smears, organics as well as areas of clean fabric. Due to the software's difficulty in recognising organic objects, the true area of this category is not realistically represented in the following graphs Figure 6-1 to Figure 6-3. The image processing software could not reliably recognise soil objects <100 microns. Anthroposol soil samples from the Rose Garden gravel path (110.5.1-6.1) produced inconclusive results from near-identical soil samples (Figure 6-1). The brick fragment sample (110.6.2) produced 15-22% of pale smears with the remainder of the fabric staying clean.

Moist soil from the Rose Garden bed (110.7.1) produced a greater percentage of soiled fabric areas than the dry fabric STEs (Figure 6-2). The quartz gravel-rich anthroposol soil of the Japanese Garden (110.8.1) and undecomposed leaf litter covering natural soil under deciduous trees near RTBG's southeast boundary (110.9.1), showed a negligible difference in quantity of soil transferred to fabric in either wet or dry runs.

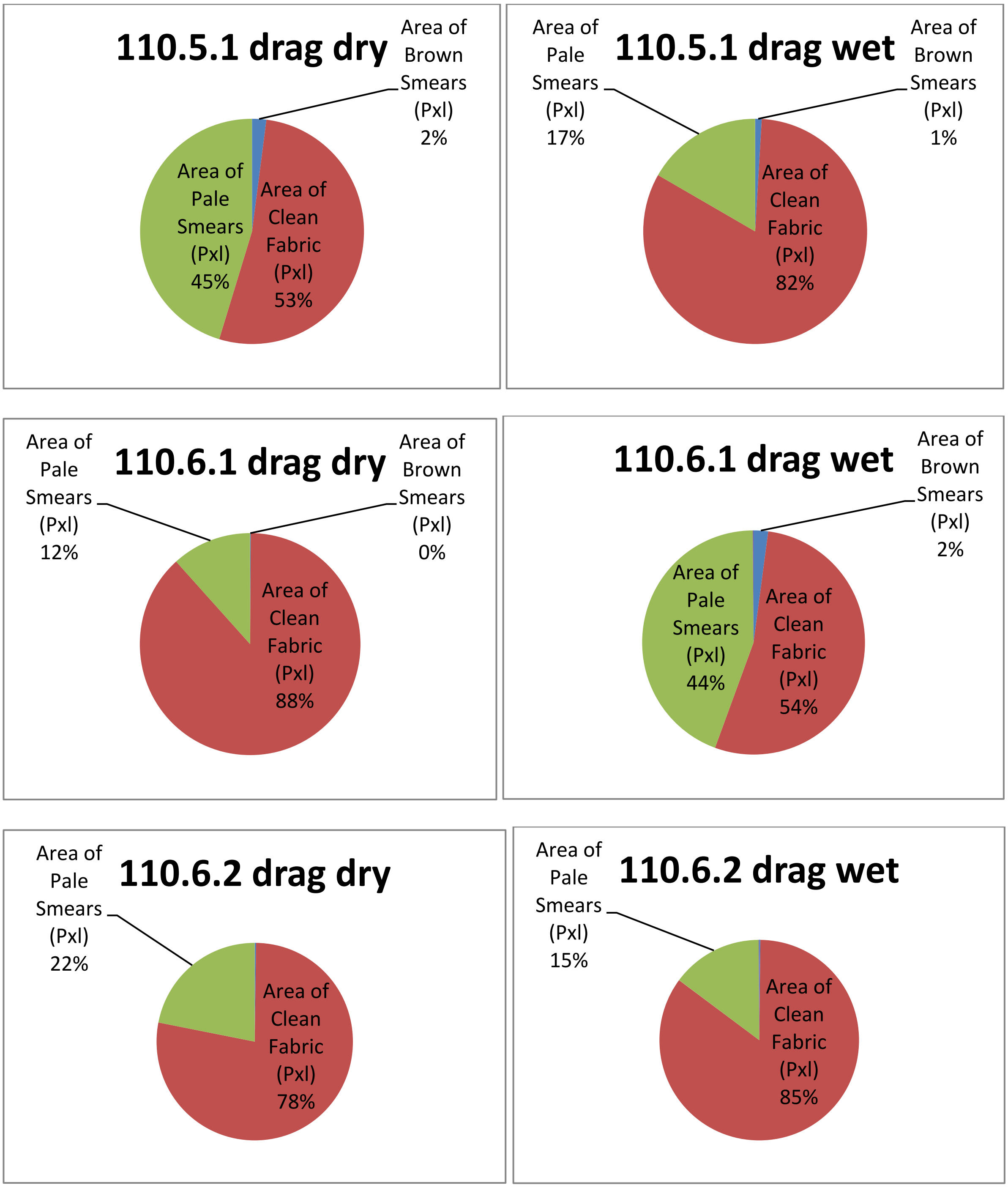


Figure 6-1 Quantity of dry and moist soil transferred to fabric from the Rose Garden path (110.5.1-6.1) and brick fragments found in lawn near the heritage brick wall (110.6.2), RTBG. Image processing showed these results as areas in pixels.

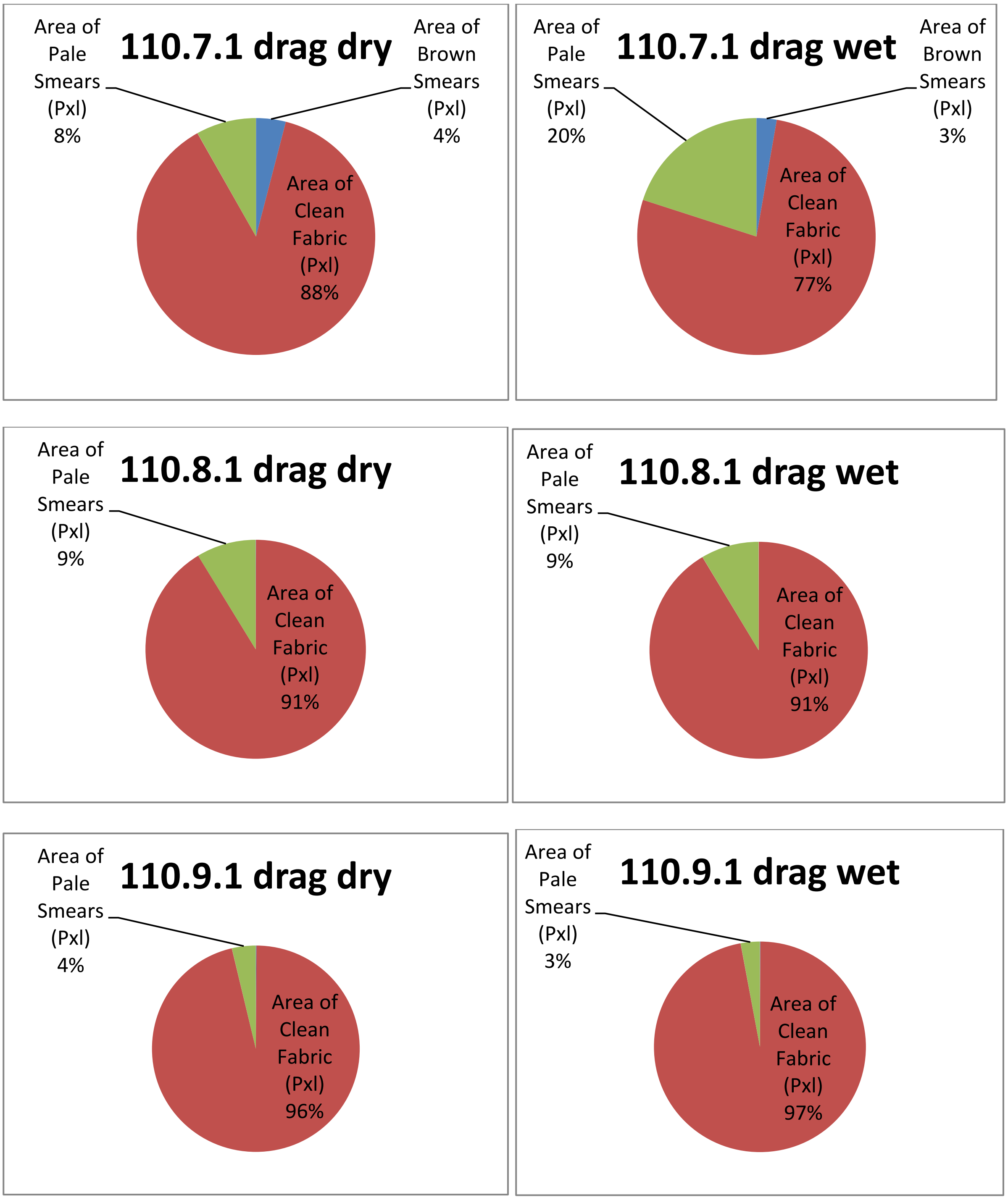
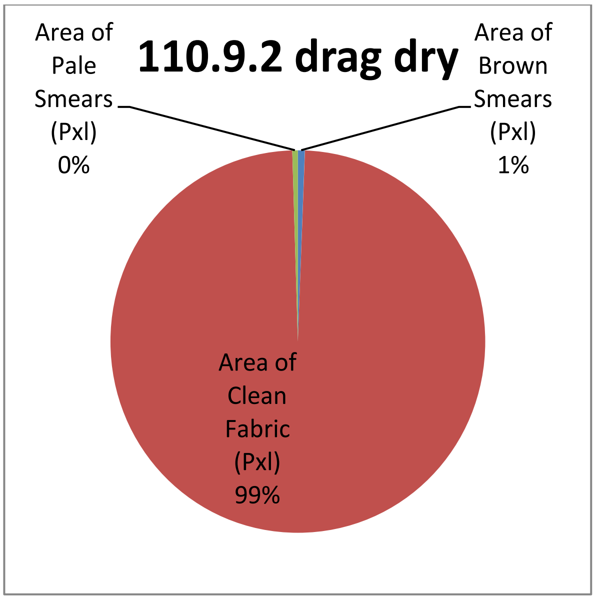


Figure 6-2 Quantity of dry and moist soil transferred to fabric from the Rose Garden bed (110.7.1), Japanese garden gravel (110.8.1) and undecomposed leaf litter covering natural soil (110.9.1), RTBG. Image processing showed these results as areas in pixels.

Natural soil (110.9.2) under deciduous tree leaves from the southeast boundary of the RTBG showed the greatest difference in the quantity of soil transferred when moist or dry soil was used, than the other anthroposol soil samples tested (Figure 6-3). Using this soil sample, only 1% of fabric area was recognised by image processing computer software as soiled when soil was dry. Whereas, 44% of the fabric area was recognised as covered by soil objects when soil was moist.



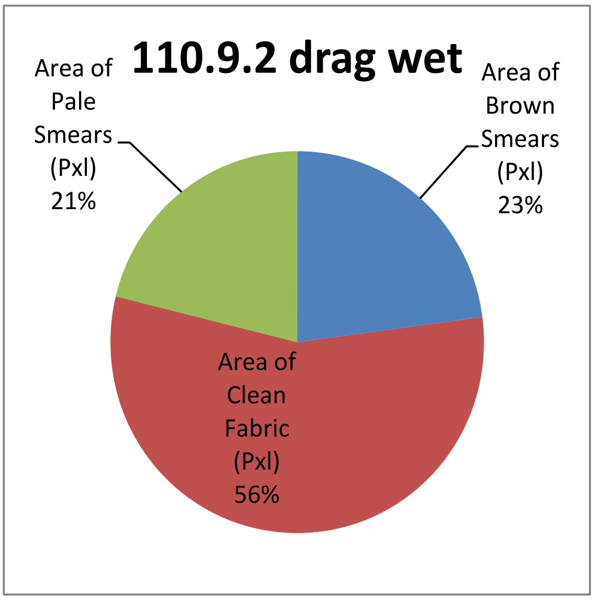
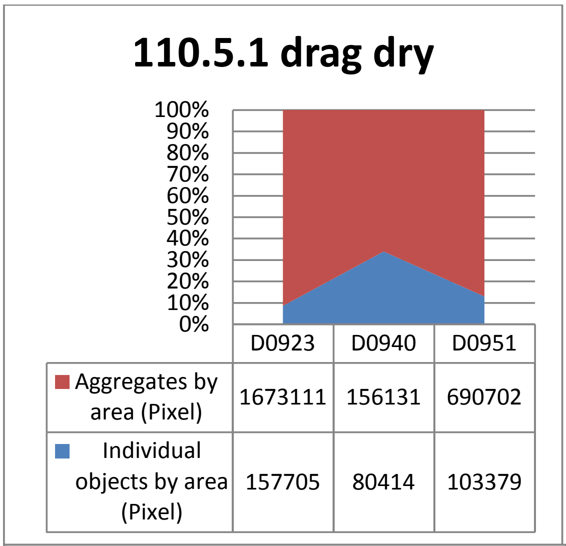


Figure 6-3 Quantity of dry and moist soil transferred to fabric from natural soil under deciduous tree leaves (110.9.2), RTBG. Image processing showed these results as areas in pixels.

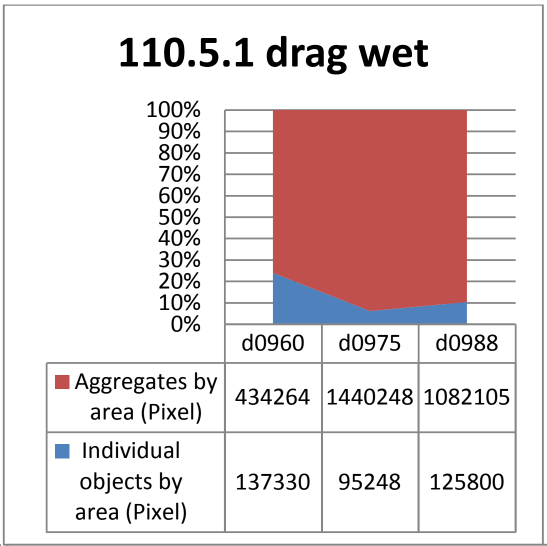
6.2 Individual soil objects and aggregates of soil objects transferred to fabric

Soil samples from the Rose Garden path (110.5.1-6.1) showed the transfer of 10-50% of individual soil objects and 50-90% of aggregates of soil objects onto fabric when dry soil is used in the STE (Figure 6-4). When wet soil is used, 10-40% of individual soil objects and 60-90% of aggregates are transferred onto fabric.

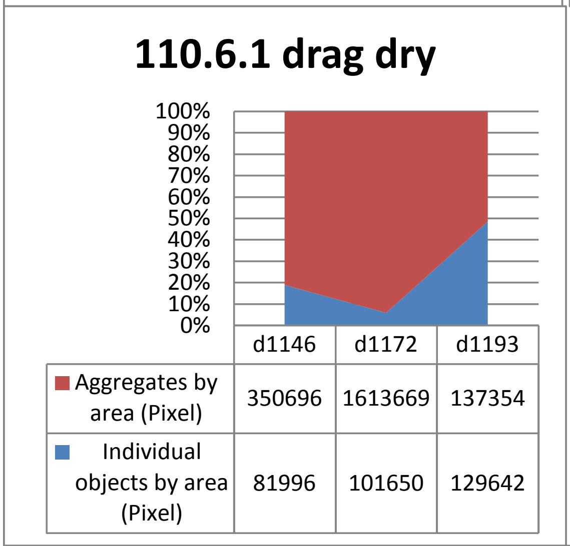
Soil composed solely of brick fragments (110.6.2) showed 5-10% of individual objects and 90-95% of aggregates when transferred during a dry run onto fabric. When soil is wet, 20-40% of individual objects and 60-80% of aggregates were transferred onto fabric.



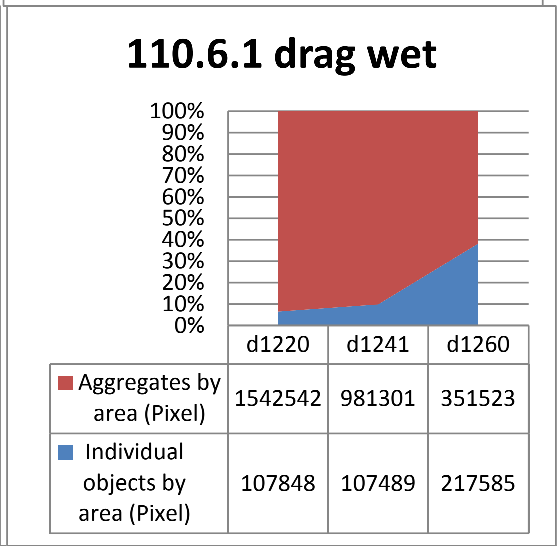
	D0923	D0940	D0951
Aggregates by area (Pixel)	1673111	156131	690702
Individual objects by area (Pixel)	157705	80414	103379



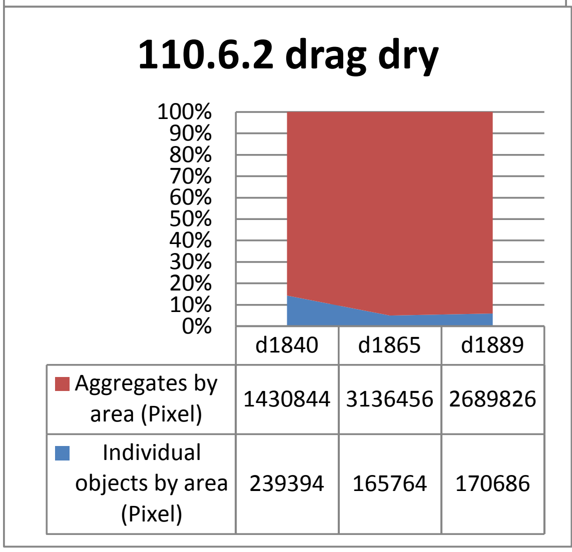
	d0960	d0975	d0988
Aggregates by area (Pixel)	434264	1440248	1082105
Individual objects by area (Pixel)	137330	95248	125800



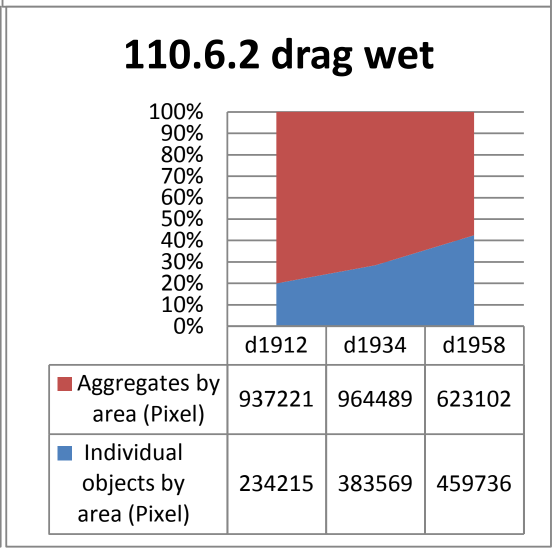
	d1146	d1172	d1193
Aggregates by area (Pixel)	350696	1613669	137354
Individual objects by area (Pixel)	81996	101650	129642



	d1220	d1241	d1260
Aggregates by area (Pixel)	1542542	981301	351523
Individual objects by area (Pixel)	107848	107489	217585



	d1840	d1865	d1889
Aggregates by area (Pixel)	1430844	3136456	2689826
Individual objects by area (Pixel)	239394	165764	170686



	d1912	d1934	d1958
Aggregates by area (Pixel)	937221	964489	623102
Individual objects by area (Pixel)	234215	383569	459736

Figure 6-4 Individual soil objects and aggregates of soil objects transferred to fabric, shown as an area of pixels, from soil from the Rose Garden path (110.5.1-6.1) and brick fragments (110.6.2).

Soiled fabric from the Rose Garden bed (110.7.1) showed 30-70% of individual soil objects and 30-70% of aggregates transferred when dry soil was used (Figure 6-5). When soil was moist, 0-15% of individual objects and 85-100% of aggregates were transferred onto fabric.

Soil transferred to fabric from the Japanese Garden (110.8.1) showed 35-55% individual objects and 45-65% aggregates when soil was dry; and 10-40% of individual objects and 60-90% of aggregates when soil was moist.

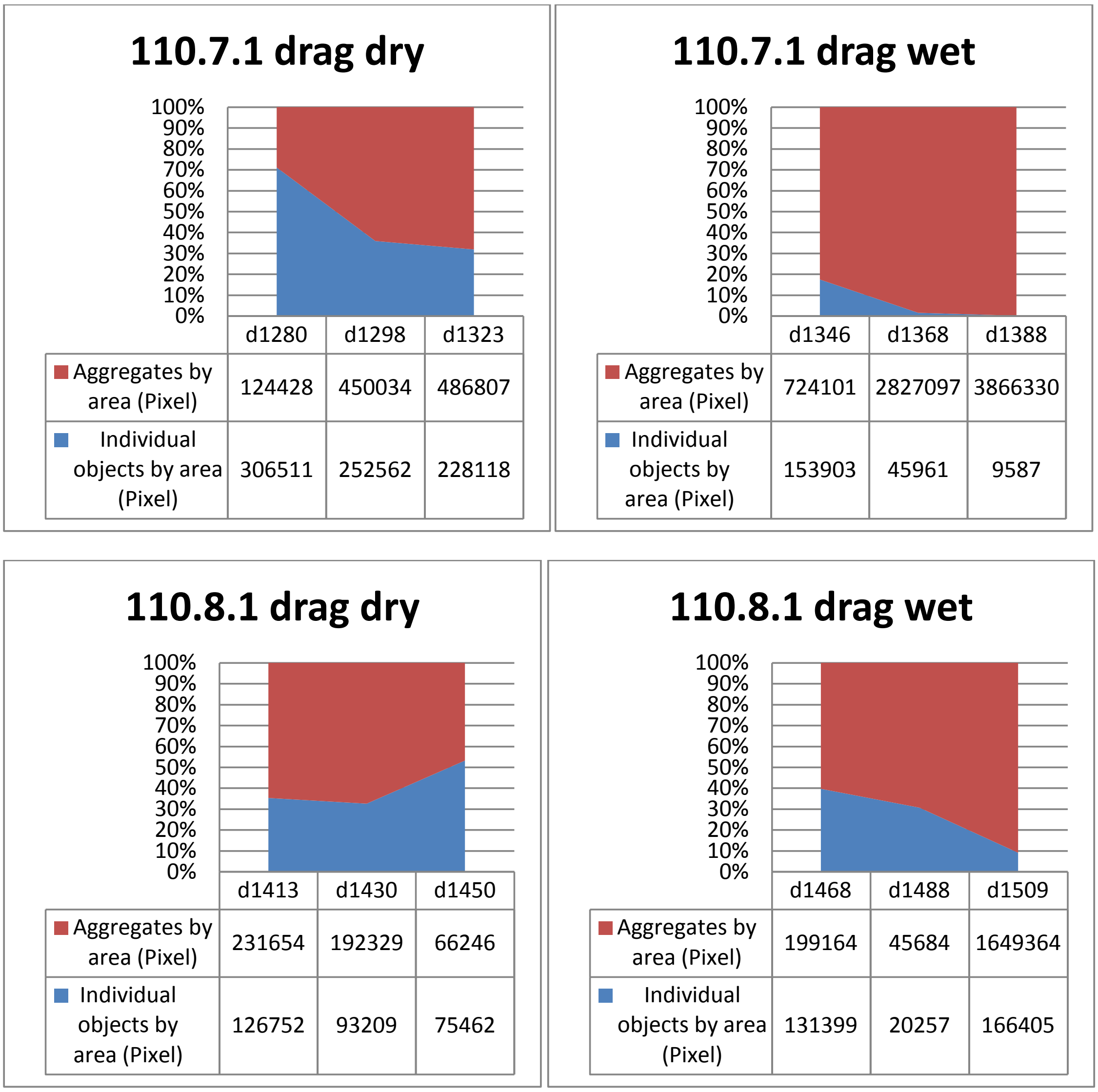


Figure 6-5 Individual soil objects and aggregates of soil objects transferred to fabric, shown as an area of pixels, from anthroposol soil from the Rose Garden bed (110.7.1) and quartz-rich gravel from the Japanese Garden (110.8.1).

The natural soil sample of leaf litter (110.9.1) transferred 30-50% of individual soil objects and 50-70% of aggregates when soil was dry; and 10-15% of individual objects and 85-90% of aggregates when soil was moist (Figure 6-6).
Natural soil lying directly beneath the leaf litter (110.9.2) transferred 25-55% individual soil objects and 45-75% of soil aggregates when dry and 10-15% of individual objects and 85-90% of aggregates when soil is moist.

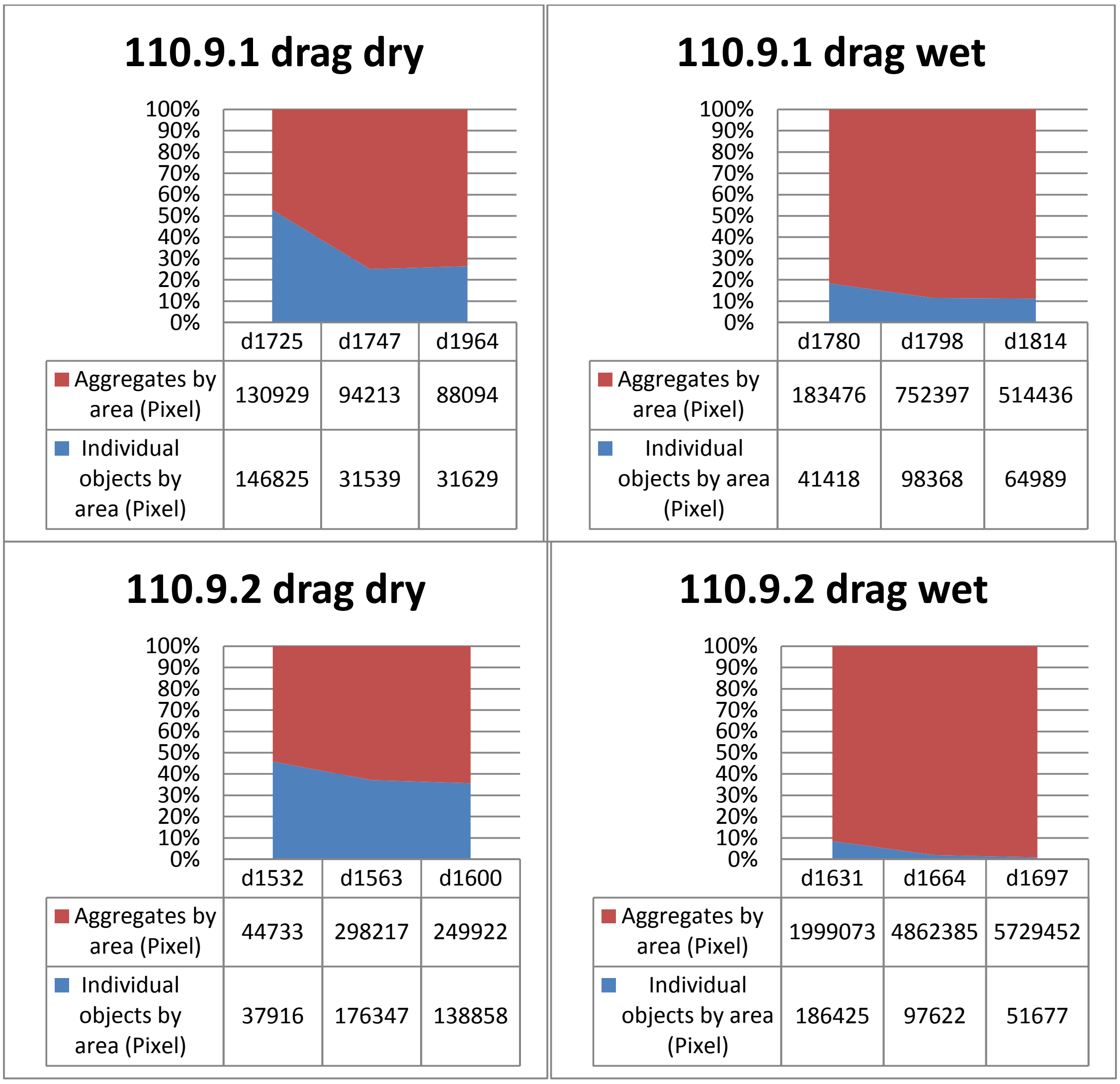


Figure 6-6 Individual soil objects and aggregates of soil objects transferred to fabric, shown as an area of pixels; from natural soil under trees from the southeast boundary of RTBG, composed of leaf litter (110.9.1) and surface soil (110.9.2).

6.3 Quantity of soil transferred to fabric analysed by soil type

Quantity of soil transferred to fabric was measured by image processing analysis using digital photographs taken of each STE. Computer analysis of the number of digital pixels, containing either individual or aggregate soil objects, provided a level of accuracy impossible by naked eye examination (Figure 6-4 to Figure 6-6). Soils were grouped by location and soil moisture content. Numerical data for individual and aggregate soil objects transferred from each soil sample to fabric, were combined and averaged.

Soil objects covering > 0.5 million pixels were classified as being a low quantity of soil transferred to fabric. Soil objects covering 0.5 million to >1 million pixels were classified as a moderate quantity of soil transferred. Soil objects covering 1 million pixels and higher were classified as a high quantity of soil transferred.

Anthropogenic gravel-rich sandy-loam soil from the Rose Garden paths (110.5.1-6.1) produced a low quantity of soil transferred when dry, increasing to moderate quantity of soil when wet. Brick fragments (110.6.2) produced high quantity of soil transferred when dry, decreasing to moderate quantity when wet. Anthropogenic organic-rich sandy loam soil from the Rose Garden bed (110.7.1) transferred a low quantity of soil to fabric when dry, increasing to high quantity of soil when wet. Anthropogenic quartz-rich gravel from the Japanese Garden (110.8.1) and natural leaves from the SE boundary (110.9.1) both produced trace to low quantity of soil to fabric when dry, increasing to low quantity when wet. Natural organic-rich loam from the SE boundary (110.9.2) produced low quantity when dry, increasing to very high quantity of soil transferred when wet.

6.4 Munsell soil colour range of soil transferred to fabric in pixels

The fine (<2mm) wet and moist fractions of each soil sample had their Munsell soil colour analysed by naked eye outside under natural daylight (see Table 2-2). Twenty-five different Munsell colours were recognised. When image processing software analysed digital photographs taken under artificial lighting conditions inside MRT laboratories for their Munsell colour, this limited range of Munsell colours were used to match the computer softwares RGB values to the standard Munsell soil colours used by forensic and agricultural soil scientists. Because artificial light drastically affects the colour of the Munsell colour chips, these 25 colours were photographed again in MRT laboratories under the same artificial lighting conditions; with an aim to ensure the most accurate recognition by image processing software of the Munsell colours of trace soil transferred.

For each soil sample, using either dry of moist soil, a set of three STEs was combined to produce a single graph (Figure 6-7 to Figure 6-13). The fine (<2mm) fraction of soils from the Rose Garden path (110.5.1), under natural daylight, showed a Munsell colour of 7.5YR 5/2 when dry and a darker 7.5YR 3/2 when moist (Table 2). However, soil transferred onto fabric and photographed under artificial lighting conditions, was analysed by image processing software as displaying a dominant colour of 2.5YR 6/1 when soil transferred was dry; with minor peaks at 7.5YR 2.5/2, 5.2 and 10YR 6/3 and 7/2. When moist, trace soil displayed three dominant Munsell colour peaks at 2.5YR 6/1, 10YR 6/3 and 7/2. Minor peaks were identified at 7.5YR 2.5/2 and 5/2 (Figure 6-7).

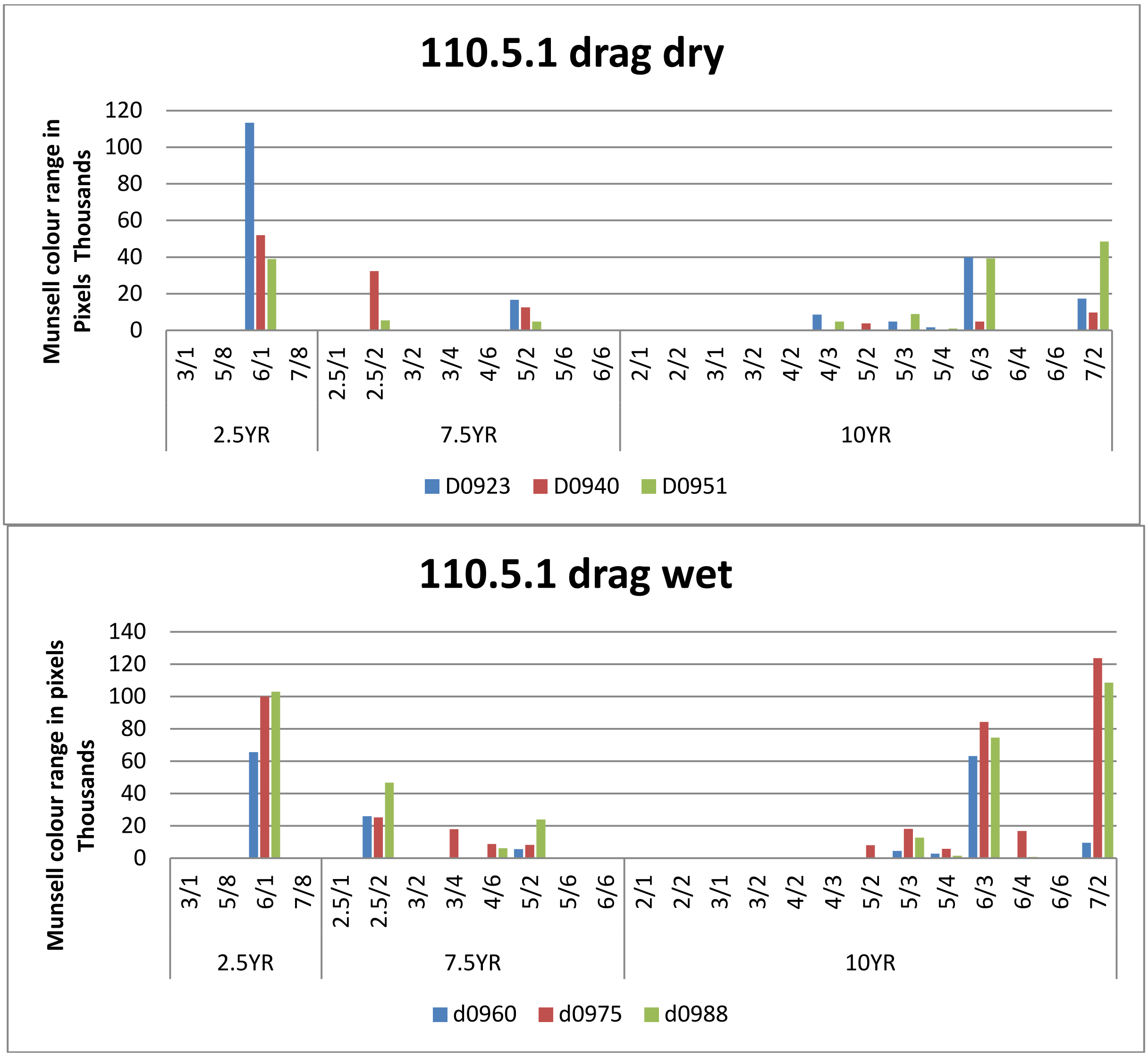


Figure 6-7 Munsell soil colour range recognised by image processing software of soil from the Rose garden path (110.5.1) transferred onto fabric when soil was dry and moist.

The other soil sample taken from the Rose Garden path (110.6.1), under natural daylight, showed the same fine fraction Munsell colours as 110.5.1; being 7.5YR 5/2 when dry and a darker 7.5YR 3/2 when moist (Table 2-2).

Image processing software recorded the colour of soil transferred to fabric as sharing dominant peaks at 2.5YR 6/1 and 7.5YR 2.5/2 when dry; with minor peaks at 7.5YR 3/4, 5/2 and 10YR 6/3. When moist, three dominant peaks were identified as 2.5YR 6/1, 10YR 6/3 and 7/2 (Figure 6-8). Minor peaks were revealed in a cluster at 7.5YR 2.5/2, 3/4, 4/6 and 5/2 plus 10YR 5/3.

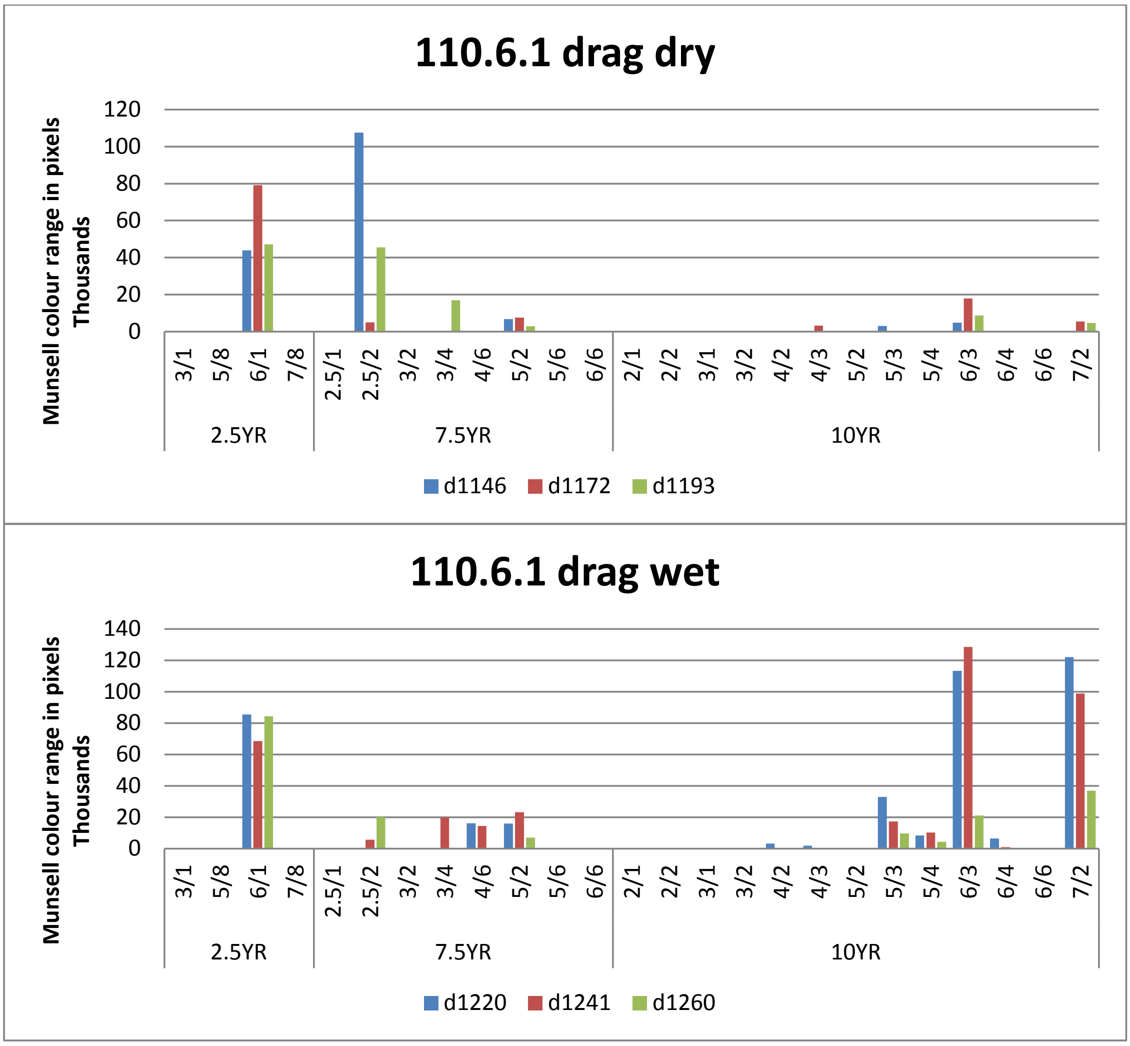


Figure 6-8 Munsell soil colour range recognised by image processing software of soil from the Rose garden path (110.6.1) transferred onto fabric when soil was dry and moist.

The soil sample composed of brick fragments taken from lawn near the heritage brick wall (110.6.2), under natural daylight, showed a fine fraction Munsell colour of 2.5YR 7/8 when dry and a darker 2.5YR 5/8 when moist (Table 2-2).

Image processing software recorded the colour of soil transferred to fabric as having a dominant peak at 2.5YR 6/1 when dry and a main peak when moist of 2.5YR 6/1, with a lesser peak at 7.5YR 2.5/2 (Figure 6-9).

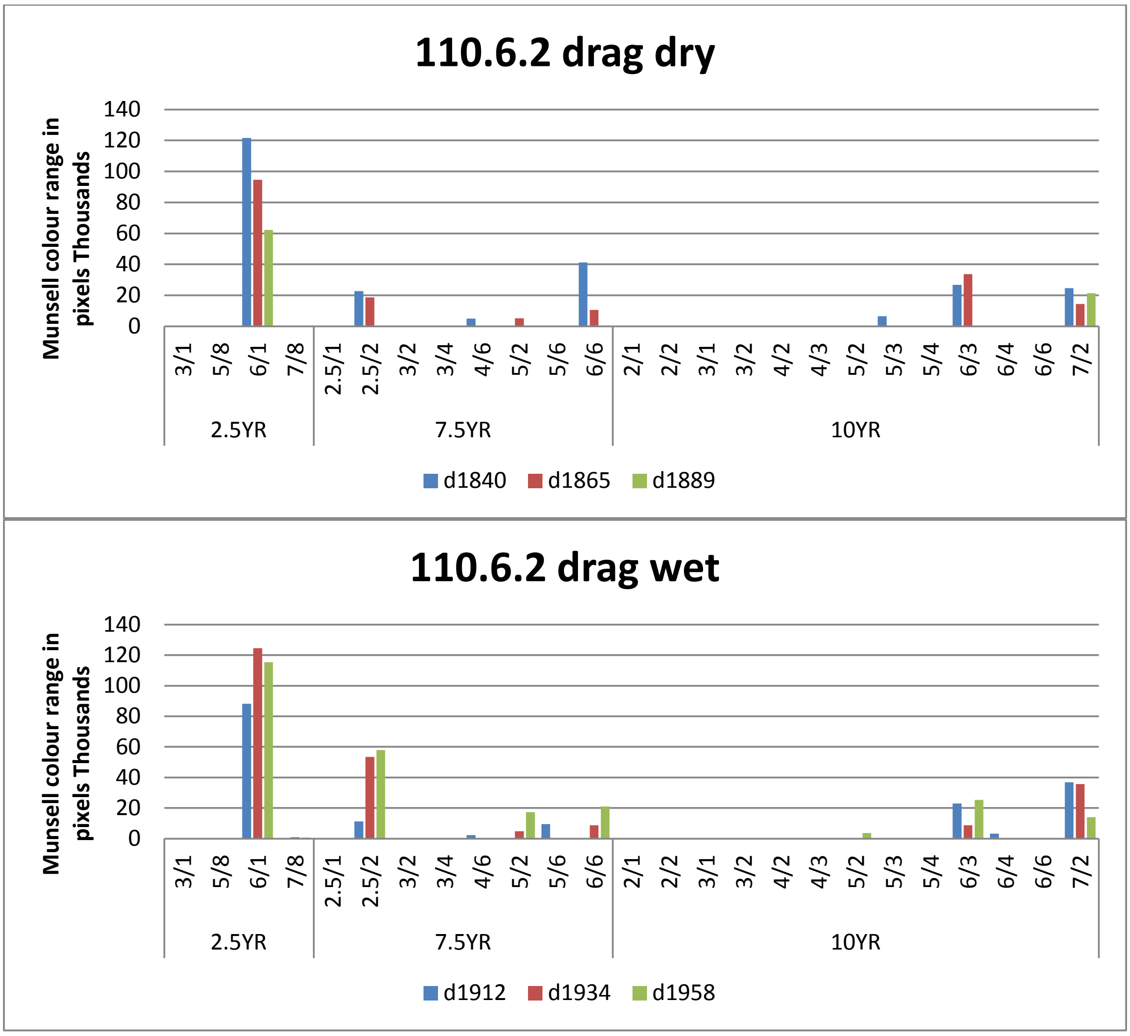


Figure 6-9 Munsell soil colour range recognised by image processing software of soil composed of brick fragments from lawn areas near the heritage brick wall (110.6.2) transferred onto fabric when soil was dry and moist.

The soil sample from the Rose Garden bed (110.7.1), under natural daylight, showed a fine fraction Munsell colour of 7.5YR 2.5/1 when dry and a darker 10YR 2/1 when moist (Table 2-2).

Image processing software recorded the colour of soil transferred to fabric as having a dominant peak at 7.5YR 2.5/2 when dry; with minor peaks at 7.5YR 3/2, 3/4, 5/2 and 10YR 6/3. When moist, a main peak was identified at 7.5YR 3/4; with a cluster of minor peaks at 7.5YR 2.5/2, 3/2, 10YR 6/3 and 7/2 (Figure 6-10).

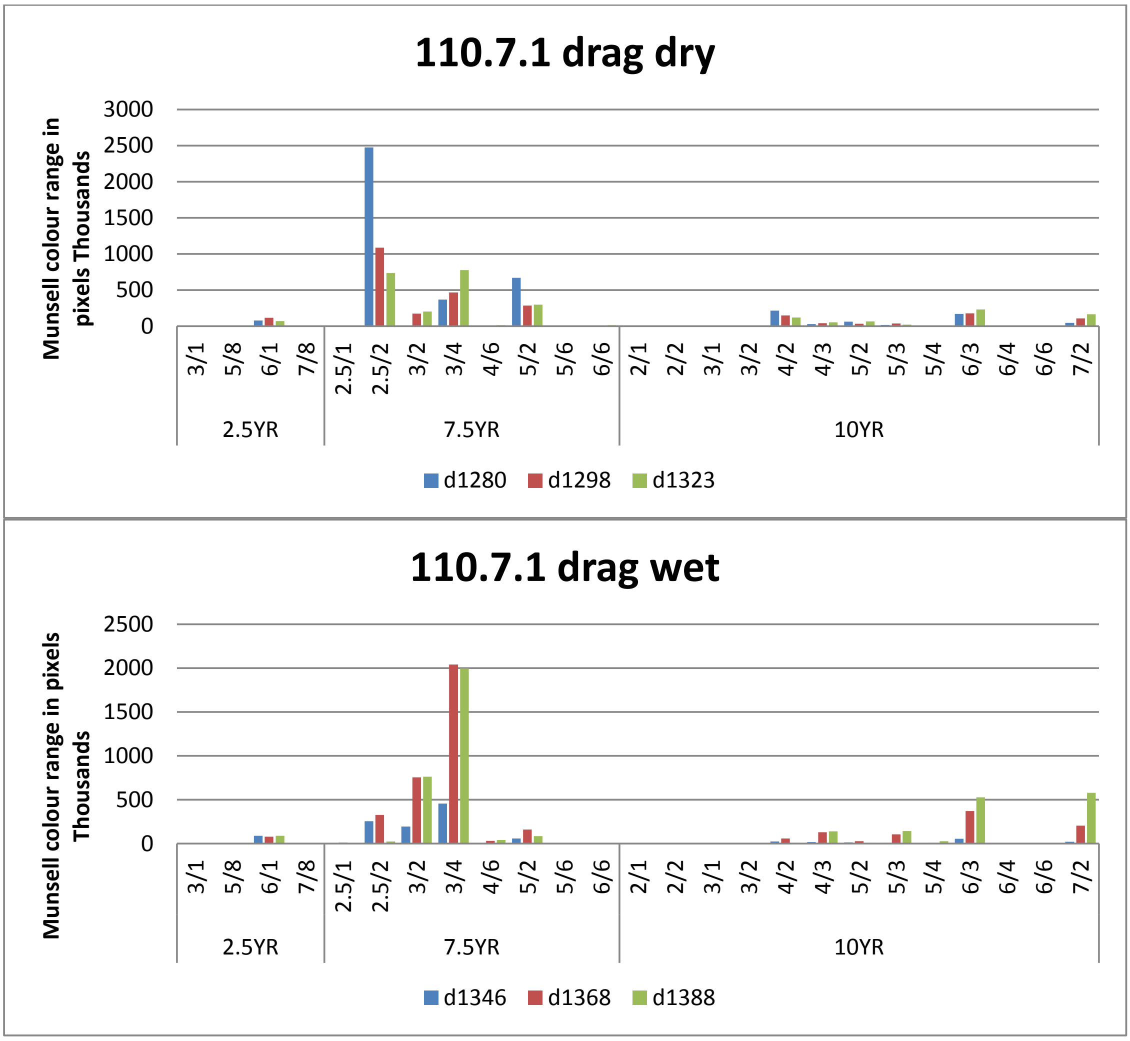


Figure 6-10 Munsell soil colour range recognised by image processing software of soil from the Rose Garden bed (110.7.1) transferred onto fabric when soil was dry and moist.

The quartz gravel-rich soil sample from the Japanese Garden (110.8.1), under natural daylight, showed a fine fraction Munsell colour of 2.5YR 6/1 when dry and a darker 2.5YR 3/1 when moist (Table 2-2).

Image processing software recorded the colour of soil transferred to fabric as having three dominant peaks when dry at 2.5YR 6/1, 7.5YR 2.5/2 and 3/4 when dry; with minor peaks at 10YR 6/3 and 7/2. When moist, two dominant peaks at 2.5YR 6/1 and 7.5YR 2.5/2 were identified; with minor peaks at 7.5YR 5/2, 10YR 6/3 and 7/2 (Figure 6-11).

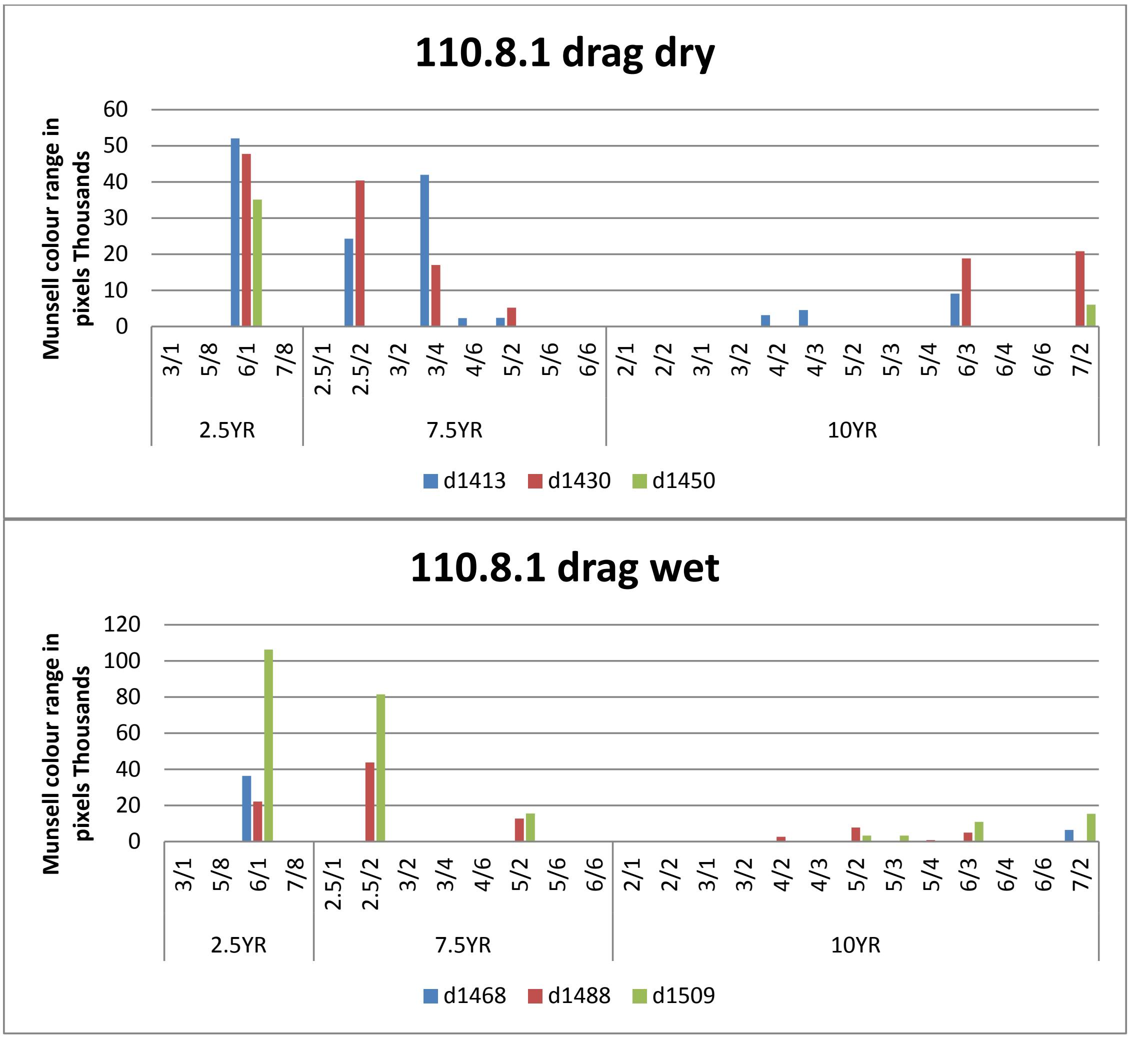


Figure 6-11 Munsell soil colour range recognised by image processing software of soil from the Japanese Garden (110.8.1) transferred onto fabric when soil was dry and moist.

The natural soil sample composed of undecomposed leaves (110.9.1) was not analysed by naked eye for a Munsell soil colour.

Image processing software recorded the colour of particles of undecomposed leaf matter transferred to fabric as having a dominant peak when dry at 7.5YR 2.5/2 when dry; with minor peaks at 2.5YR 6/1, 7.5YR 3/4 , 5/2 and 10YR 6/3 and 7/2. When moist, a cluster of dominant peaks at 7.5YR 2.5/2, 10YR 6/3 and 7/2 are identified; with minor peaks at 2.5YR 6/1, 7.5YR 3/4 and 5/2 (Figure 6-12).

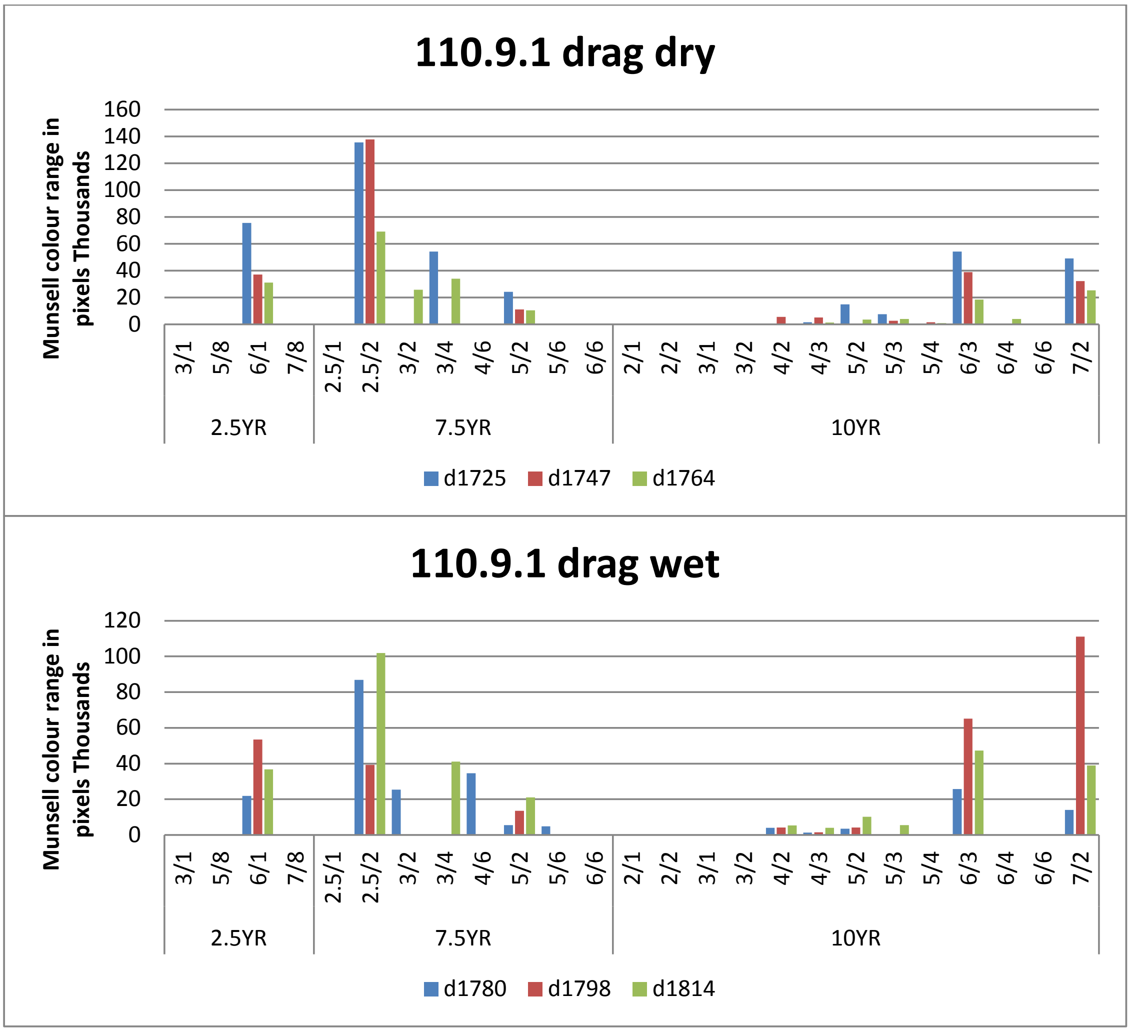


Figure 6-12 Munsell soil colour range recognised by image processing software of soil of undecomposed leaf litter covering natural soil on the southeast boundary of RTBG (110.9.1) transferred onto fabric when soil was dry and moist.

The natural soil sample underlying the leaf matter (110.9.2), under natural daylight, showed a fine fraction Munsell colour of 7.5YR 2.5/2 when dry and a darker 10YR 2/2 when moist (Table 2-2).

Image processing software recorded the colour of soil transferred to fabric as having dominant peaks when dry at 7.5YR 2.5/2 and 3/4; with minor peaks at 7.5YR 3/2 and 2.5YR 6/1 and 10YR 6/3. When moist, a cluster of dominant peaks are identified at 7.5YR 2.5/2, 3/2 and 3/4; with minor peaks at 2.5YR 6/1, 7.5YR 5/2, and 10YR 6/3 (Figure 6-13).

In order to further identify the level of analysis that image processing can provide forensic soil investigators, a single graph was also produced for every soil transfer pattern photographed (Appendix 3). A very similar range of Munsell soil colours was appearing in each of the three soil transfer patterns analysed by image processing. The tremendous potential of image processing analysis to accurately identify and compare the Munsell colour of trace soil evidence on fabric, without requiring a spectrophotometer, is detailed in the 'Discussion' section of this paper.

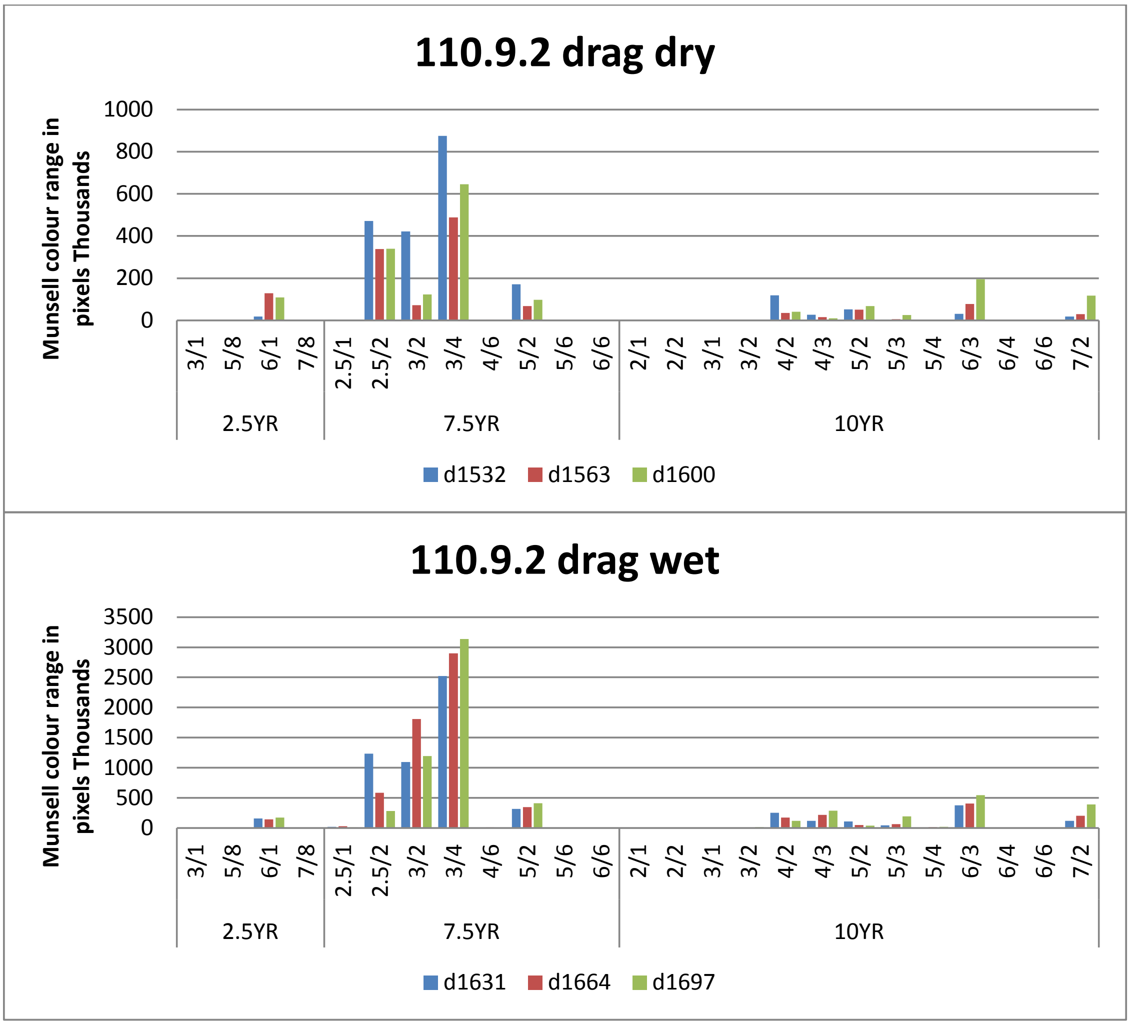


Figure 6-13 Munsell soil colour range recognised by image processing software of natural soil on the southeast boundary of RTBG (110.9.2) transferred onto fabric when soil was dry and moist.

6.5 Directionality

Often it is desirable to present orientation data in such a way that the distribution of orientations is emphasised independently of the geographic location of data; such as whether there is a pattern of preferred orientation of the soil patterns in an area on the bras. The types of diagrams most frequently used to present such information are histograms, rose diagrams and spherical projections (Allaby and Allaby 1999). Rose diagrams are essentially histograms for which the orientation axis is transformed into a circle to give a true circular plot. They are commonly used in structural geology to plot the orientation of joints and dykes. Wind directions and frequencies are also be plotted on rose diagrams.

Using directional numerical data provided by image processing software, Rose diagrams illustrated the directionality of moist and dry soil particles transferred onto fabric (Figure 6-14). This methodology was important to objectively prove that any directional patterns recognised by the human eye, could also be identified by computer software. This objectivity is important during criminal investigations using forensic soil evidence.

Rose diagrams mapped the directionality of thousands of soil particles over 2 pixels diameter. This method consistently created a simple yet definitive pictorial record of the soil transferred onto fabric during dragging experiments. Each Rose diagram only took minutes to create, relying upon image processing directional numerical data.

Strong uni-modal directionality was displayed when fabric was dragged in one direction across the soil surface. This was demonstrated by the black directional lines reaching the edges of the rose diagram, with a distinct horizontal line trending right to left. Dry soil particles had a greater tendency than moist soil to gather against the bra's perpendicular middle seam; producing more of a bi-modal directionality. Dry soil had a greater percentage of individual soil objects. This would create a more scattered and random directionality than the same soil wet. During soil transfer experiments using a soil sample from the Japanese garden (110.8.1) composed of 90% white gravel and a natural soil sample composed entirely of undecomposed leaves (110.9.1), with negligible mineral soil content, minimal trace soil was transferred to the bra fabric. Despite this minute amount of trace soil quantified by image processing software, the Rose Diagrams created still recorded a strong uni-modal directionality; very similar to soil transfer results using other soil samples with higher amounts of fine clay-sized soil particles.

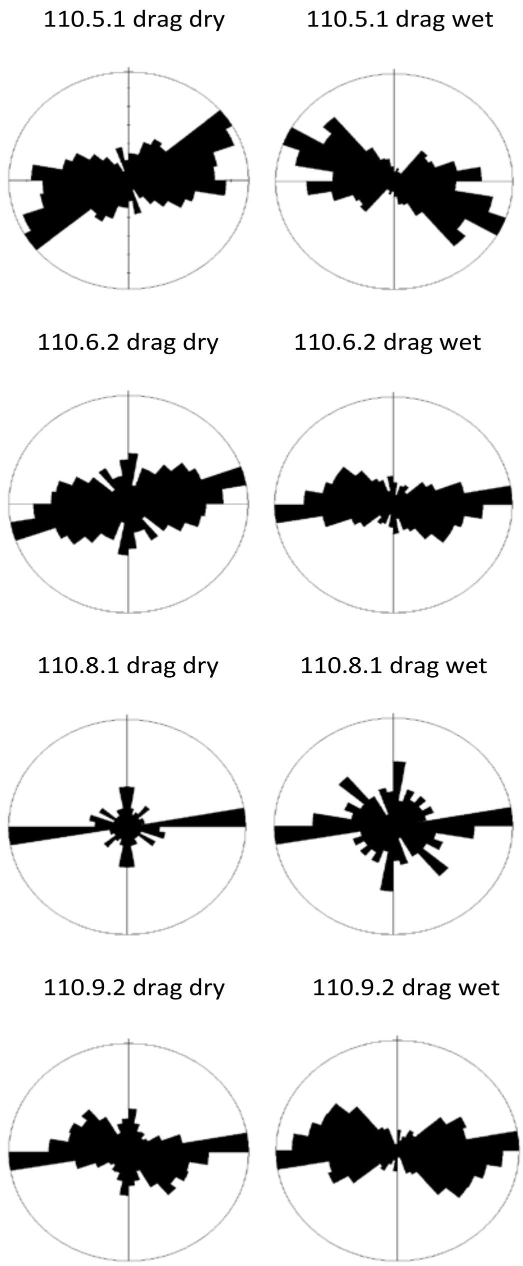


Figure 6-14 Rose diagrams of the directionality of dry and moist soil transferred onto fabric during STEs. Strong uni-modal directionality was produced when fabric was dragged from right to left across the soil surface. Dry soil particles had a greater tendency than wet soil to gather against the middle seam, creating more of a bi-modal directionality.

7. DISCUSSION

This report has focused on the soil transfer method of dragging weighted clothing (bra) across a wide range of soil surfaces, to simulate a female victim being dragged during the perpetration of a crime. Therefore, this set of soil transfer patterns cannot indicate other modes of transfer, such as placing loose or weighted clothing on a soil surface or a combination of several methods. It is our intention to write subsequent reports and papers describing different modes of transfer, to be used by Police and forensic investigators at crime scenes.

7.1 Size and quantity of soil particles transferred in STE

The majority of soil particles transferred in all STEs were very fine silt or clay-sized fragments. The largest fragment transferred was a 5mm x 4mm brick fragment from sample 110.6.2 (Figure 3-4). When the 2kg weight was removed, the larger (>0.5cm) loose fragments were easily dislodged and moved across the bra's surface; often accumulating in the bottom of the storage bag. Whereas, the fine fractions, such as those transferred in sediment trails, tended to remain in situ; half-embedded in the fabric.

7.2 How soil texture and mineralogy affected the resulting Soil Transfer Patterns

The texture of the seven soil samples used in these experiments was either loamy-sand, sand, brick or undecomposed leaves (McDonald and Isbell 2009). All textures produced soil transfer patterns in every test, to a greater or lesser extent (Table 4-1). The soil samples with the texture of loamy-sand produced the most easily identifiable soil transfer patterns; possibly due to the organic carbon content of these soil samples. These dark, loamy-sand samples produced soil transfer patterns that were the easiest to identify on the white fabric of each bra (See Figure 5-2, Figure 5-3, Figure 5-7, Figure 5-10).

A soil sample's clay content greatly influenced the resulting soil transfer patterns; as well as the quantity and persistence of soil particles transferred. Fine clay-sized particles showed greatest adherence or persistence on the fabric when both wet and dry soil was used. Clay particles also acted as a 'mortar' to secure larger grains or aggregates of soil (See Figure 5-2 and Figure 5-7).

7.3 How moisture content of soil affected the resulting Soil Transfer Patterns and the persistence of trace soil on the fabric

As revealed in the results of these STEs, whether soil is wet or dry when transferred onto clothing can have a major influence on the ease of visual identification of soil transfer patterns, the amount and particle size of soil transferred, it's adherence to the fabric and the mineralogy of particles transferred.

Fine clay-sized particles showed greatest adherence or persistence on the fabric when both wet and dry soil was used. Their persistence was greatly enhanced when soil was moist; enabling these soil particles to not only coat but impregnate the fabric fibres (See Figure 5-2 and Figure 5-7).

7.4 Discussion of XRD and NDIR analysis of soil samples from Royal Tasmanian Botanical Gardens

To compare the effect of soil mineralogy on resulting transfer patterns, all soil samples underwent analyses using powder X-ray diffraction. If soils tested were vastly different in mineralogical composition, this might imply a ‘universality’ to transfer patterns seen across all soils tested. Soil mineralogical results are summarised in Table 3-1.

High clay content soils included the two spolic Anthroposols from the Rose Garden path; consisting of 90% sandstone and mafic igneous gravel with negligible organic content. Mineralogy was approximately 40% weight of quartz, with 20% of both plagioclase and smectite clay. Humose mesotrophic brown dermosol (Sth-E-bound-Nat) also had similar levels of quartz and smectite clay content to Rose garden path soils, but differed with its high organic content of 38% weight.

Hortic anthroposol (Rose garden bed) was 69% weight quartz with organic content of 24%. Another spolic anthroposol (Japanese garden soil) had high quartz content (83%), minimal clay or organic content. Brick fragments (110.6.2) had high quartz content, with negligible organic content and traces of mullite, calcite, rutile and hematite. The greatest differences between soils were the carbon levels; ranging from 0.26-3.10% in the gravel-rich Anthroposols. In contrast, 14% carbon was measured in the Rose garden bed soil and 22.8% carbon in SE boundary underlying natural mineral soil (Table 3-2). Small Sulfur contents were noted but no Sulfur-bearing species identified; generally correlating with organic matter.

7.5 Discussion of Image Processing quantitative numerical data of soil transfer patterns on fabric

Image processing of digital photographs taken of soil transferred onto fabric was undertaken to provide an objective approach to graphically present soil transfer patterns. This more quantitative graphical presentation of soil patterns assisted or confirmed the interpretation of soil transfer patterns such as directionality of soil transferred; whilst adding a standardised objectivity to the results not possible through identification by naked eye alone.

Image processing of all soil objects ≥2 pixels diameter (>100 microns) were collated; including the quantity of soil transferred, percentage of individual soil objects and aggregates, Munsell soil colour range and directionality of soil transferred. Due to limitations in the software’s programming, the smallest soil particle that could be reliably identified was >100 microns.

Difficulties differentiating mineral from organic soil objects could feasibly be overcome with more complex programming. Both Rose garden path soils and mineral-based SE boundary natural soil had smectite clay content between 15-20% weight. A much greater quantity of soil objects, in particular soil aggregates, were transferred to fabric when these soils were moist.

Classifying soils for a particular purpose involves the ordering of soils into groups with similar properties and for potential end uses. In general, soil classification systems currently used in most countries involve the use of the following three broad approaches (Fitzpatrick 2013a).

- General-purpose broad soil classifications such as World Reference Base (World_Reference_Base 2014), which communicate soil information at international scales; and national scale classifications, such as Australian Soil Classification (Isbell 2002), shown in Table 1.
- State, provincial or regional soil classifications, which are designed both to assist with ''user-friendly'' communication of soil information and to account for the occurrence of soils that impact on existing and future industry development and prosperity (Fitzpatrick 2013a).
- Special-purpose and more technical soil classification systems, which are used for local or single-purpose applications such as in Soil Forensics (Fitzpatrick 2013a). These Special-purpose systems generally involve using plain language names for soil types for users such as police [42] but must also correlate with the general-purpose international and national classifications as shown in Table 3.

Using image processing numerical data that measured the quantity of soil objects (both individual and aggregates) transferred to fabric, a relationship between soil type, clay (smectite) and soil moisture content was discovered.

Anthropogenic, gravelly, sandy loam soil (Table 2) with high organic carbon content (Rose garden paths), produced a low-moderate quantity of very dark brown soil objects when transferred to the fabric when dry and increasing to moderate quantity when wet (dark brown).

Anthropogenic, brick fragment-rich soil with high quartz and negligible organic and smectite content (Brick-Anth), produced a high quantity of reddish-grey soil objects when transferred to the fabric when dry, decreasing to moderate quantity when wet (reddish grey).

Anthropogenic organic-rich sandy loam soil with approximately 15 to 19 % smectite and high amounts of arkosic sandstone and andesitic-to-weathered mafic igneous rock (Rose garden beds) produced a low to moderate quantity of reddish-grey soil objects when transferred to the fabric when dry and increasing to a high quantity when wet (light-grey to reddish grey).

Anthropogenic, quartz-rich, gravelly, sandy soil with high quartz content and negligible organic and smectite content (Japan-bed-Anth), produced a trace grey coloured soil transference pattern to fabric when dry, increasing to a low quantity when wet.

Natural organic-rich soil with very high organic carbon content (Non-mineral based horizon Sth-E-bound-Nat leaves), produced a trace quantity of very dark brown soil objects when transferred to the fabric when dry and increasing to low quantity when wet (very dark brown).

Natural loamy soil with approximately 20% smectite (Sth-E-bound-Nat underlying mineral soil) produced a moderate quantity of dark brown soil objects when transferred to the fabric when dry and increasing to high quantity when wet (dark brown).

Smectite is highly susceptible to soil moisture and soils with high smectite content can undergo as much as a 30% volume change; an indication of smectite's shrink/swell potential (Weaver 1990). This characteristic of smectite clay may help explain the differences seen in trace soil patterns when dry or moist soil was transferred to fabric.

Both Japanese garden soil (110.8.1) and Brick fragments (110.6.2), with high quartz content and negligible organic and smectite content, transferred minimal trace soil to fabric; as did the natural soil horizon composed of undecomposed leaves. (which did not undergo XRD analysis.)

In the seven soil samples tested, the greatest quantity of soil transferred onto fabric was from mineral-based underlying natural soil sample 110.9.2 (Figure 6-6). The least soil transferred came from Anthroposol (human-made) gravel-rich soil from the Rose garden path (110.5.1-6.1) (Figure 6-4), Japanese Garden (110.8.1) (Figure 6-5) and natural soil composed of undecomposed leaves (110.9.2).

In all soil samples, aggregates of soil objects made up approximately two-thirds of all soil objects detected by image processing. Dry soil samples provided the greatest percentage of individual soil objects, with moist soil producing a greater area of aggregates.

Because photographs of trace soil patterns were taken using a very basic 14.1 megapixel digital camera under artificial lighting in the laboratory, it was correctly predicted that initial Munsell colours chosen for soils by naked eye in natural daylight would differ from those detected by image processing software.

Despite the limitations of these source photographs, image processing chose the same colour for dry Japanese garden soil. Dry SE boundary underlying natural mineral soil had a semi-dominant peak of the same Munsell colour chosen under natural daylight. Dry Rose garden bed soil was only one Munsell colour shade different than the initial Munsell colour chosen for dry fine soil fraction under natural daylight. When Munsell colour results are so close, the variability of the human retina must also be considered.

Only SE boundary underlying natural mineral soil produced clusters of neighbouring Munsell colours in dry and moist trace soil transferred. Other soils produced more distant Munsell colour peaks.

Not only did image processing software create a range of Munsell colours using photographs of trace soil on fabric, the same range of Munsell colours was correctly identified from trace soil on twelve different bras; linking this trace soil ‘evidence’ to the Rose Garden path. Using two soils sampled only four metres apart, image processing matched the same dominant peaks of Munsell colours in both dry and moist trace soil on fabric.

Comparing graphs of image processing numerical data of all soil samples revealed this software identified the same range of specific Munsell colours in individual photographs of STEs. The power of image processing to identify Munsell colour ranges to link trace soil on clothing to a specific location may prove as integral to forensic soil investigation as XRD’s ability to identify peaks of soil minerals.

A thorough comparison between the three STEs done for each dry and wet soil sample discovered that image processing software could identify the same range of specific Munsell colours in all three photographs (Appendix 4). Looking at the peaks of colour shared between each set of three photographs was reminiscent of looking at DNA ‘fingerprint’ bands; where each ‘band’ in a child’s DNA fingerprint must also be present in the fingerprint of one or other (or both) of the parents.

In forensic soil science, XRD analysis of soil provides a proven method of analysing the mineral composition of trace soil evidence on clothing. But in cases where soil evidence from multiple locations share very similar mineralogy, image processing the colour of trace soil evidence using digital photographs may provide a new objective, accurate and detailed method to compare and contrast soil evidence by colour alone.

This new level of detail in Munsell colour analysis was accomplished using no other source but digital photographs of the STEs taken in the lab under artificial lighting conditions. The resolution of this digital camera was only 14.1 megapixels.

Further research using image processing to analyse crime scene photographs may enable trace soil on clothing and possibly even shoe and tyre treads to be compared by Munsell colour. The same colour standard, such as the white scale bar used in this paper, would be required to allow photographs taken under a variety of lighting conditions to be compared using image processing software. This new method of analysing the colour of trace soil on fabric could enable crime scene evidence to be accurately analysed for the full range of 450 different standard Munsell colour chips, even when a spectrophotometer is not available. Image processing of digital trace soil photos may only be used as a preliminary step to compare and contrast different soil evidence before more expensive and time-consuming analytical testing is undertaken; such as XRD analysis of a soil's mineralogy. But this initial step may mean that vital forensic soil evidence is not completely ignored, as often happens, because the funds or expertise in more expensive analytical techniques are not available.

Once the image processing software was programmed, the analysis of each digital photograph took only 2 minutes for quantifiable numerical data to be produced. Simple Excel graphs then made comparison of the different soil transfer experiments very easy to comprehend.

A valuable outcome was the use of image processing software to produce Rose diagrams that plotted the directionality of soil transferred onto fabric. All digital photographs were taken of soil transfer patterns, with the direction of movement running horizontally from right to left. This would aid recognition of soil transfer patterns that were being documented for the very first time. This resulted in digital photographs with all soil 'trail' patterns running horizontally. Rose diagrams accordingly indicated strong uni-modal directionality; even with minimal trace soil transferred. There was also a trend for dry soil particles to be 'dammed' against the perpendicular middle seam during the dragging experiments; creating a more bi-modal directionality in these Rose diagrams.

Rose diagrams provided a quick, simple and cheap pictorial record of numerical data analysis of directionality of soil transferred to fabric. By combining image processing with Rose diagram software, this method could assist forensic investigators understand the circumstances behind fabric making contact with a soil surface. This method may also be used to gain the acceptance of these particular circumstances from a judge or jury, beyond reasonable doubt, in a court of law.

Combining image processing with rose diagrams objectively proved directional patterns recognised by naked eye could also be identified by computer software. The current forensic soil techniques utilising light microscopy, XRD and Scanning Electron Microscopy (Pelton 1995, 1998), could include image processing of trace soil patterns on clothing or other fabrics. The standardised objectivity achieved by combining these techniques, could not only assist forensic investigators understand the circumstances behind fabric making contact with a soil surface, but gain acceptance of this evidence beyond reasonable doubt in a court of law.

In future papers, the authors intend to use image processing software to analyse soil transfer patterns produced by different methods of transfer; including placing weighted fabric on a soil surface, as well as placing unweighted, randomly folded fabric on a soil surface for a set time.

7.6 How soil transfer patterns on clothing can assist police forensic officers to interpret soil evidence at a crime scene

At a crime scene, the tell-tale characteristics of whether trace soil was wet or dry when initially transferred to clothing, may be used to discover a ‘window of opportunity’ for when the soil was transferred. Using meteorological records corresponding to the date (and preferably time) of the crime, will help confirm trace soil evidence indicating soil was either wet or dry when initially transferred. If trace soil evidence seems to contradict the weather record, this may indicate that more than one location was used during the perpetration of the crime.

Other dry soil locations to consider would include a shed, a bus shelter or the inside of a vehicle. Other wet soil locations to consider would include soil surface areas with such bad drainage that water is unable to disperse; including areas paved with concrete or bricks, a riverbank, an open drain or irrigated paddock.

7.7 Loose trace soil evidence on clothing and the need to photographic soil transfer patterns *in situ*

From analyses of the eighty-four (84) soil transfer experiments undertaken, it soon became apparent that any loose soil would not remain *in situ* given the slightest movement of the clothing. Great care had to be taken to gently and quickly turn the tested bra upright so as to retain on the bra as much trace soil as possible. Digital photographs were then taken of the trace soil patterns *in situ* in the laboratory; followed by analysis using light microscopy. Just walking to the adjacent microscopy room would generate movement and loss of the loose soil particles.

Thus, the most pristine record of the trace soil transferred and soil transfer patterns produced, were detailed photographs taken using a basic digital camera at the testing site. Once morphological analyses were completed, the fabric surface was kept as level and stable as possible whilst removing the bra from the 2kg weight; before being stored horizontally in a plastic clip-lock bag. Despite all these efforts, once the fabric was removed from the weight, the intricate details of each soil transfer pattern were lost. Photos and photomicroscopy (whilst the 2kg weight was still in situ) then provided the only complete record of each transfer pattern obtained.

The delicate and impermanent nature of soil transfer patterns is dependent upon the soil texture, mineralogy and moisture content, which indicates that this type of forensic soil evidence will not survive the robust forensic testing of trace soil currently practised in most Police forensic laboratories.

The research conducted in this paper suggests that the circumstances behind soil making contact with fabric at a crime scene can be better understood by retaining a pristine method of the soil transference pattern recorded on the fabric. When soil evidence is scraped or shaken off clothing for XRD analysis, or the fabric is actually cut up, valuable soil evidence can be irreparably destroyed in the process. For this new method of soil forensic science to be of full use in a court of law, detailed photographs must be taken on site; preferably before the victim is moved or clothing removed.

8. CONCLUSIONS

Laboratory STEs used the transfer method of dragging weighted clothing (bras) across wet and dry RTBG soils. Digital photography taken immediately after each STE provided a pristine record of soil transference patterns on clothing fabric before each bra was removed from the stabilising 2kg weight.

In eighty-four (84) soil transfer experiments undertaken on seven anthropogenic soil samples from the RTBG, eight transference patterns were identified by the naked eye, and confirmed by light microscopy. However, only the first six patterns were seen with 100% consistency in soil transferred onto each bra.

Soils were further categorised by compositional characteristics into six different soil types, both natural and anthropogenic. Soil transfer patterns were then investigated to determine the most influential factors that characterised the composition of the source soil. Quantity of soil transferred was dependant primarily on soil type, moisture content, particle size and mineralogy. Dark organic loamy-sand textured soil provided the most abundant and easy to identify soil transfer patterns against the white bra fabric. Gravel-rich, matrix-poor and low-clay soils transferred the lowest quantity of soil to fabric.

Image processing software proved valuable in providing quantifiable graphical presentations on:
(i) quantity of soil transferred, (ii) percentage of individual soil objects and aggregates transferred and (iii) direction patterns. (iv) the ability to identify and compare Munsell colours.

Dragging was the only transfer method tested. Future experiments will need to be conducted using different transfer methods to identify whether any soil transfer patterns on fabric are so unique that they can be used to indisputably identify a specific transfer method.

XRD results indicated the mineral composition, which comprised thirteen (13) minerals of the bulk soil samples as being typical loamy to clayey Tasmanian soils. NDIR identified carbon levels as being up to 3.10% on the gravel-rich soils, 14% for the Rose garden bed and 22.8% in natural soil. No Sulfur-bearing species were identified.

Image processing software proved valuable in providing in-depth quantifiable numerical data on: (i) quantity of soil transferred, (ii) percentage of individual soil objects and aggregates transferred in relation to soil type and (iii) direction patterns.

There is tremendous potential for image processing analysis to accurately identify and compare the Munsell colour of trace soil evidence on fabric without requiring a spectrophotometer.

The most forensically valuable data involved a specific, reproducible Munsell soil colour range for trace soil evidence on fabric that shared the same location; as well as the directionality of soil transferred plotted as Rose diagrams.

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10. REFERENCES

Aardahl, K (2003) Evidential value of glitter particle trace evidence. National University.

Aardahl, K, Kirkowski, S, Blackledge, R (2005) A target glitter study. *Sci Justice* **45**, 7-12.

Allaby, A, Allaby, M (1999) 'A Dictionary of Earth Sciences.' (Oxford University Press:

ASRIS (Australian Soil Resources Information System) (2013) 'Maps, ASRIS (Australian Soil Resources Information System), [Database].' Available at www.asris.csiro.au [Accessed May 6].

Bull, P, Morgan, R, Sagovsky, A, Hughes, G (2006a) The transfer and persistence of trace particulates: Experimental studies using clothing fabrics. *Sci Justice* **46**, 185-195.

Bull, P, Parker, A, Morgan, R (2006b) The forensic analysis of soils and sediment taken from the cast of a footprint. *Forensic Sci Int* **162**, 6-12.

Chung, F (1975) Quantitative Interpretation of X-Ray Diffraction patterns of mixtures. III. Simultaneous determination of a set of reference Intensities. *J. Applied Crystallography* **8**, 17-19.

Fitzpatrick, R (2008) Nature, distribution and origin of soil materials in the forensic comparison of soils. In 'Soil analysis in forensic taphonomy: chemical and biological effects of buried human remains.' (Eds M Tibbett, D Carter.) pp. 1-28. (CRC Press: Doca Raton, FL)

Fitzpatrick, R, 2011. The value of soil in criminal investigations. Soil Forensics profile Newsletter. The Australian Society for Soil Science Inc, Victoria. 5-6.

Fitzpatrick, R, 2012. Forensic earth science: Getting the dirt on crime. e-Science. Faculty of Sciences, The University of Adelaide, Adelaide. 5-11.

Fitzpatrick, R (2013a) Demands on soil calssification and soil survey strategies: Special-purpose soil classification systems for local practical use. In 'Developments in soil classiification, land use planning and policy implications: Innovative thinking of soil inventory for land use planning and management of land resources.' (Eds S Shahid, F Taha, M Abdelfattah.) pp. 51-83. (Springer Science+Business Media Dordrecht: Netherlands)

Fitzpatrick, R (2013b) Soil: Forensic Analysis. In 'Wiley Encyclopedia of Forensic Science.' (Eds A Jamieson, A Moenssens.) Chichester, West Sussex)

Fitzpatrick, R, Raven, M (2012a) How Pedology and mineralogy helped solve a double murder case: Using forensics to inspire future generations of soil scientists. *Soil Horizons* **53**, 14-29.

Fitzpatrick, R, Raven, M (2012b) The State of Western Australia v. Lloyd Patrick Rayney Trail: Request for supplementary statement relating to extraction of particulate material from bra. Centre for Australian Forensic Soil Science.

Fitzpatrick, R, Raven, M (2013) Soils. In 'Encyclopedia of Forensic Sciences.' (Eds J Siegel, P Saukko.) pp. 206-212. (Academic Press: Waltham)

Fitzpatrick, R, Raven, M, Forrester, S (2009) A systematic approach to soil forensics: Criminal case studies involving transference from crime scene to forensic evidence. In 'Criminal and Environmental Soil Forensics.' (Eds K Ritz, L Dawson, D Miller.) pp. 105-127. (Springer Netherlands: Netherlands)

Fitzpatrick, R, Raven, M, Self, P (2011) Detailed mineralogical characterization of small brick and soil fragments (<0.5mm diameter) by Synchrotron X-ray diffraction analyses for further forensic comparisons relating to Operation Dargan.

Fitzpatrick, R, Raven, M, Self, P (2012a) Sampling and analyses of 18 soil samples relating to a murder investigation by WA Police named Operation ONXY Final Report. Centre for Australian Forensic Soil Science, Adelaide.

Fitzpatrick, R, Raven, M, Self, P (2012b) Soil as significant evidence in a sexual assault case. In 'Proceedings of the 5th Joint Australian and New Zealand Soil Science Conference: Soil solutions for diverse landscapes.' (Eds L Burkitt, L Sparrow.) (Australian Society of Soil Science Inc: Hobart)

Fitzpatrick, R, Raven, M, Self, P RJ Gilkes (Ed.) (2014) 'Clay mineralogy as significant evidence in 4 murder investigations involving a wide range of earth materials from Perth, Adelaide, Melbourne and Sydney, Proceedings 23rd Australian Clay Minerals Society Conference.' Perth, 3-5 February, 2014. (Australian Clay Minerals Society

Galbraith, J (2012) Rationale for proposed changes to Soil Taxonomy concerning the International Committee for Anthropogenic Soils. *Soil Horizons* **March-April**, 2-6.

Hergt, J, Chappell, B, McCulloch, M, McDougall, I, Chivas, A (1989) Geochemical and isotopic constraints on the origin of the Jurassic Dolerites of Tasmania. *Journal of Petrology* **30**, 841-883.

Hicks, T, Vanina, R, Margot, P (1996) Transfer and persistence of glass fragments on garments. *Sci Justice* **36**, 101-107.

Holcombe, R (2011) 'GEOrient.' (School of Earth Sciences, University of Queensland: Queensland, Australia)

Isbell, R (2002) 'The Australian soil classification.' (CSIRO Publishing: Melbourne)

Klug, H, Alexander, L (1954) 'X-Ray diffraction procedures for polycrystalline and amorphous materials.' (Wiley: New York)

Leaman, D, 1976. Hobart. Geological Atlas 1:50 000 series. Geological Survey Tasmania, Tasmania, Australia. Sheet 82 (8312S).

Locard, E (1930) Analyses of dust traces parts I, II and III. *American Journal of Police Science.* **1**, 276-98, 401-18, 496-514.

Maniar, P, Cooke, G (1987) Modal analyses of granitoids by qualitative X-ray diffraction. *American Mineralogist* **72**, 433-437.

Martin, B, 2012a. Judgement summary: The State of Western Australia v. Rayney. [No 3]. WASC, 404 (INS 83 of 2011): 1-13.

Martin, B, 2012b. The State of Western Australia v. Rayney. [No 3]. WASC, 404: 1-369.

McDermott, S (2013) Trace evidence: Transfer, persistence adn value. In 'Encyclopedia of forensic sciences.' (Ed. J Siegel.) (Academic press: Waltham)

McDonald, R, Isbell, R (2009) 'Soil profile.' (CSIRO Publishing: Melbourne)

McKenzie, N, Jacquier, D, Isbell, R, Brown, K (2004) 'Australian soils and landscapes: an illustrated compendium.' (CSIRO Publishing: Australia)

Morgan, R, Bull, P (2007) Forensic geosciences and crime detection: Identification, interpretation and presentation in forensic geoscience. *Minerva Medicolegale* **127**, 73-89.

Morgan, R, Cohen, J, McGookin, I, Murly-Gotto, J, O'Connor, R, Muress, S, Freudiger-Bonzon, J, Bull, P (2009) The relevance of the evolution of experimental studies for the interpretation and evaluation of some trace physical evidence. *Sci Justice* **49**, 277-285.

Munsell_Color_Company (2009) 'Munsell soil color book.' (Munsell Color X-rite: Michigan)

Murray, K, Fitzpatrick, R, Doyle, R (2012) Development of soil forensic methods databases from targeted locations in Tasmania to assist police. In 'Proceedings of the 5th Joint Australian and New Zealand Soil Science Conference: Soil solutions for diverse landscapes.' (Eds L Burkitt, L Sparrow.) pp. 661. (Australian Society of Soil Science Inc: Hobart)

Murray, R (2011) 'Evidence from the earth: Forensic geology and criminal investigation.' (Mountain Press Publishing: Missoula, MT)

Pelton, W (1995) Distinguishing the cause of textile fibre damage using the scanning electron microscope (SEM). *J Forensic Sci* **40**, 874–882.

Pelton, W (1998) Use of SEM in textile forensic work. In 'Atlas of Fibre Fracture and Damage to Textiles.' (Eds J Hearle, B Lomas, W Cooke.) pp. 406–415. (Woodhead Publishing Limited: Cambridge)

Pounds, C, Smalldon, K (1975a) The transfer of fibres between clothing materials during simulated contacts and their persistence during wear. III: A preliminary investigation of the mechanisms involved. *Journal Forensic Science Soc.* **15**, 197-207.

Pounds, C, Smalldon, K (1975b) The transfer of fibres between clothing materials during simulated contacts and their persistence during wear. Part I: fibre transference. *Journal Forensic Sci Society* **15**, 17-27.

Pounds, C, Smalldon, K (1975c) The transfer of fibres between clothing materials during simulated contacts and their persistence during wear. Part II: fibre persistence. *Journal Forensic Sci Soc.* **15**, 29-37.

Pye, K (2007) 'Geological and soil evidence: Forensic applications.' (CRC Press: Boca Raton, Florida)

Reid, D, 2012. Unpublished statement from RTBG Horticultural Coordinator, regarding the establishment of the gardens and the heritage-listed convict-built Eardley Wilmot brick wall.

Roux, C, Robertson, J (2013) Fibers. In 'Encyclopedia of forensic sciences.' (Ed. J Siegel.) (Academic Press: Waltham)

Ruffell, A, McKinley, J (2008) 'Geoforensics.' (John Wiley & Sons, Ltd.: Chichester)

Rumney, P (2006) False allegations of rape. *Cambridge Law Journal* **65**, 128-158.

Schoeneberger, P, Wysocki, D, Benham, E, Broderson, W (2002) 'Field book for describing and sampling soils.' (USDA-NRCS, National Soil Survey Center: Lincoln, NE)

Soil_Survey_Staff (2014) 'Keys to Soil Taxonomy.' (United States Department of Agriculture, Natural Resources Conservation Service: Washington)

Sugita, R, Marumo, Y (1996) Validity of color examination for forensic soil identification. *Forensic Sci International* **83**, 201-210.

Sun, S, Nesbitt, R (1978) Geochemical regularities and genetic significance of ophiolitic basalts. *Geology* **6**, 689-693.

Taupin, J (2000) Clothing damage analysis and the phenomenon of the false sexual assault. *Journal of Forensic Sciences* **45**, 568-572.

Weaver, C (Ed.) (1990) 'Clays, muds and shales.' In 'Developments in sedimentology'. (Elsevier: Amsterdam)

World_Reference_Base (2014) World Reference Base (WRB) for Soil Resources 2014: A framework for international classification, correlation and communication. Food and Agriculture Organization of the United Nations Rome, Rome.

11. Appendix 1 – Soil Transference patterns identified in STEs using the transfer method of dragging

SOIL TRANSFERENCE PATTERNS:			Bra-strap &/or cup		Bra-strap only					Cup only
Soil Sample no.	Location Description	Run	Soil trails strap/cup	Elongated fragments aligned	Strap edge soil build-up	Buckle soil build-up	Fluffy seam soil build-up	Dry: Dusting of soil evenly over buckle	Wet: buckle clean &/or muddy clumps	Cup seam soil build-up
110.5.1	Rose	Dry 1	√	√	√	√	√	√	N/A	√
	Garden	Dry 2	√	Strap only	√	√		√	N/A	√
	Path	Dry 3	√	√	√	√	√	√	N/A	√
	(<2mm	Wet 1	√		√	√		N/A	√	√
	Texture	Wet 2	√	√	√	√		N/A	√	√
	= LS)	Wet 3	√	√	√	√		N/A	√	√
% occurrence of patterns		Dry	100%	83.3%	100%	100%	66.6%	100%	N/A	100%
in 110.5.1		Wet	100%	66.6%	100%	100%	0%	N/A	100%	100%
110.6.1	Rose	Dry 1	√	√	√	√	√	√	N/A	√
	Garden	Dry 2	√	√	√	√	√	√	N/A	√
	Path	Dry 3	√	√	√	√		√	N/A	√
	near wall	Wet 1	√		√	√		N/A	√	√
	(<2mm	Wet 2	√	√	√	√	√	N/A	√	√
	Tex = S)	Wet 3	√	√	√	√		N/A	√	√
% occurrence of patterns		Dry	100%	100%	100%	100%	66.6%	100%	N/A	100%
in 110.6.1		Wet	100%	66.6%	100%	100%	33%	N/A	100%	100%
110.6.2	Brick	Dry 1	√		√	√		√	N/A	√
	fragments	Dry 2	√	Cup only	√	√	√	√	N/A	√
		Dry 3	√		√	√		√	N/A	√
	(<2mm	Wet 1	√	Cup only	√	√		N/A	√	√
	Texture	Wet 2	√	√	√	√		N/A	√	√
	= Brick)	Wet 3	√		√	√		N/A	√	√
% occurrence of patterns		Dry	100%	16.6%	100%	100%	33.3%	100%	N/A	100%
in 110.6.2		Wet	100%	50%	100%	100%	0%	N/A	100%	100%
110.7.1	Rose	Dry 1	√	√	√	√	√	√	N/A	√
	Garden	Dry 2	√	√	√	√		√	N/A	√
	Bed	Dry 3	√	√	√	√		√	N/A	√
	(<2mm	Wet 1	√	√	√	√		N/A	√	√
	Texture	Wet 2	√	√	√	√	√	N/A	√	√
	= LS)	Wet 3	√	√	√	√		N/A	√	√
% occurrence of patterns		Dry	100%	100%	100%	100%	33.30%	100%	N/A	100%
in 110.7.1		Wet	100%	100%	100%	100%	33.30%	N/A	100%	100%
110.8.1	Japanese	Dry 1	√	Cup only	√	√		√	N/A	√
	Garden	Dry 2	√		√	√	√	√	N/A	√
	Path	Dry 3	√		√	√		√	N/A	√
	(<2mm	Wet 1	√	Strap only	√	√		N/A	√	√
	Texture	Wet 2	√		√	√		N/A	√	√
	= LS)	Wet 3	√	Strap only	√	√		N/A	√	√
% occurrence of patterns		Dry	100%	16.6%	100%	100%	33.3%	100%	N/A	100%
in 110.8.1		Wet	100%	33.3%	100%	100%	0%	N/A	100%	100%

Appendix 1 continued…

SOIL TRANSFERENCE PATTERNS:			Bra-strap &/or cup		Bra-strap only					Cup only
Soil Sample no.	Location Description	Run	Soil trails strap/cup	Elongated fragments aligned	Strap edge soil build-up	Buckle soil build-up	Fluffy seam soil build-up	Dry: Dusting of soil evenly over buckle	Wet: buckle clean &/or muddy clumps	Cup seam soil build-up
110.9.1	Natural Soil (Leaf litter)	Dry 1	√		√	√		√	N/A	√
		Dry 2	√	√	√	√		√	N/A	√
		Dry 3	√		√	√		√	N/A	√
		Wet 1	√	Strap only	√	√		N/A	√	√
		Wet 2	√		√	√	√	N/A	√	√
		Wet 3	√	√	√	√	√	N/A	√	√
% occurrence of patterns in 110.9.1		Dry	100%	33.3%	100%	100%	0%	100%	N/A	100%
		Wet	100%	50%	100%	100%	66.6%	N/A	100%	100%
110.9.2	Natural Soil (<2mm Texture = LS)	Dry 1	√	√	√	√	√	√	N/A	√
		Dry 2	√	√	√	√	√	√	N/A	√
		Dry 3	√	√	√	√	√	√	N/A	√
		Wet 1	√	√	√	√		N/A	√	√
		Wet 2	√	√	√	√	√	N/A	√	√
		Wet 3	√	√	√	√	√	N/A	√	√
% occurrence of patterns in 110.9.2		Dry	100%	100%	100%	100%	100%	100%	N/A	100%
		Wet	100%	100%	100%	100%	100%	N/A	100%	100%
TOTAL AVERAGE % occurrence of patterns		Dry	100%	64.2%	100%	100%	47.6%	100%	N/A	100%
		Wet	100%	66.6%	100%	100%	28.6%	N/A	100%	100%

KEY:

√ = pattern occurs on both bra-strap and cup

N/A = Not applicable

Dry run: soil has been air-dried in soil tray for a month

Wet run: soil has been sprayed with distilled water until colour has changed and surface is wet and glistening.

Soil trails strap/cup: Soil trail appears as a brownish streak parallel to direction of movement; or as a trail of fine (<2mm) rounded particles, aligned parallel with the direction of movement

Elongate fragments aligned: One or more elongate particles are aligned with the direction of movement

Strap edge soil build-up: Soil has been transferred along either edge of the bra-strap

Buckle soil build-up: Soil has transferred over the top fabric on buckle and is absent directly behind back metal buckle-bar

Fluffy seam soil build-up: Soil accumulated on fluffy raised seam at top/bottom of bra-strap in a greater quantity/mm Than seen on smoothly-woven strap

Dry: Dusting soil evenly on buckle: During a dry run, soil has been dusted evenly over entire metal buckle

Wet: buckle clean &/or muddy clumps: During a wet run, the buckle is clean, except for individual wet muddy clumps of soil (2mm-5mm)

Cup seam soil build-up: Soil has accumulated across raised cup seam; and behind this seam, there is less soil than in front.

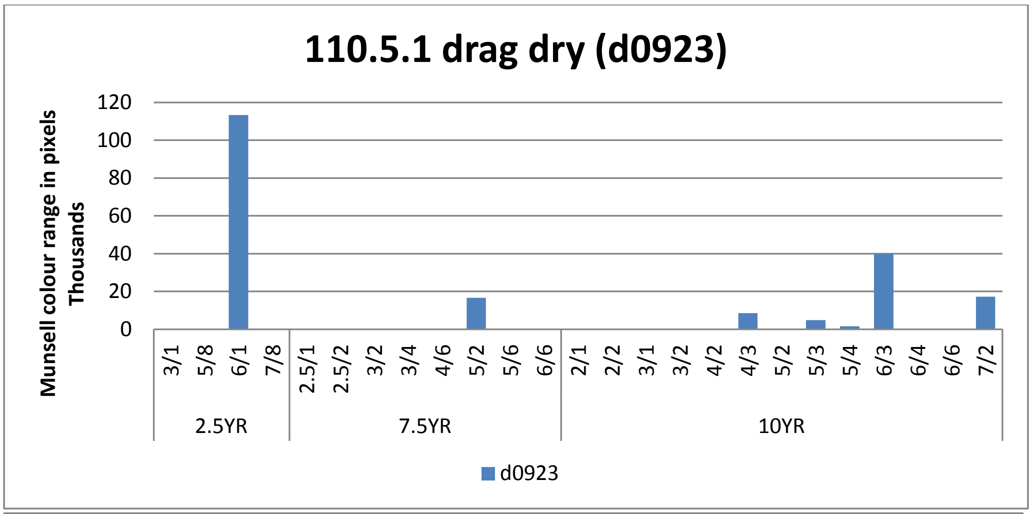
12. APPENDIX 2 – Image processing numerical data showing Munsell colour range of soil samples shown as area in pixels

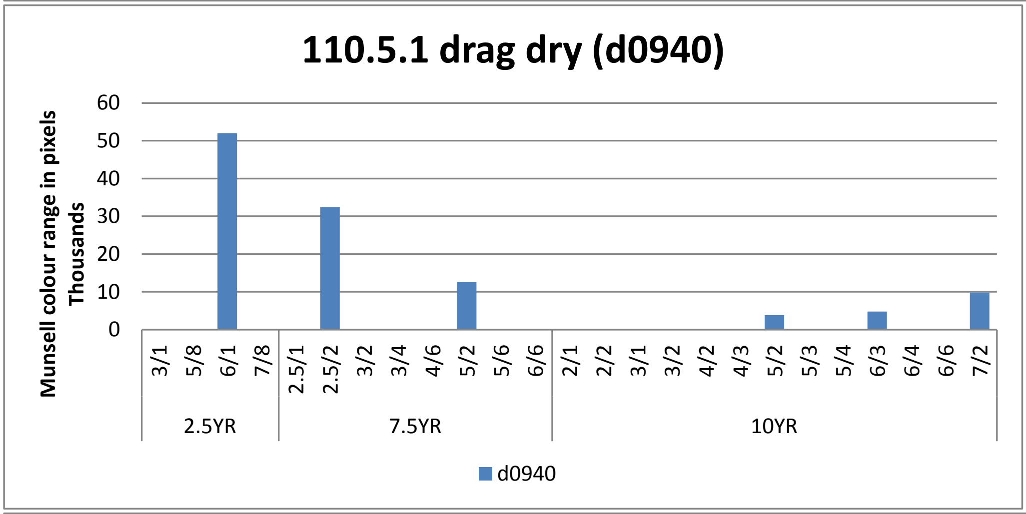
Soil Sample no.	Soil Transfer Method	Soil moisture content	Digital Photo no.	Munsell colour range (Area of each colour in pixels)											
				2.5YR				7.5YR							
				3/1	5/8	6/1	7/8	2.5/1	2.5/2	3/2	3/4	4/6	5/2	5/6	6/6
110.5.1	drag	dry	d0923	0	0	113331	0	0	0	0	0	0	16651	0	0
110.5.1	drag	dry	d0940	0	0	52037	0	0	32448	0	0	0	12597	0	0
110.5.1	drag	dry	d0951	0	0	38887	0	0	5529	0	0	0	4904	0	0
110.5.1	drag	wet	d0960	0	0	65695	0	0	25942	0	0	0	5576	0	0
110.5.1	drag	wet	d0975	0	0	99924	0	0	25270	0	17954	8807	8261	0	0
110.5.1	drag	wet	d0988	0	0	102981	0	0	46754	0	0	6223	23886	0	0
110.6.1	drag	dry	d1146	32	0	43993	0	0	107462	0	0	0	6899	0	0
110.6.1	drag	dry	d1172	0	125	79130	0	0	5010	0	0	0	7656	0	0
110.6.1	drag	dry	d1193	0	0	47210	0	0	45549	0	16994	0	2969	0	0
110.6.1	drag	wet	d1220	0	0	85460	0	0	0	0	0	16201	15990	0	0
110.6.1	drag	wet	d1241	0	0	68460	0	0	5688	0	19828	14486	23145	0	0
110.6.1	drag	wet	d1260	0	0	84324	0	0	20232	0	0	0	7040	0	0
110.6.2	drag	dry	d1840	0	263	121548	241	0	22703	0	0	5074	0	0	41318
110.6.2	drag	dry	d1865	0	263	94715	0	0	18640	0	0	0	5234	0	10642
110.6.2	drag	dry	d1889	0	0	62224	27	0	0	0	0	0	0	0	0
110.6.2	drag	wet	d1912	0	0	88272	40	0	11324	0	0	2324	0	9609	0
110.6.2	drag	wet	d1934	0	151	124520	956	0	53400	0	0	0	4812	0	8766
110.6.2	drag	wet	d1958	0	239	115282	696	0	57974	0	0	0	17400	0	20950
110.7.1	drag	dry	d1280	0	0	80078	0	0	2474518	0	365845	3429	668399	0	0
110.7.1	drag	dry	d1298	8	0	114874	34	0	1086558	172143	464924	5129	283960	0	0
110.7.1	drag	dry	d1323	1	0	71086	0	2298	736083	202271	777067	10450	296127	0	11068
110.7.1	drag	wet	d1346	0	0	88409	0	1935	254862	195497	457550	0	59681	0	0
110.7.1	drag	wet	d1368	0	0	77759	0	11322	325412	756886	2038868	29978	161194	0	0
110.7.1	drag	wet	d1388	0	0	87639	0	2322	25364	762162	1997056	42271	84291	0	0
110.8.1	drag	dry	d1413	0	0	52053	0	0	24332	0	42000	2353	2424	0	0
110.8.1	drag	dry	d1430	0	0	47770	0	0	40413	0	17062	0	5197	0	0
110.8.1	drag	dry	d1450	0	0	35087	0	0	0	0	0	0	0	0	0
110.8.1	drag	wet	d1468	0	0	36312	0	0	0	0	0	0	0	0	0
110.8.1	drag	wet	d1488	0	0	22148	0	0	43766	0	0	0	12858	0	0
110.8.1	drag	wet	d1509	0	0	106176	0	0	81552	0	0	0	15607	0	0
110.9.1	drag	dry	d1725	0	0	75649	0	0	135416	0	54153	0	24213	0	0
110.9.1	drag	dry	d1747	0	0	37250	0	0	137791	0	0	0	11225	0	0
110.9.1	drag	dry	d1764	0	0	31107	52	0	69017	25883	33999	0	10610	0	0
110.9.1	drag	wet	d1780	0	121	21907	61	0	86930	25385	0	34629	5531	4913	0
110.9.1	drag	wet	d1798	0	0	53381	0	0	39241	0	0	0	13600	0	0
110.9.1	drag	wet	d1814	0	0	36713	0	0	101949	0	41138	0	21108	0	0
110.9.2	drag	dry	d1532	126	122	18569	0	3956	471883	422358	875503	0	170797	0	0
110.9.2	drag	dry	d1563	0	0	129008	0	0	338745	71727	488347	2029	67421	0	0
110.9.2	drag	dry	d1600	0	0	109028	0	0	339312	123250	644913	1905	97453	0	0
110.9.2	drag	wet	d1631	47	0	159346	0	17565	1231489	1092405	2521171	0	318993	0	0
110.9.2	drag	wet	d1664	0	0	145622	0	28404	583207	1808232	2896262	9058	345897	0	0
110.9.2	drag	wet	d1697	0	0	172117	0	10325	284132	1194127	3138044	1614	409613	0	0

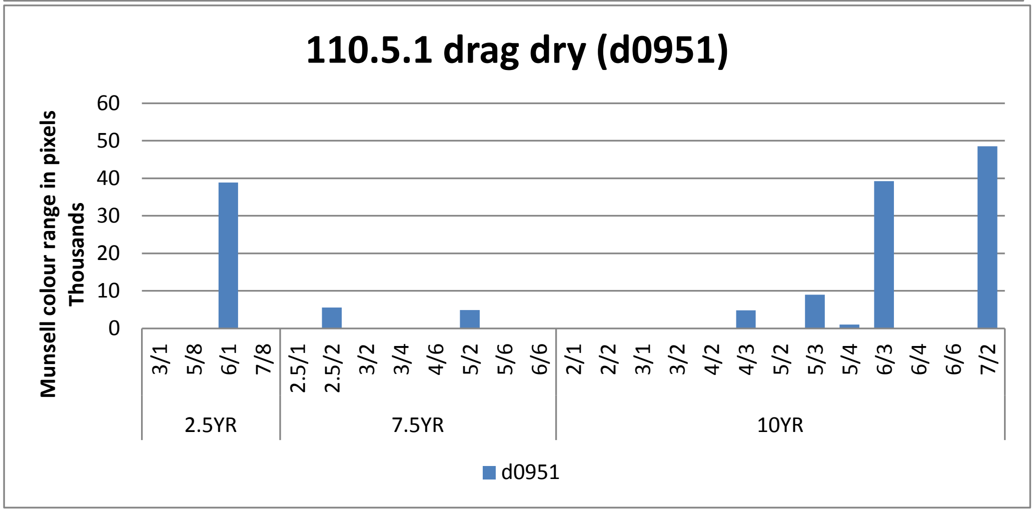
Appendix 2 continued…

Soil Sample no.	Soil Transfer Method	Soil moisture content	Digital Photo no.	Munsell colour range (Area of each colour in pixels)												
				10YR												
				2/1	2/2	3/1	3/2	4/2	4/3	5/2	5/3	5/4	6/3	6/4	6/6	7/2
110.5.1	drag	dry	d0923	0	0	0	0	0	8594	0	4871	1627	39965	0	0	17304
110.5.1	drag	dry	d0940	0	0	0	0	0	0	3841	0	0	4815	0	0	9821
110.5.1	drag	dry	d0951	0	0	0	0	0	4831	0	9009	1035	39216	0	0	48534
110.5.1	drag	wet	d0960	0	0	0	0	0	0	0	4497	2791	63258	0	0	9512
110.5.1	drag	wet	d0975	0	0	0	0	0	0	7999	18106	5807	84337	16872	0	123635
110.5.1	drag	wet	d0988	0	0	0	0	0	0	0	12735	1584	74571	812	0	108605
110.6.1	drag	dry	d1146	0	0	0	0	0	0	0	3062	0	4835	0	0	0
110.6.1	drag	dry	d1172	0	0	0	0	0	3260	0	0	0	17930	0	0	5596
110.6.1	drag	dry	d1193	0	0	0	0	0	0	0	0	0	8737	0	0	4658
110.6.1	drag	wet	d1220	0	0	0	0	3188	1783	0	32993	8313	113309	6462	0	122005
110.6.1	drag	wet	d1241	0	0	0	0	0	0	0	17281	10333	128533	898	0	98707
110.6.1	drag	wet	d1260	0	0	0	0	0	0	0	9668	4356	21074	0	0	36990
110.6.2	drag	dry	d1840	0	0	0	0	0	0	0	6549	0	26724	0	0	24653
110.6.2	drag	dry	d1865	0	0	0	0	0	0	0	0	0	33694	0	0	14488
110.6.2	drag	dry	d1889	0	0	0	0	0	0	0	0	0	0	0	0	21427
110.6.2	drag	wet	d1912	0	0	0	0	0	0	0	0	0	23072	3213	0	36802
110.6.2	drag	wet	d1934	0	0	0	0	0	0	0	0	0	8815	0	0	35590
110.6.2	drag	wet	d1958	0	0	0	0	0	0	3641	0	0	25274	0	0	14064
110.7.1	drag	dry	d1280	0	0	0	0	215155	29892	61336	17698	1681	170577	0	0	47076
110.7.1	drag	dry	d1298	0	0	0	0	150695	40825	33776	38327	3750	177262	1656	0	106122
110.7.1	drag	dry	d1323	0	0	0	0	121451	55321	65694	21543	7876	233031	8183	0	163613
110.7.1	drag	wet	d1346	0	0	0	0	23446	18575	13111	6109	604	54799	0	0	20694
110.7.1	drag	wet	d1368	0	0	0	0	57862	130192	29053	104840	6854	370562	0	0	204645
110.7.1	drag	wet	d1388	0	0	0	0	7009	140584	8072	145026	26655	527096	3811	0	579963
110.8.1	drag	dry	d1413	0	0	0	0	3166	4573	0	0	0	9106	0	0	0
110.8.1	drag	dry	d1430	0	0	0	0	0	0	0	0	0	18860	0	0	20871
110.8.1	drag	dry	d1450	0	0	0	0	0	0	0	0	0	0	0	0	6083
110.8.1	drag	wet	d1468	0	0	0	0	0	0	0	0	0	0	0	0	6490
110.8.1	drag	wet	d1488	0	0	0	0	2787	0	7855	0	827	5028	0	0	0
110.8.1	drag	wet	d1509	0	0	0	0	0	0	3367	3310	0	10969	0	0	15361
110.9.1	drag	dry	d1725	0	0	0	0	0	1576	14968	7714	0	54195	0	0	49054
110.9.1	drag	dry	d1747	0	0	0	0	5669	5100	0	2820	1593	39016	0	0	32206
110.9.1	drag	dry	d1764	0	0	0	0	0	1398	3742	3994	1070	18416	4176	0	25480
110.9.1	drag	wet	d1780	0	0	0	0	3995	1353	3538	0	0	25784	0	0	13954
110.9.1	drag	wet	d1798	0	0	0	0	4235	1425	4162	0	0	65105	0	0	111153
110.9.1	drag	wet	d1814	0	0	0	0	5365	4042	10235	5478	0	47233	0	0	38878
110.9.2	drag	dry	d1532	0	0	0	0	118188	26494	51720	3523	0	30505	0	0	18937
110.9.2	drag	dry	d1563	0	0	0	0	35341	15433	50263	6043	575	78304	0	0	29579
110.9.2	drag	dry	d1600	0	0	0	0	40944	10172	67638	25990	2056	194771	0	0	117478
110.9.2	drag	wet	d1631	0	0	0	0	251492	117341	110215	46498	2582	373810	0	0	119050
110.9.2	drag	wet	d1664	0	0	0	0	173640	217797	48211	65892	14799	406602	0	0	204336
110.9.2	drag	wet	d1697	0	0	0	12385	119736	286754	39344	193941	21102	545406	0	0	391694

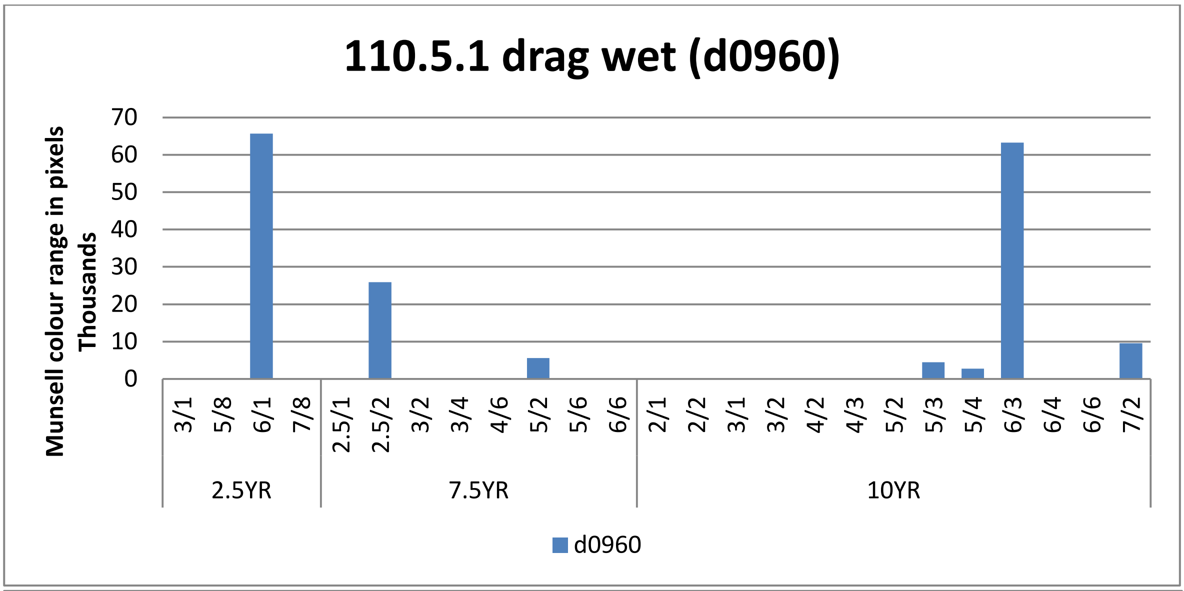
13. Appendix 3 – Graphs of Munsell colour range identified by image processing software for the digital photo taken of each soil sample

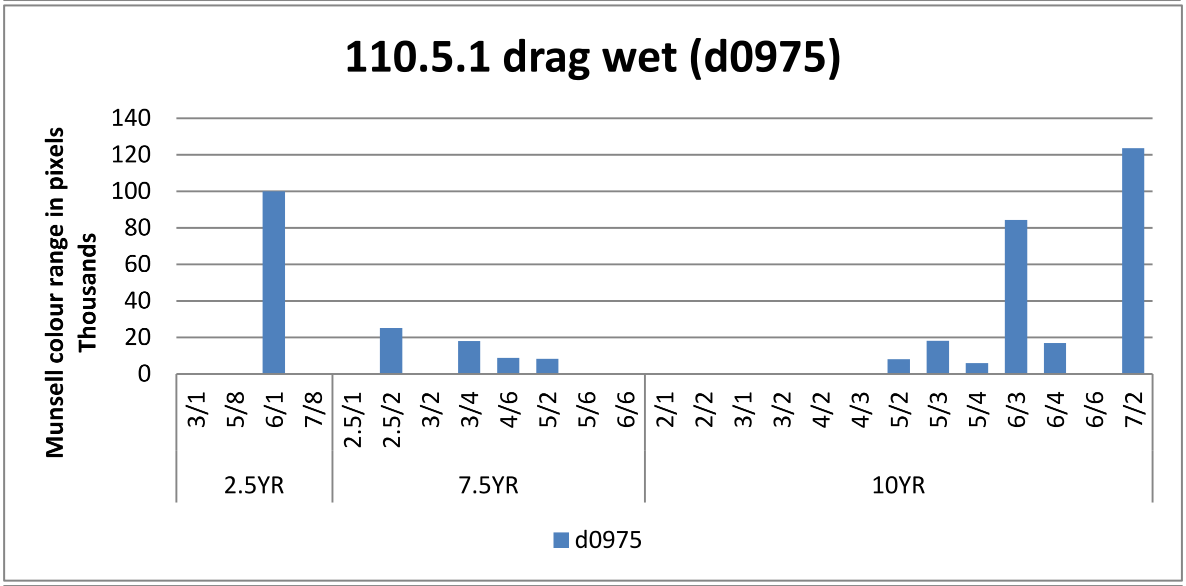


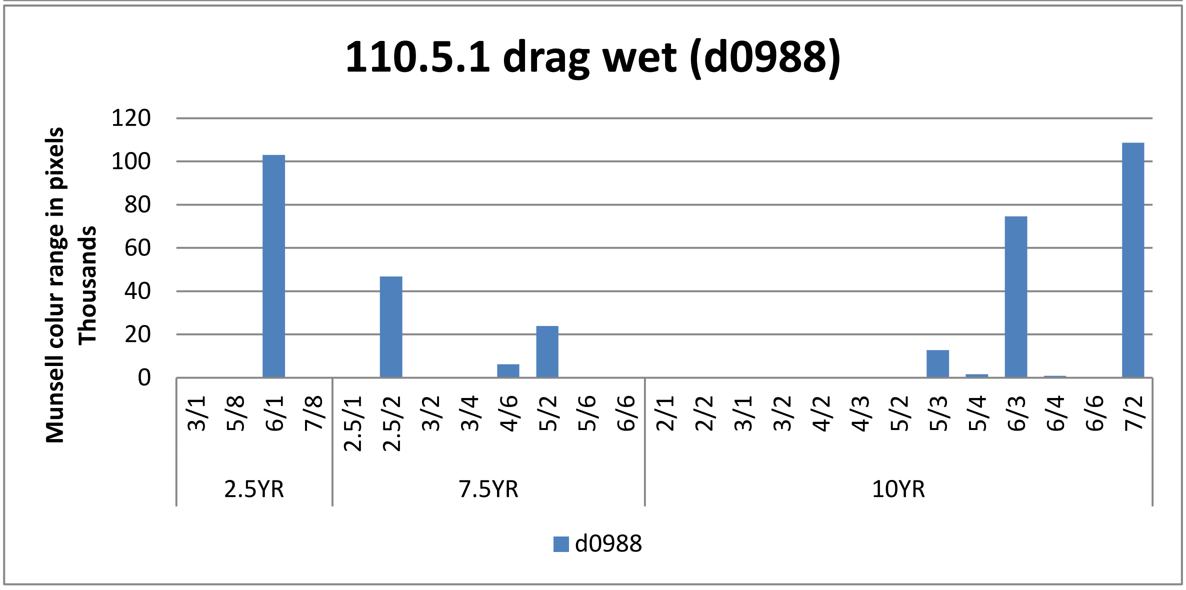




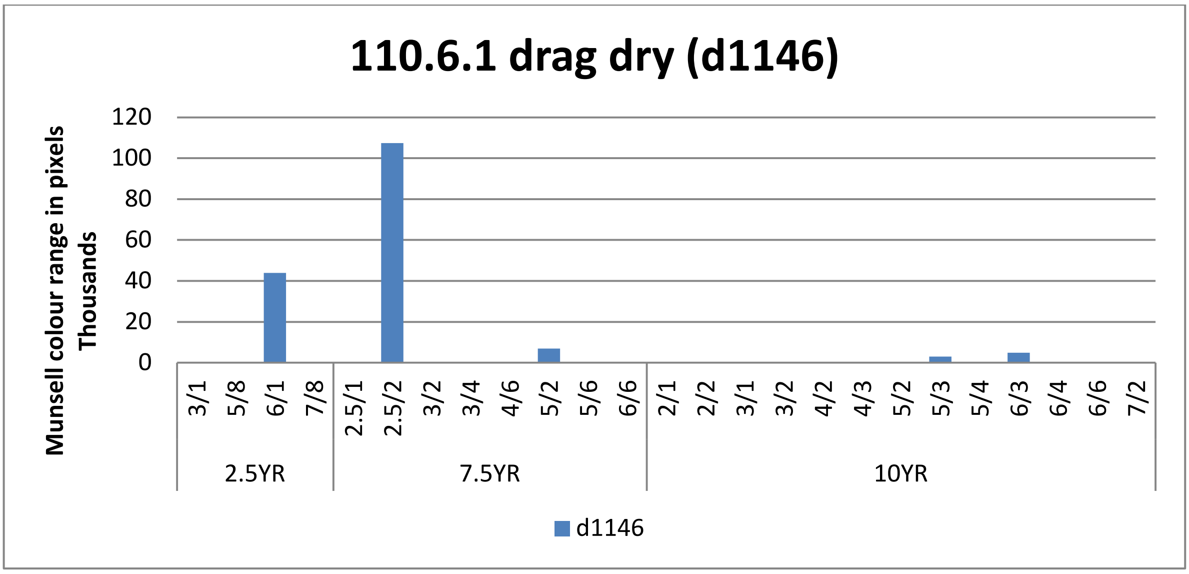
Appendix 3 continued...

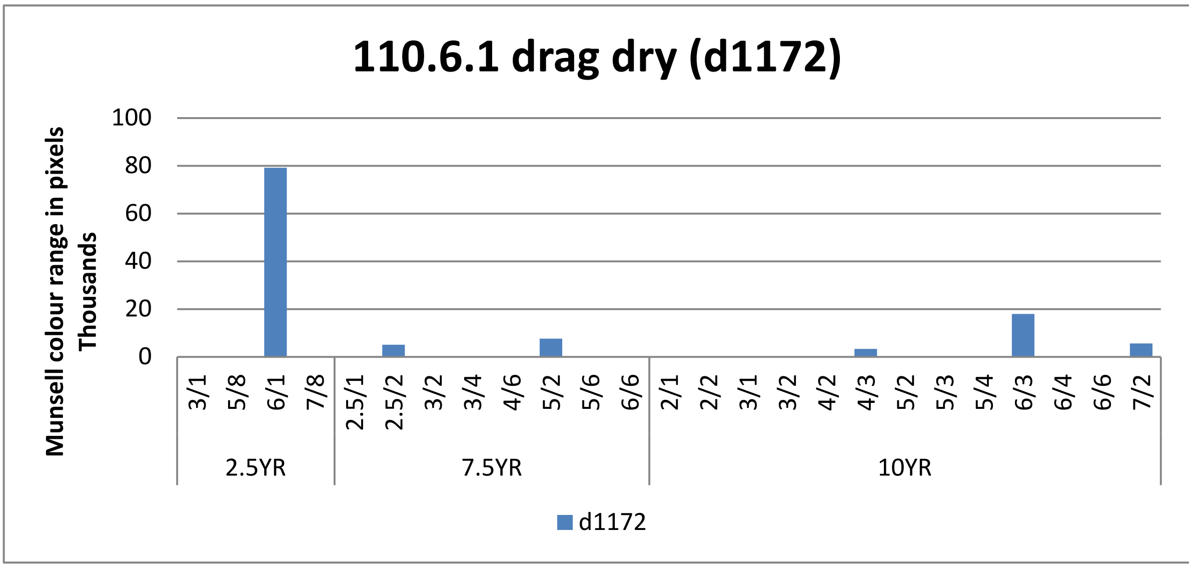


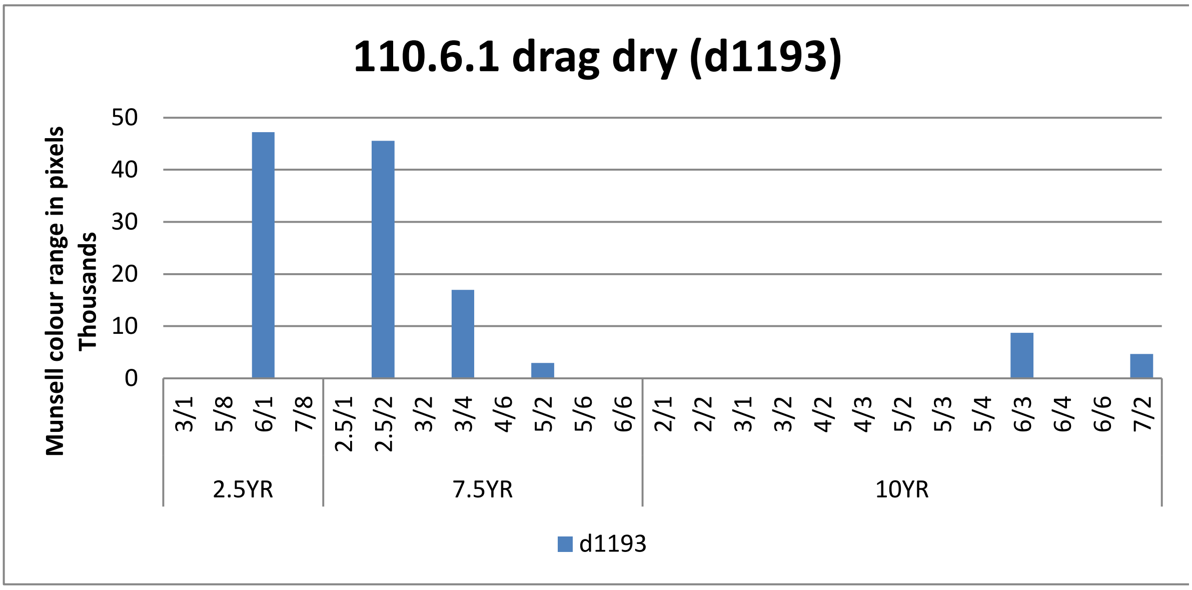




Appendix 3 continued...







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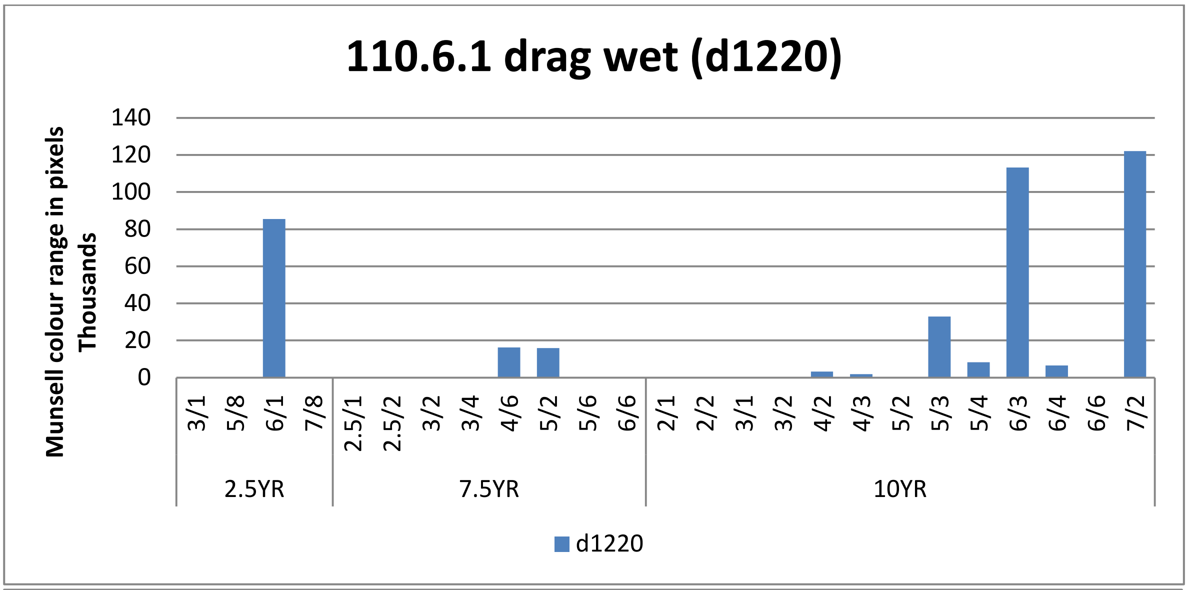

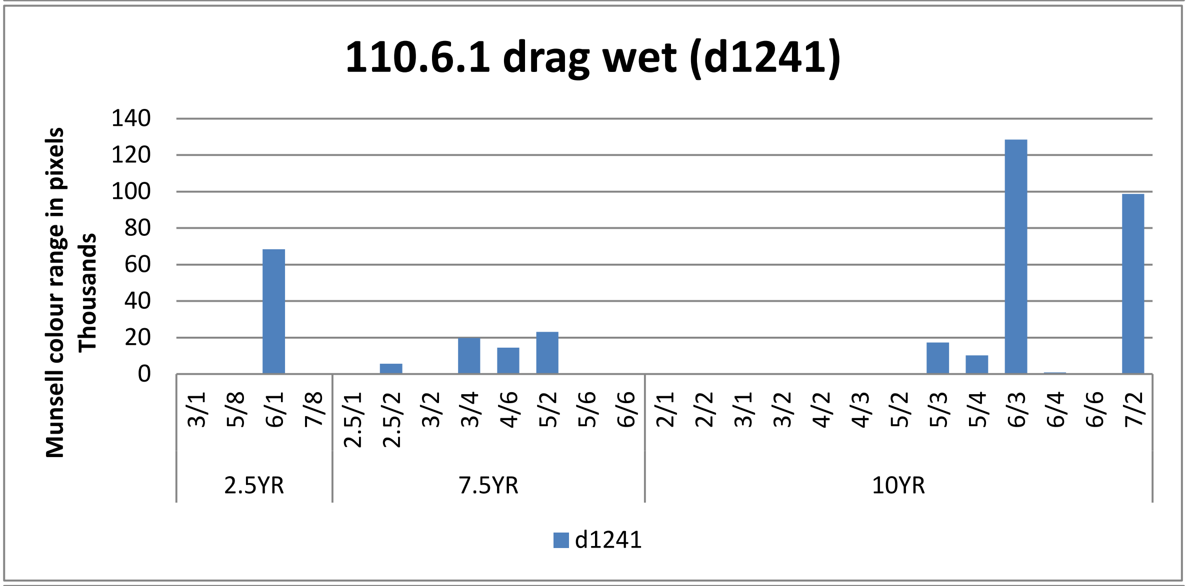

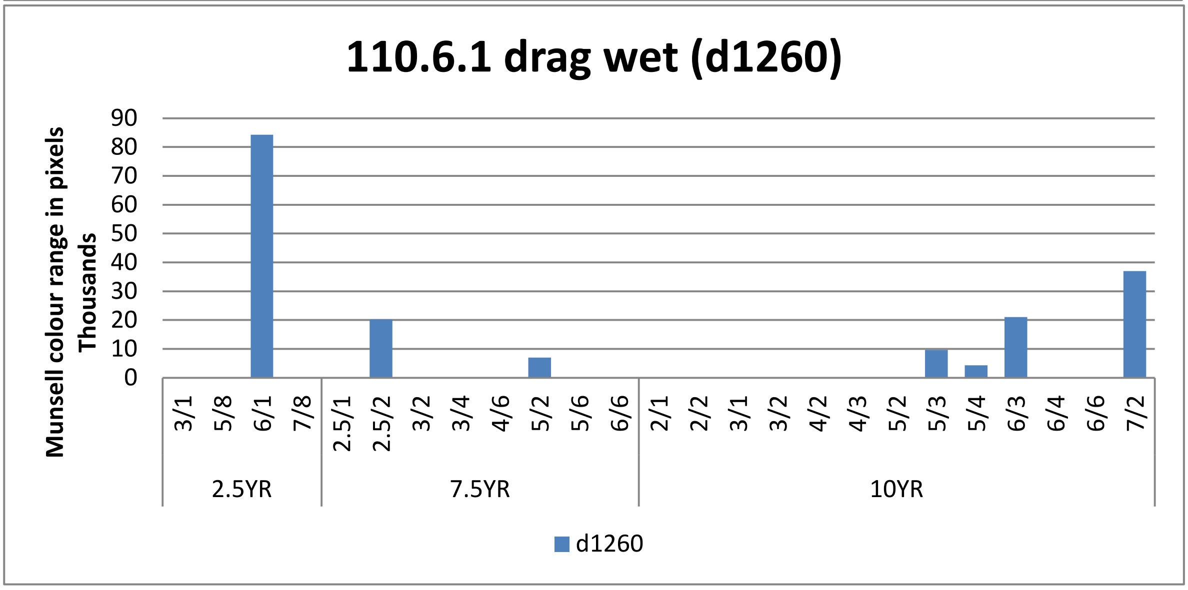

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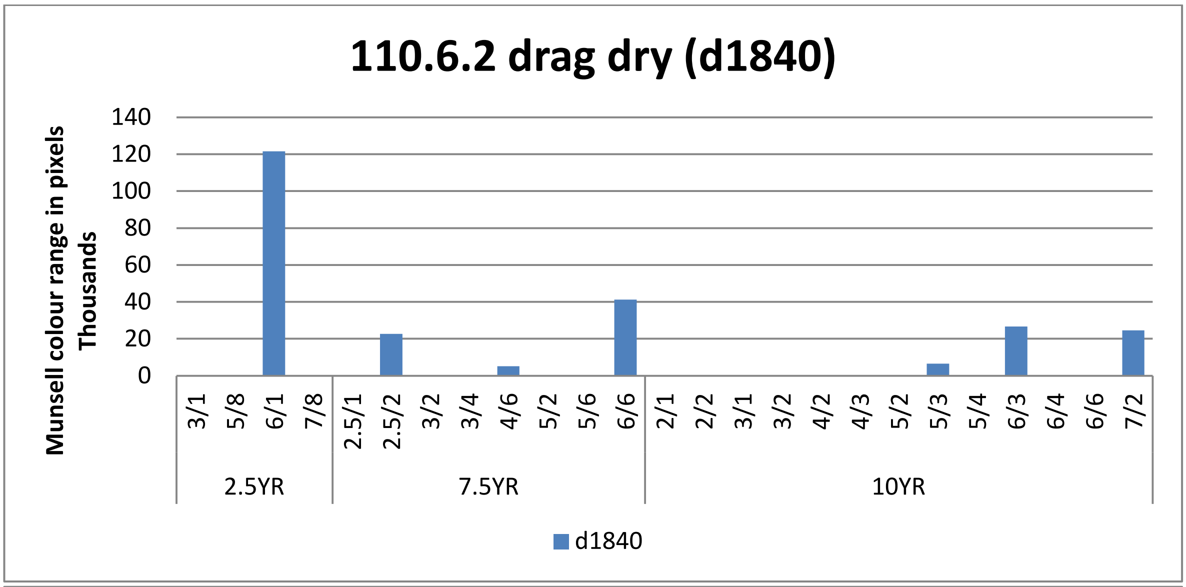
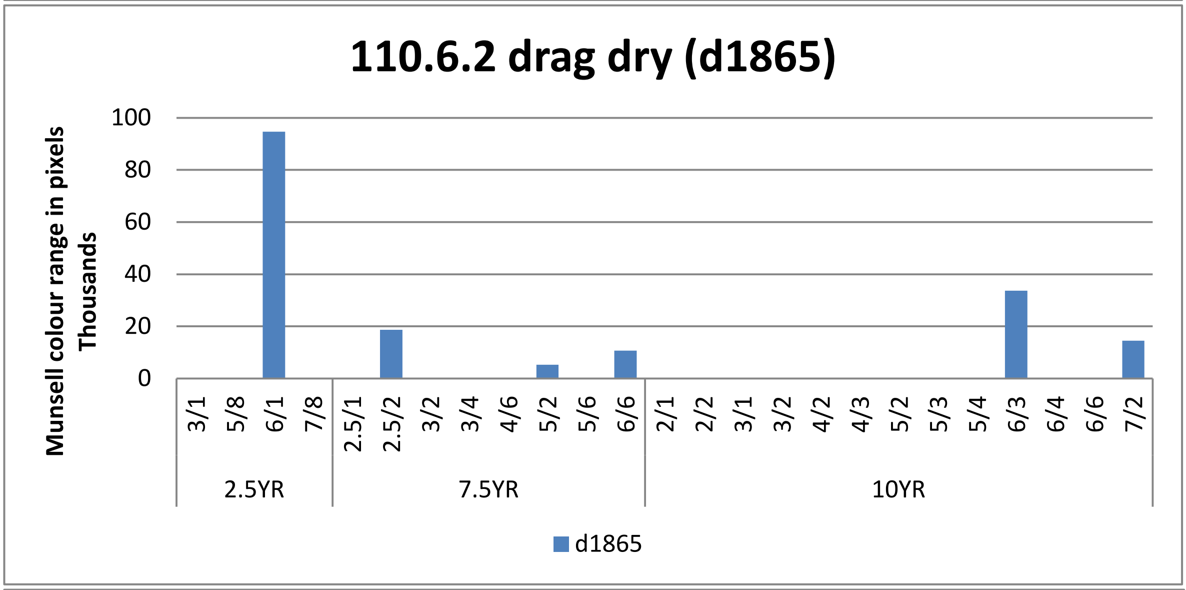
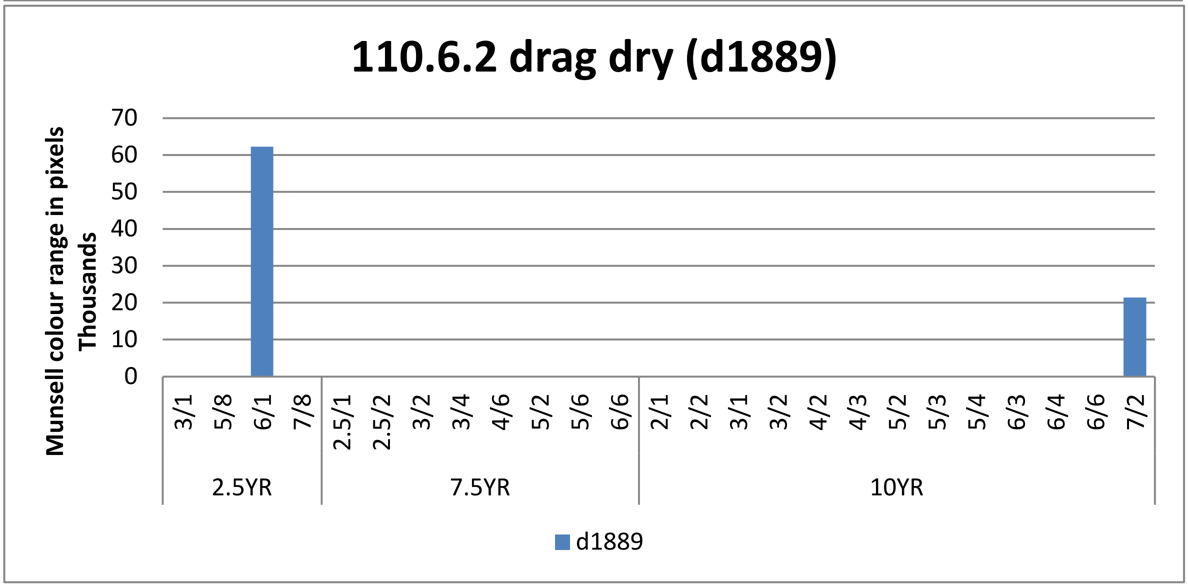
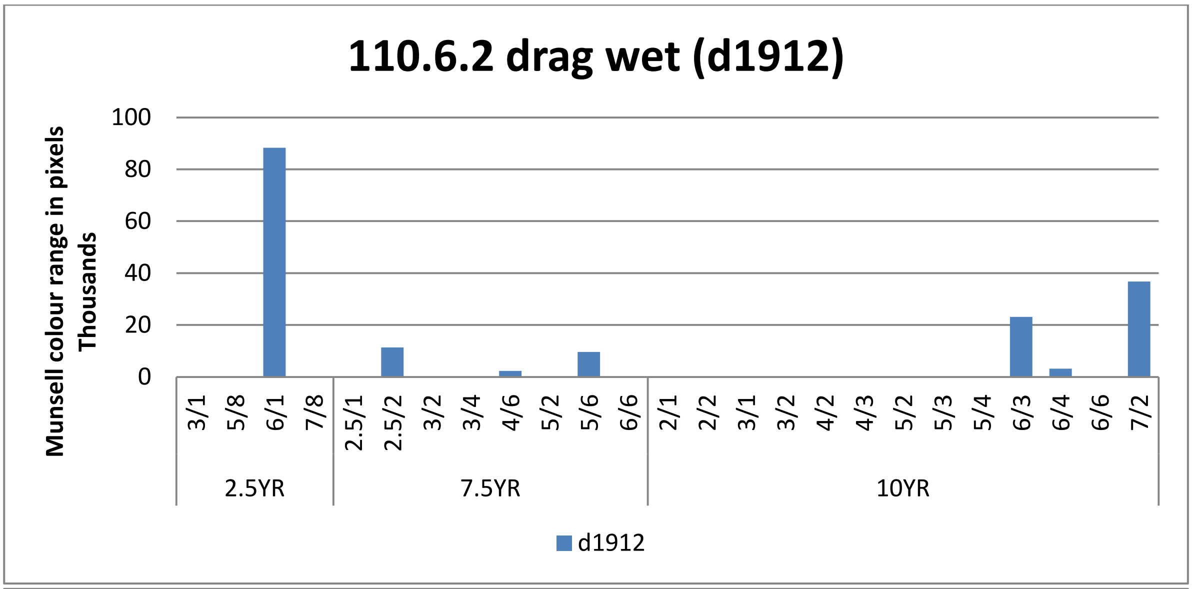
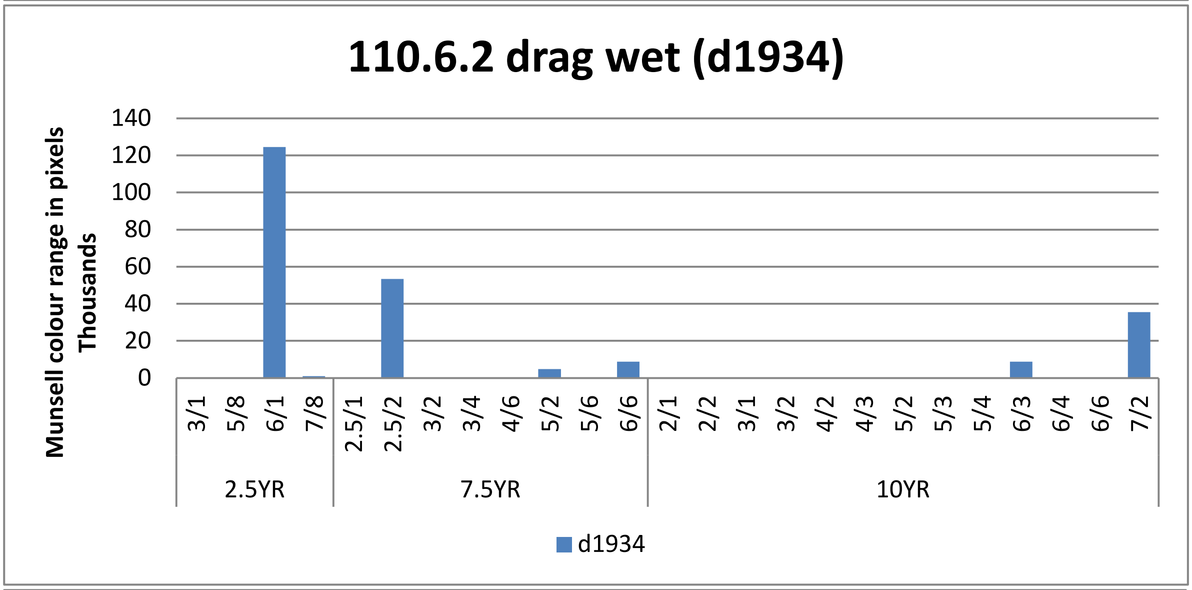


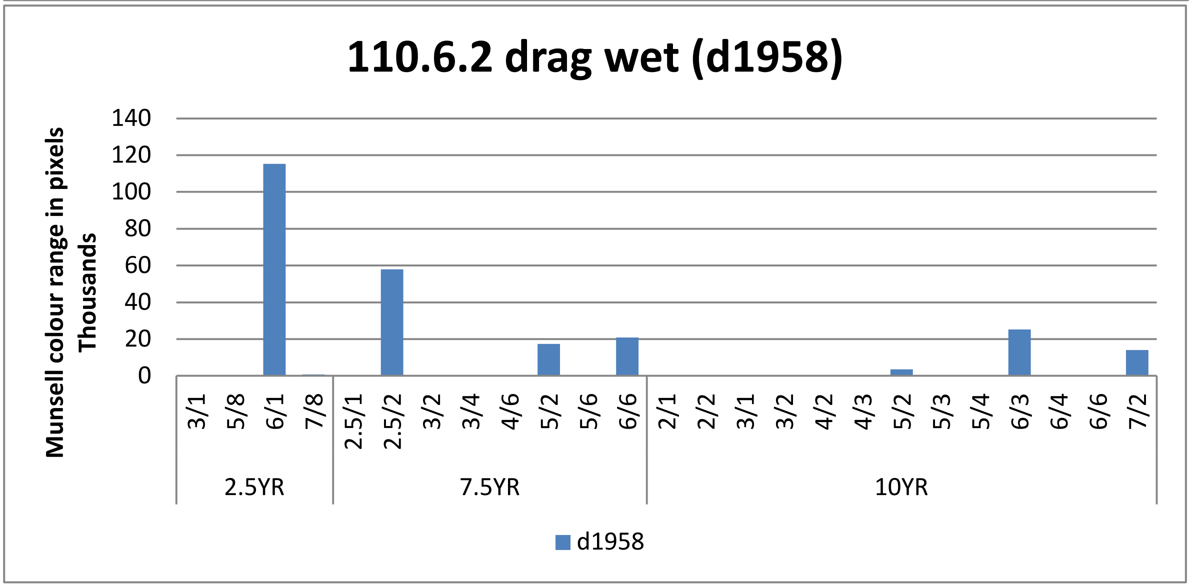




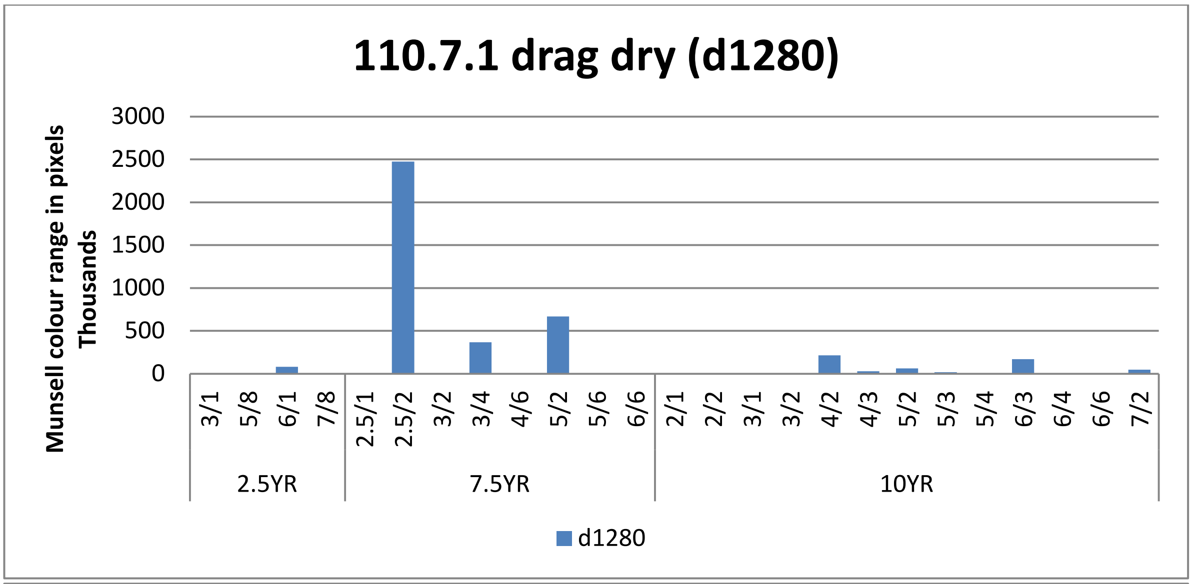
Appendix 3 continued...

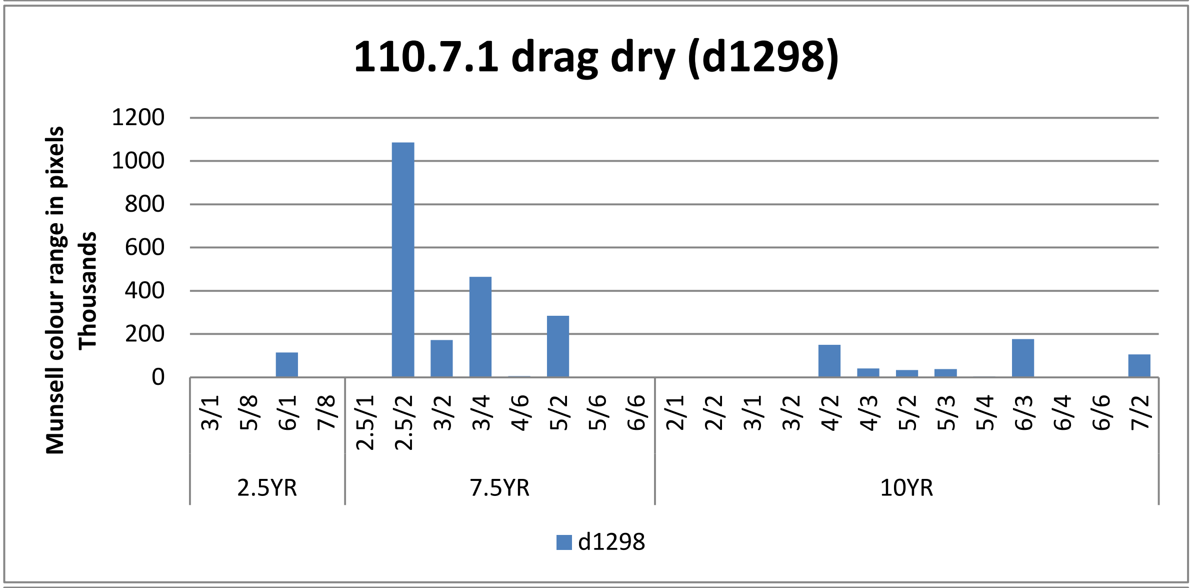


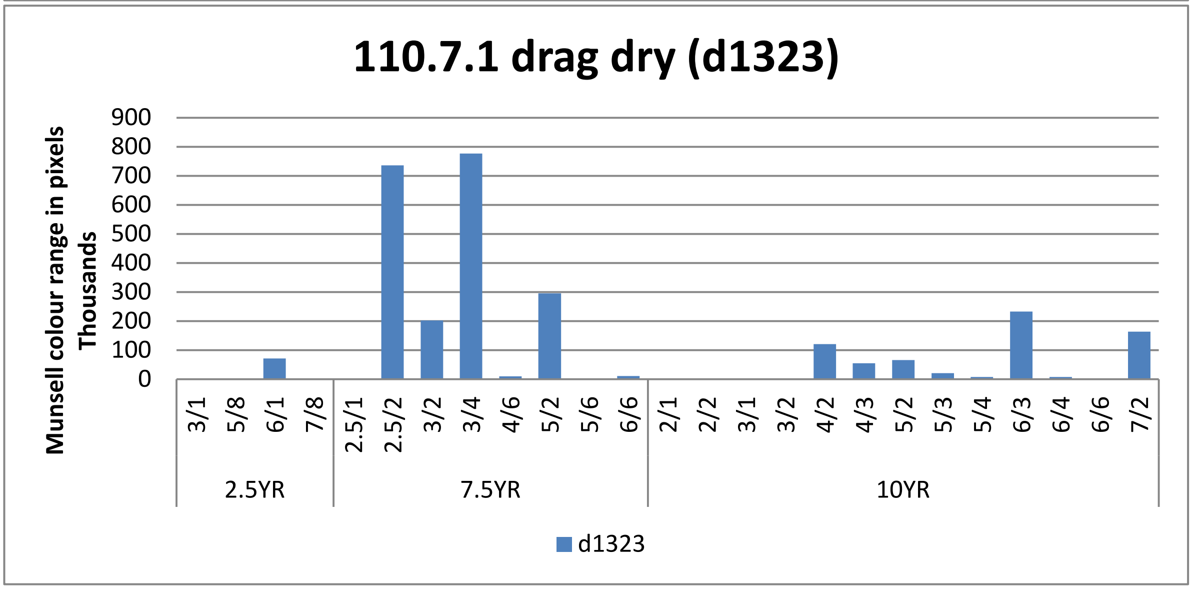




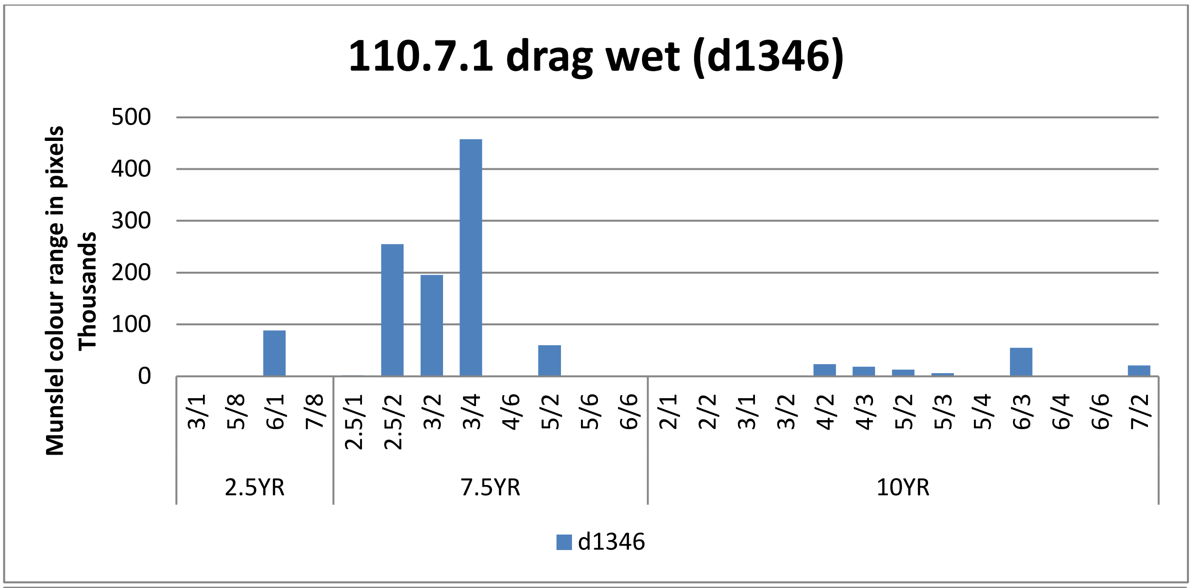
Appendix 3 continued...

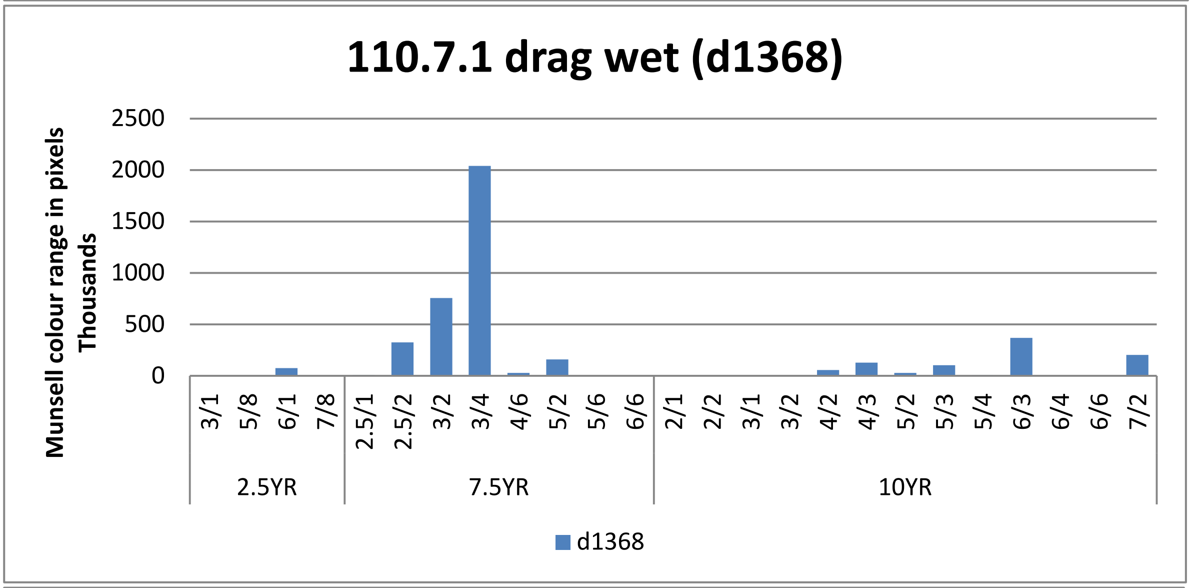


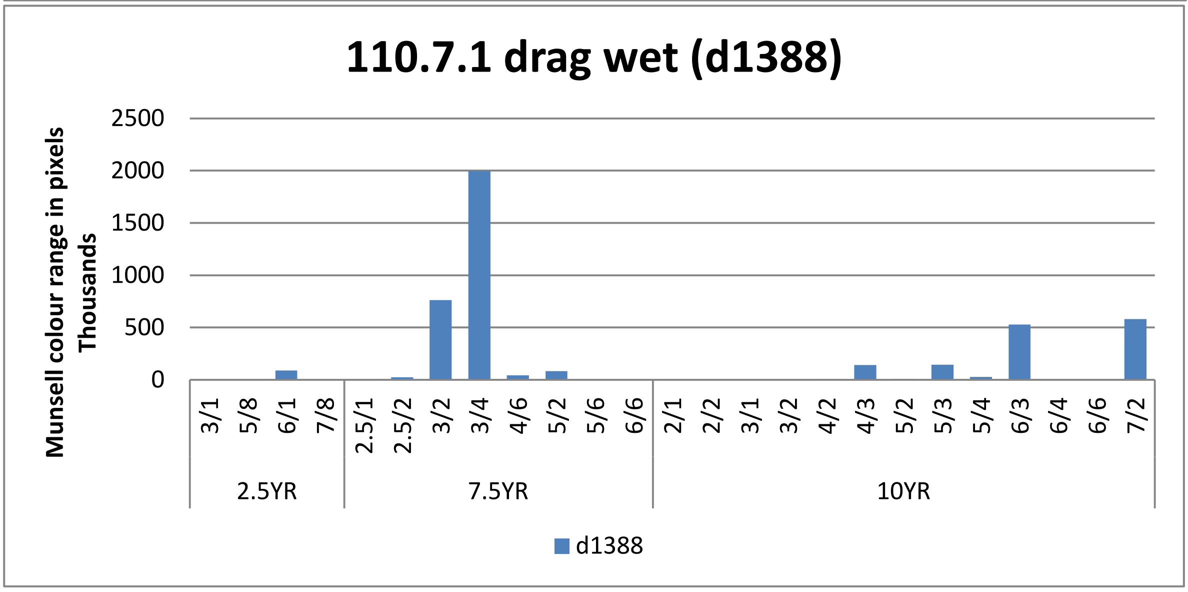




Appendix 3 continued...







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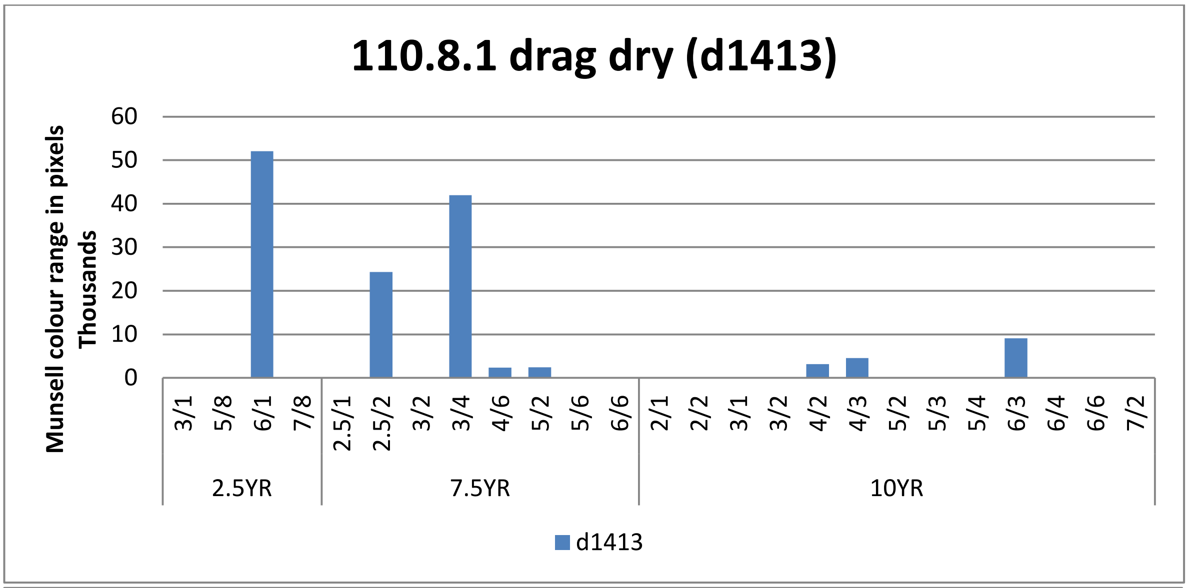

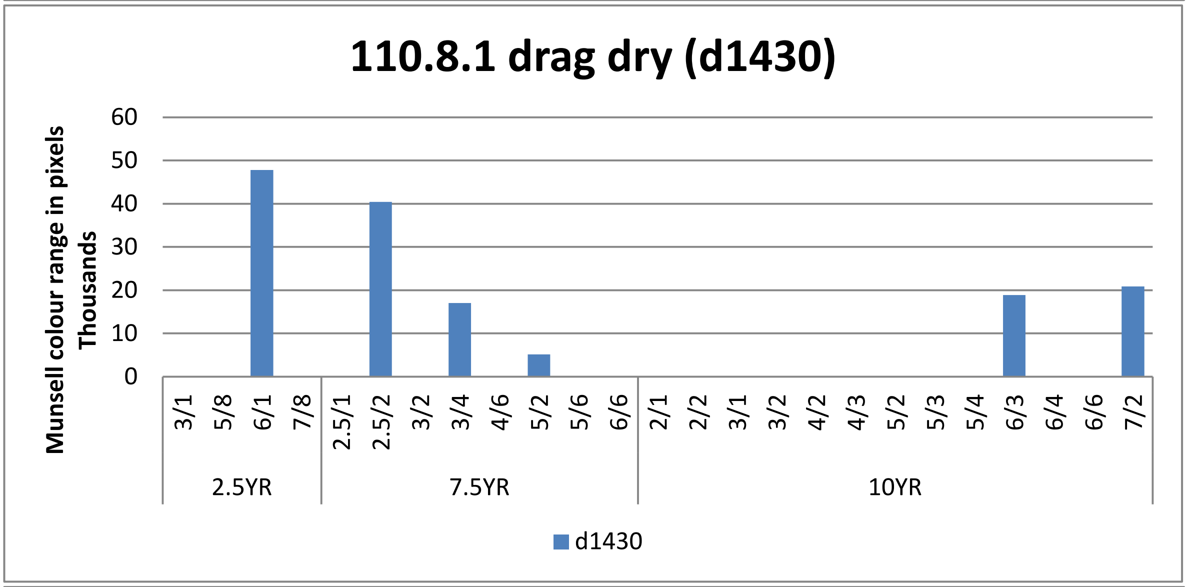

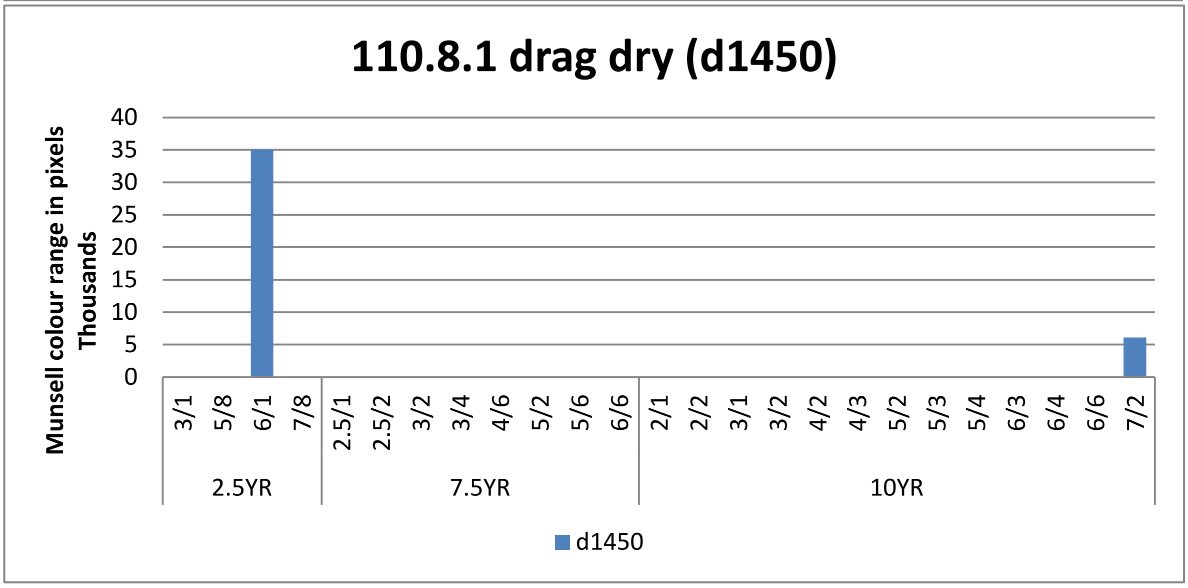

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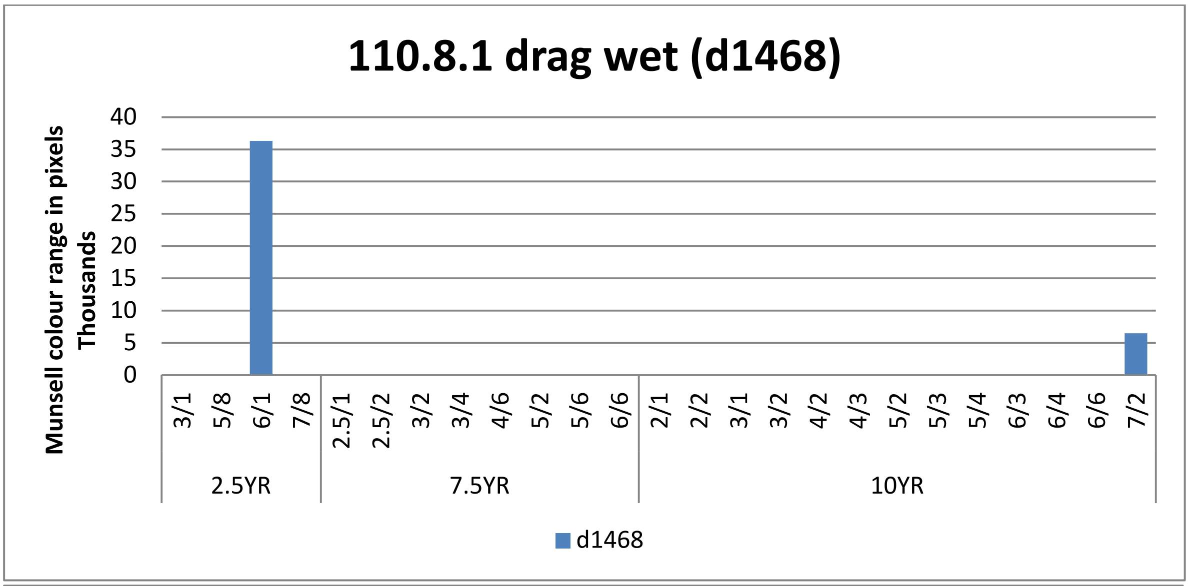

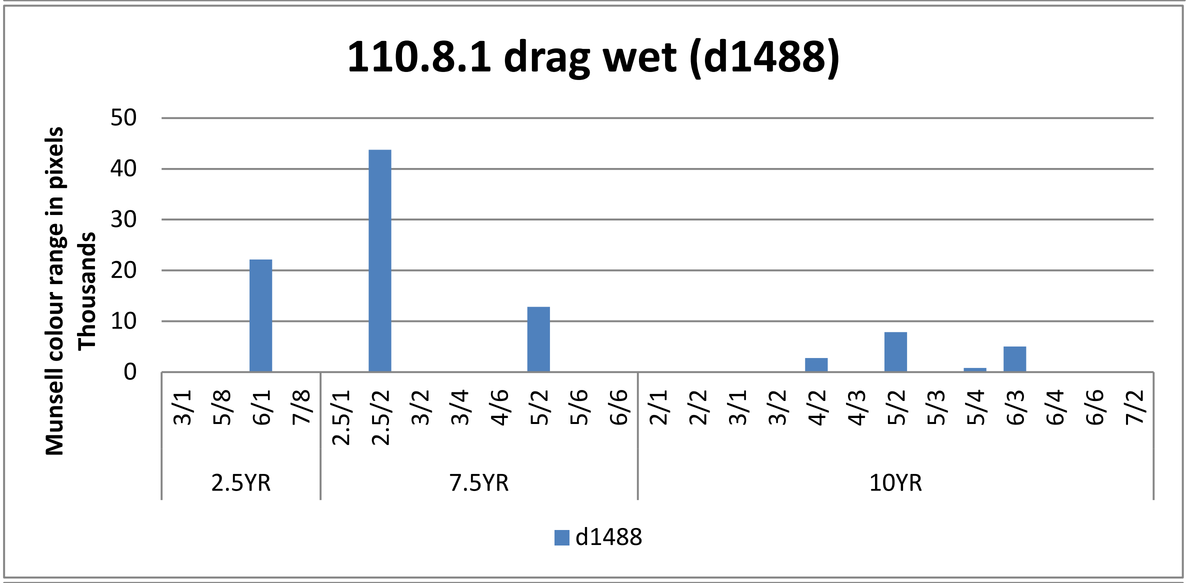

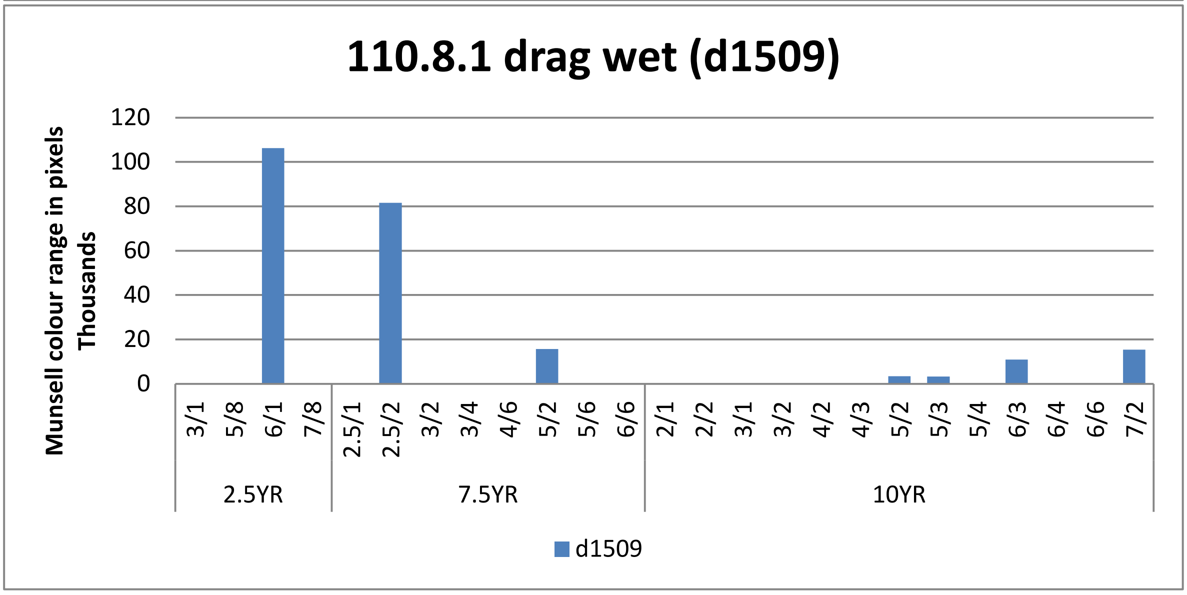

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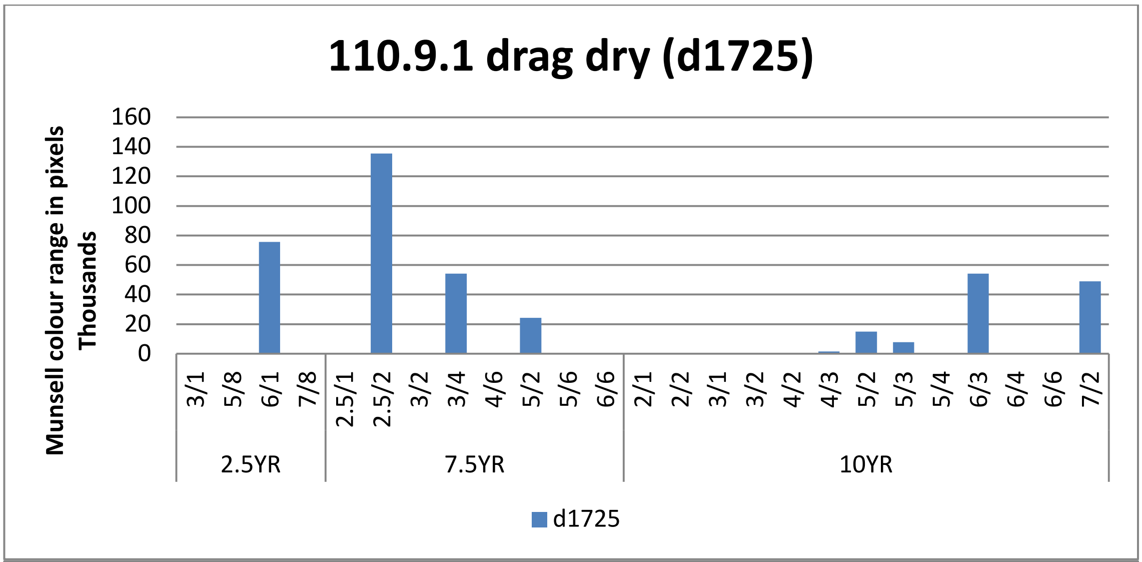

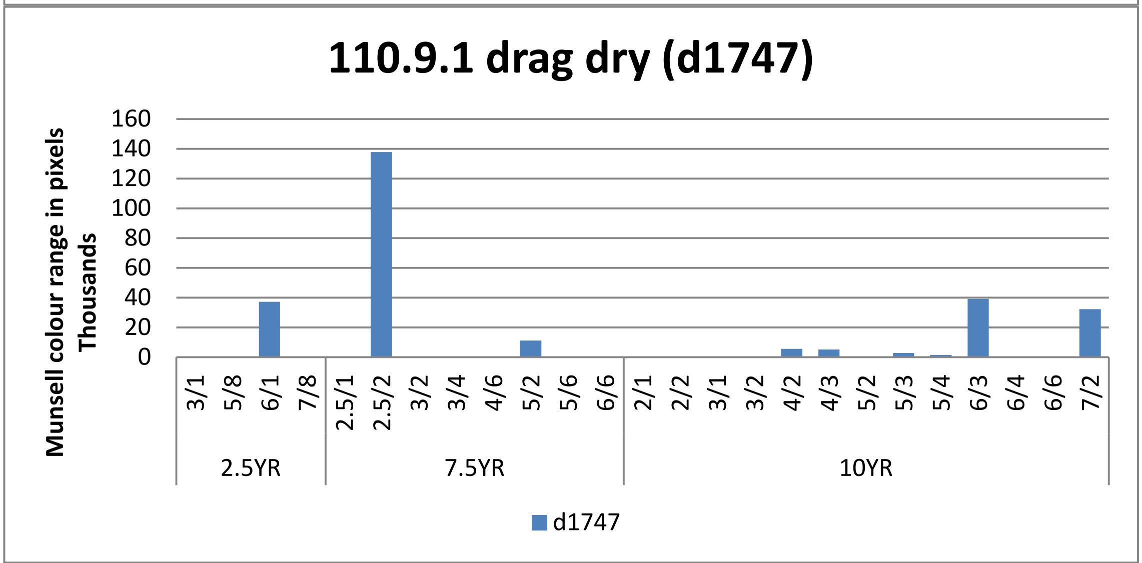

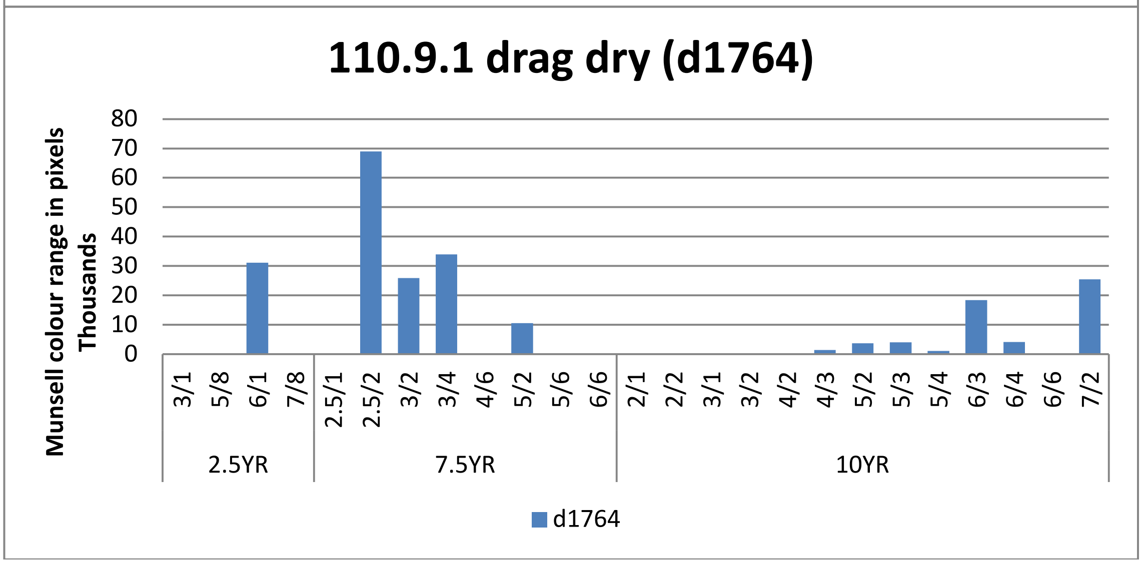

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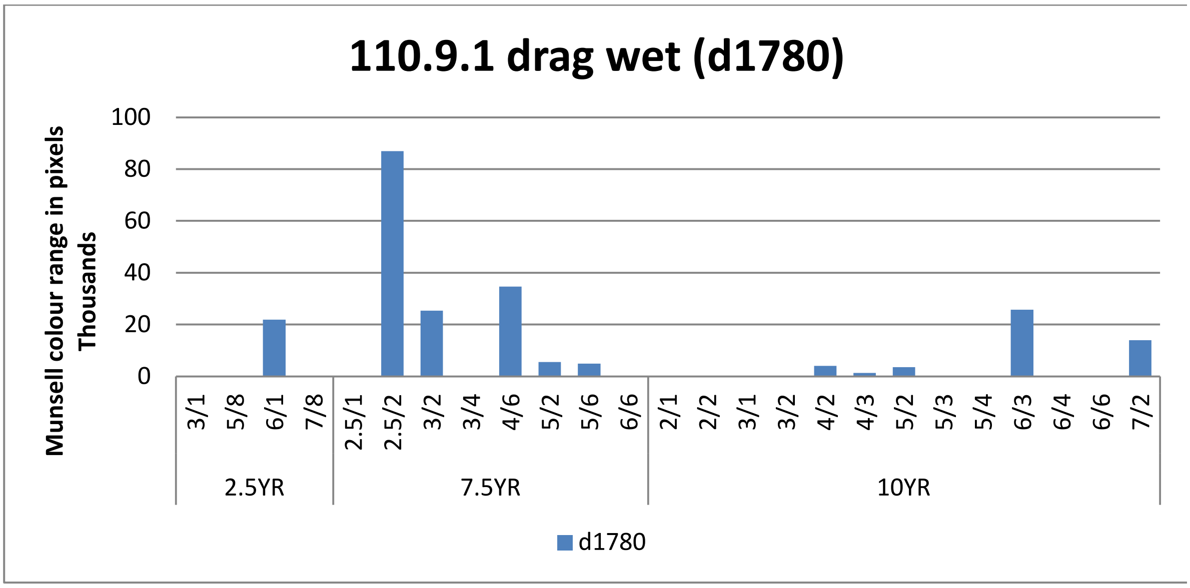

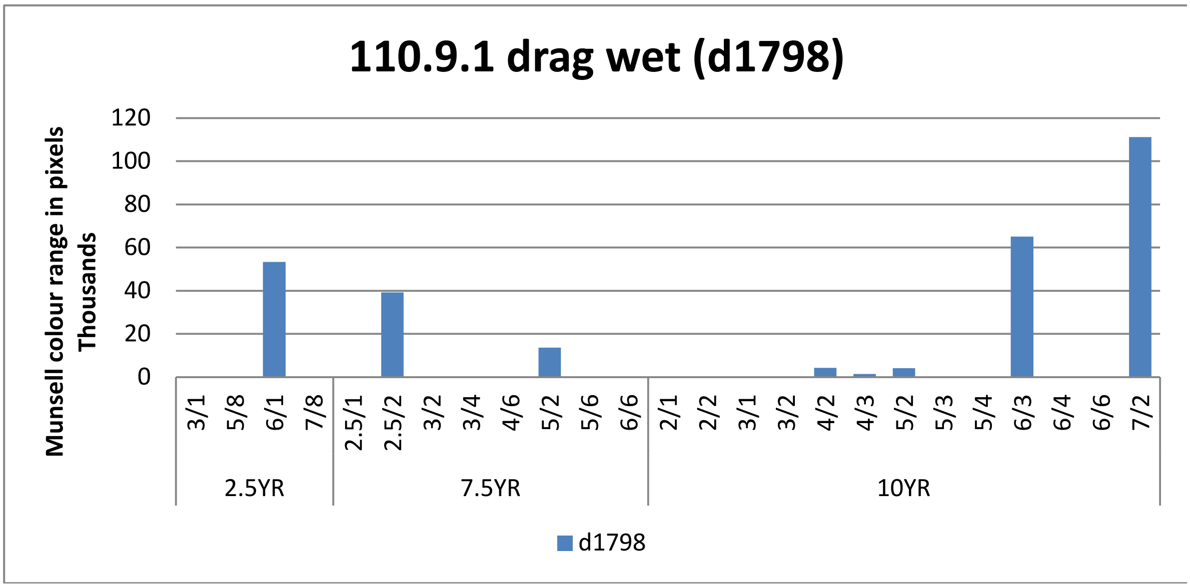

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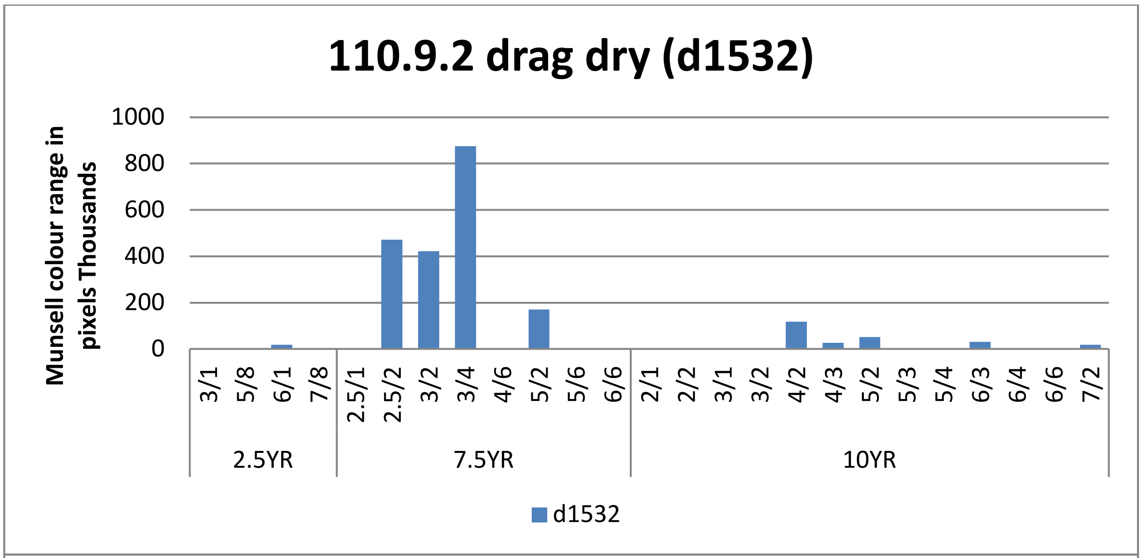

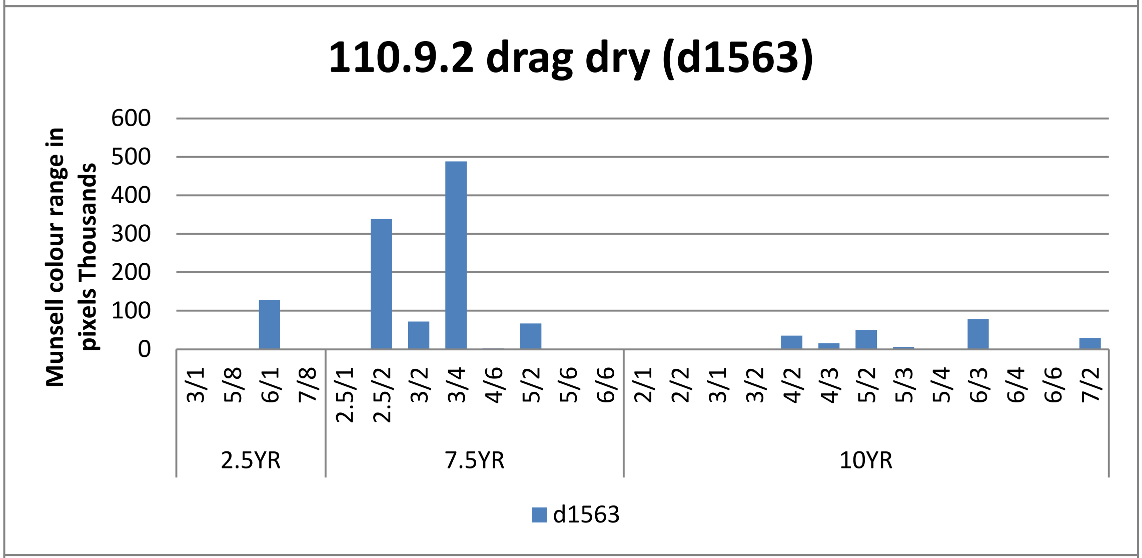

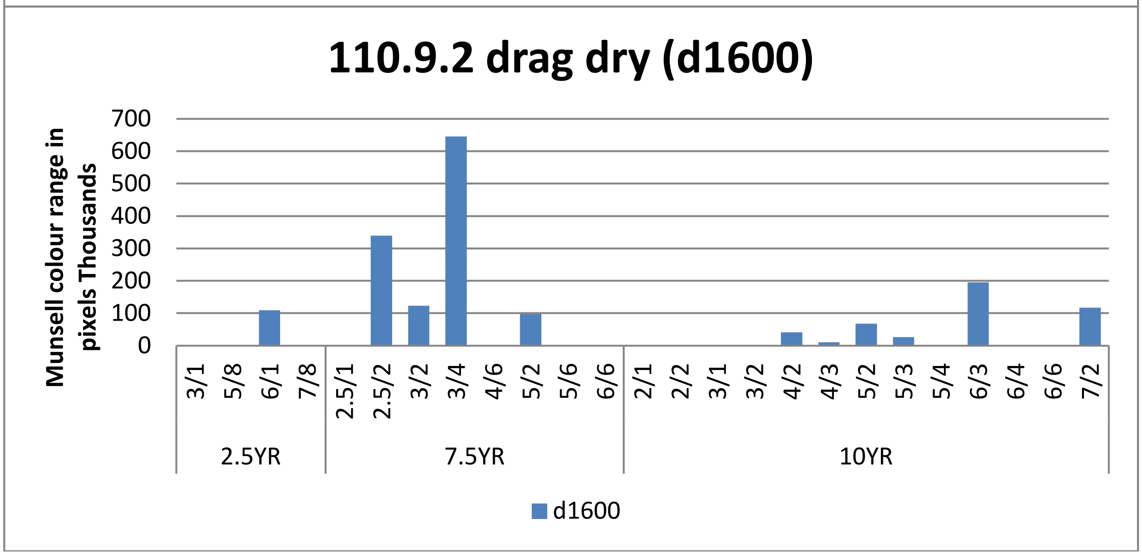

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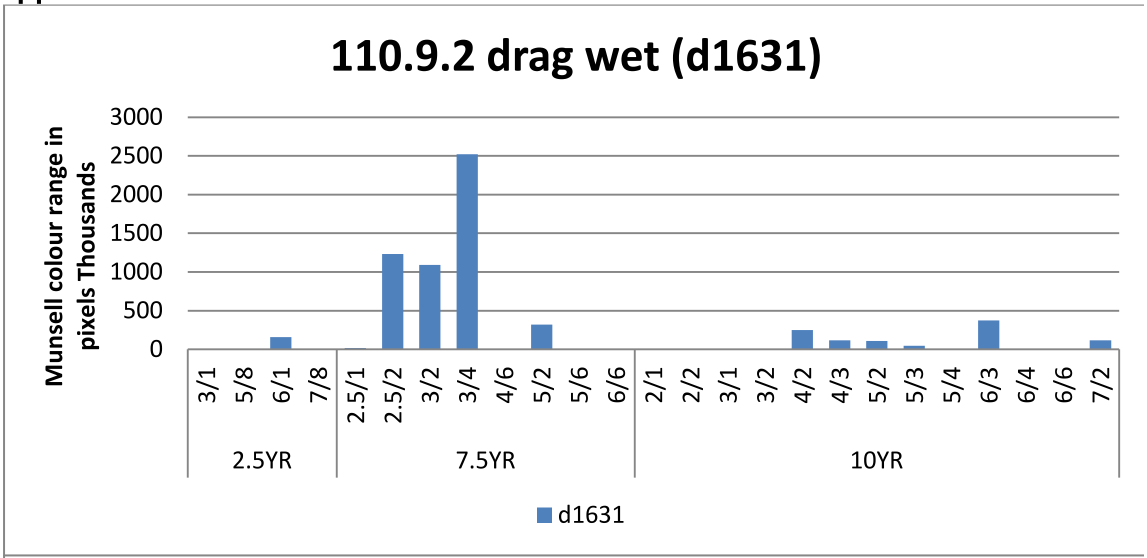
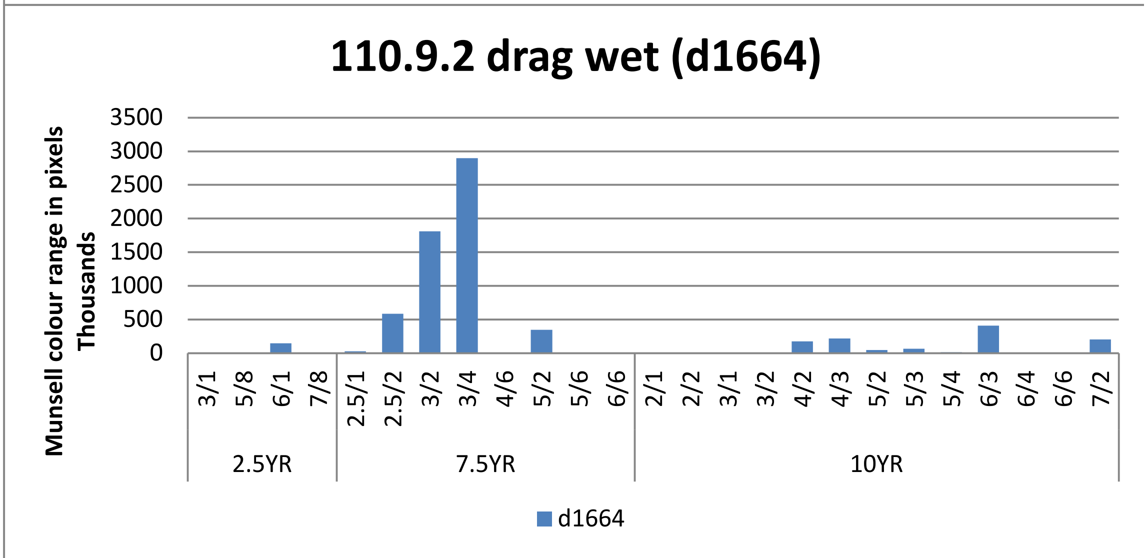
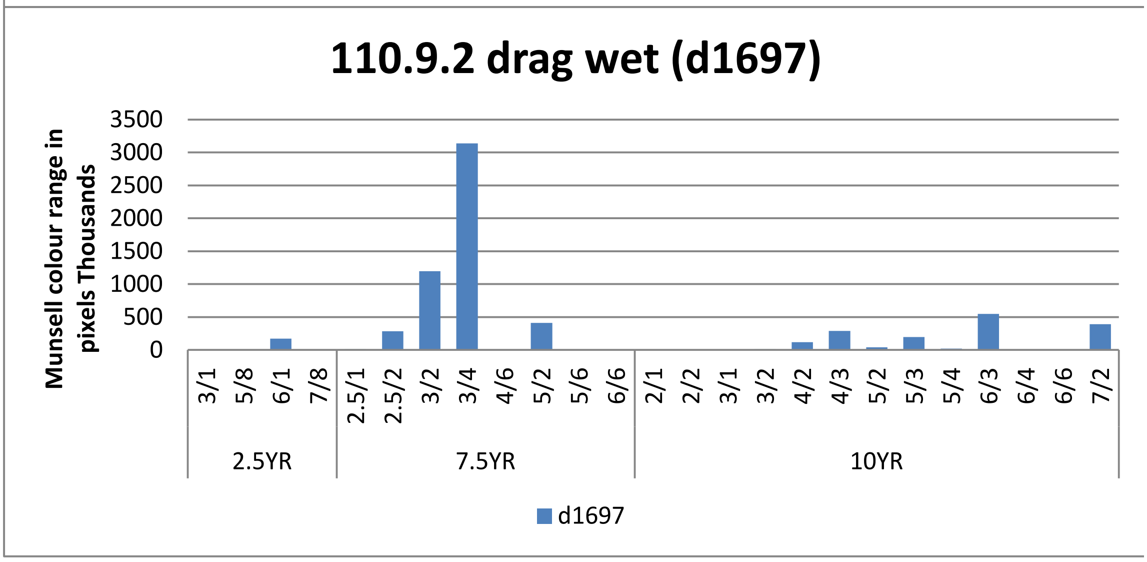
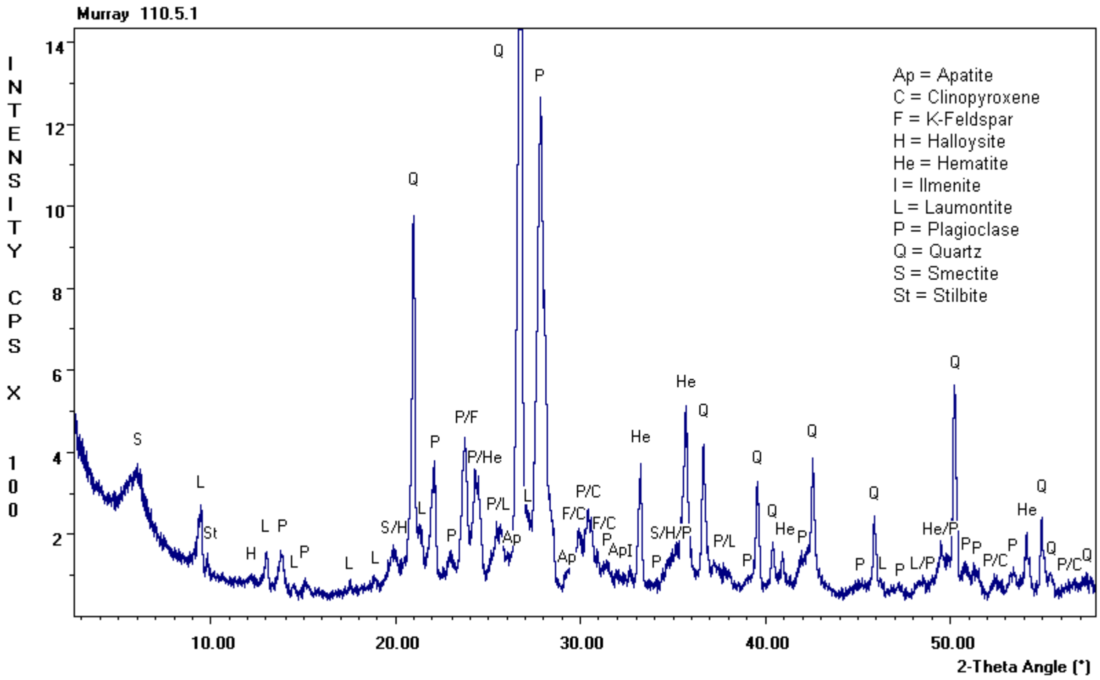




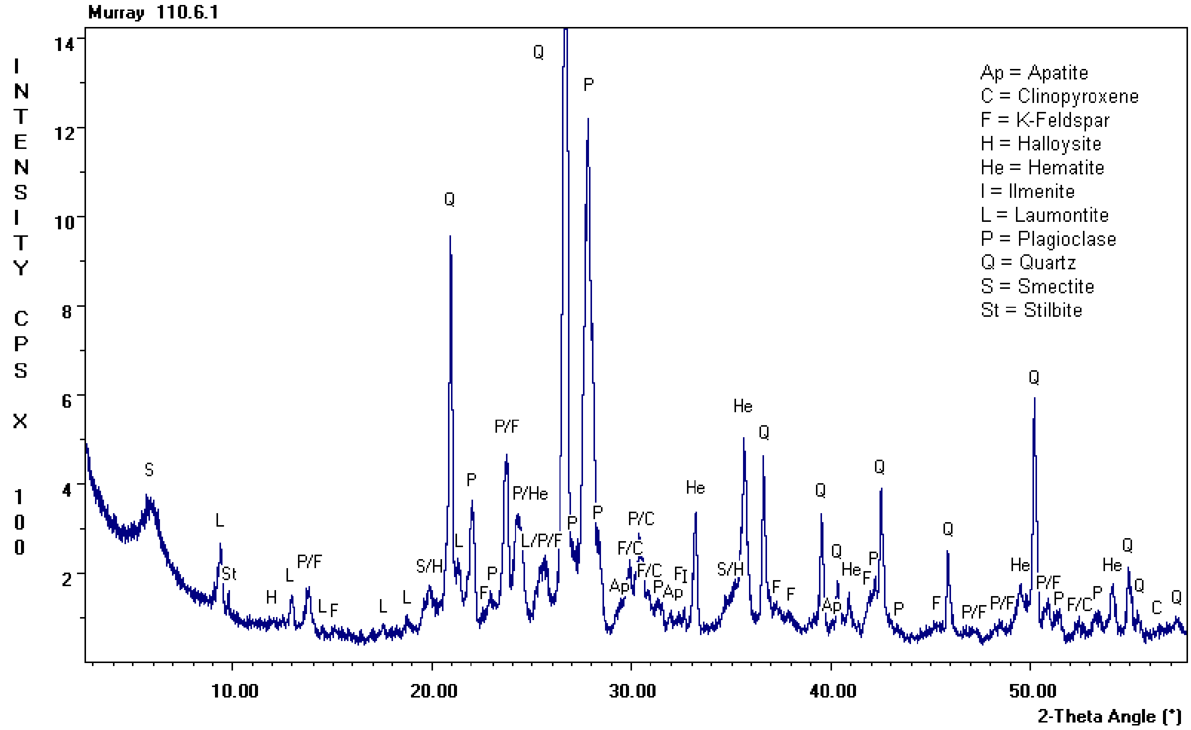


14. Appendix 4 – XRD patterns

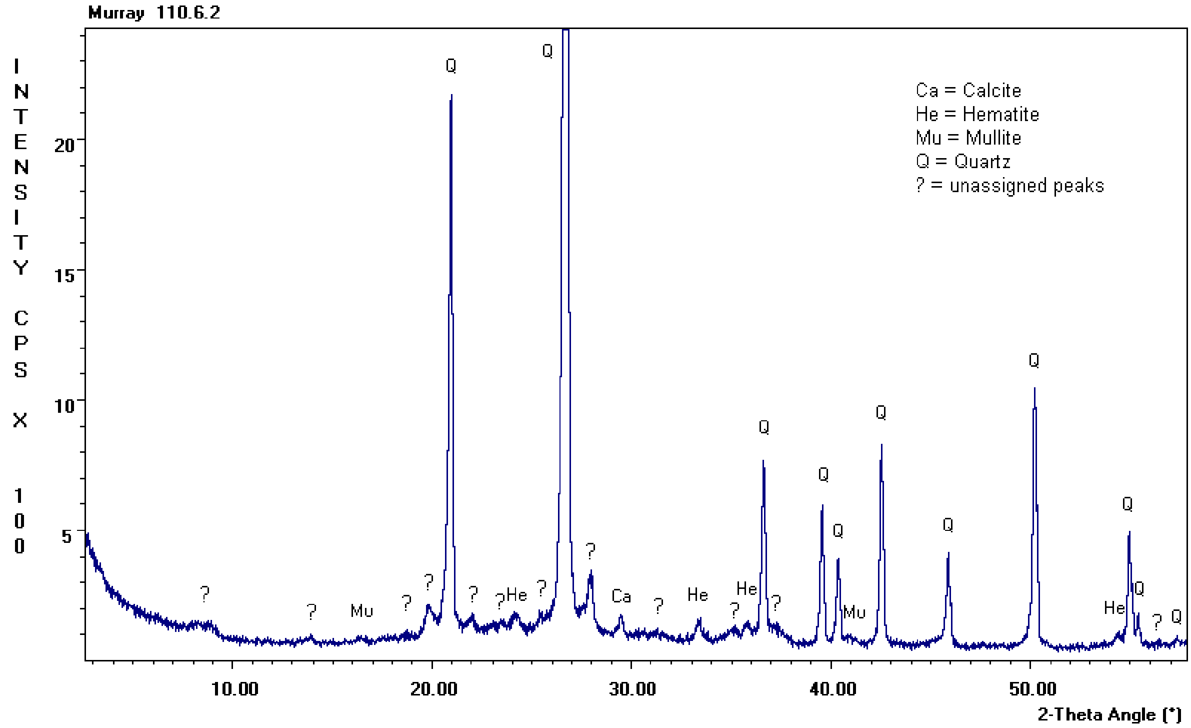
Soil no. 110.5.1	*Site 5 RTBG, Rose Garden path*	Queens Domain, Hobart	Dark brown Soil
Soil no. 110.6.1	*Site 6 RTBG, Rose Garden path near wall*	Queens Domain, Hobart	Dark brown Soil
Soil no. 110.6.2	*Site 6 RTBG, Brick fragments, near wall*	Queens Domain, Hobart	Red Soil
Soil no. 110.7.1	*Site 7 RTBG, Rose Garden bed*	Queens Domain, Hobart	Black Soil
Soil no. 110.8.1	*Site 8 RTBG, Japanese Garden*	Queens Domain, Hobart	Dark reddish gray Soil
Soil no. 110.9.2	*Site 9 RTBG, Natural soil*	Queens Domain, Hobart	Very dark brown Soil



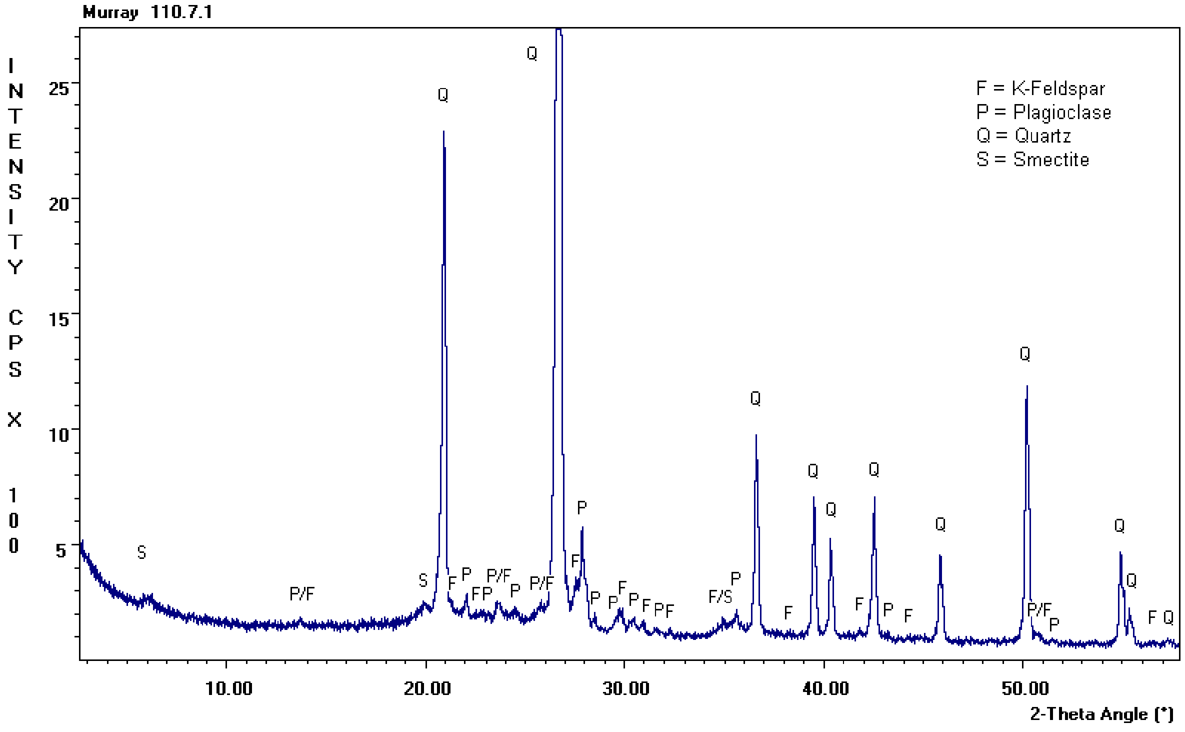
Sample no. 110.5.1: Site 5 Rose Garden path, RTBG, Queens Domain, Hobart. Dark brown Soil



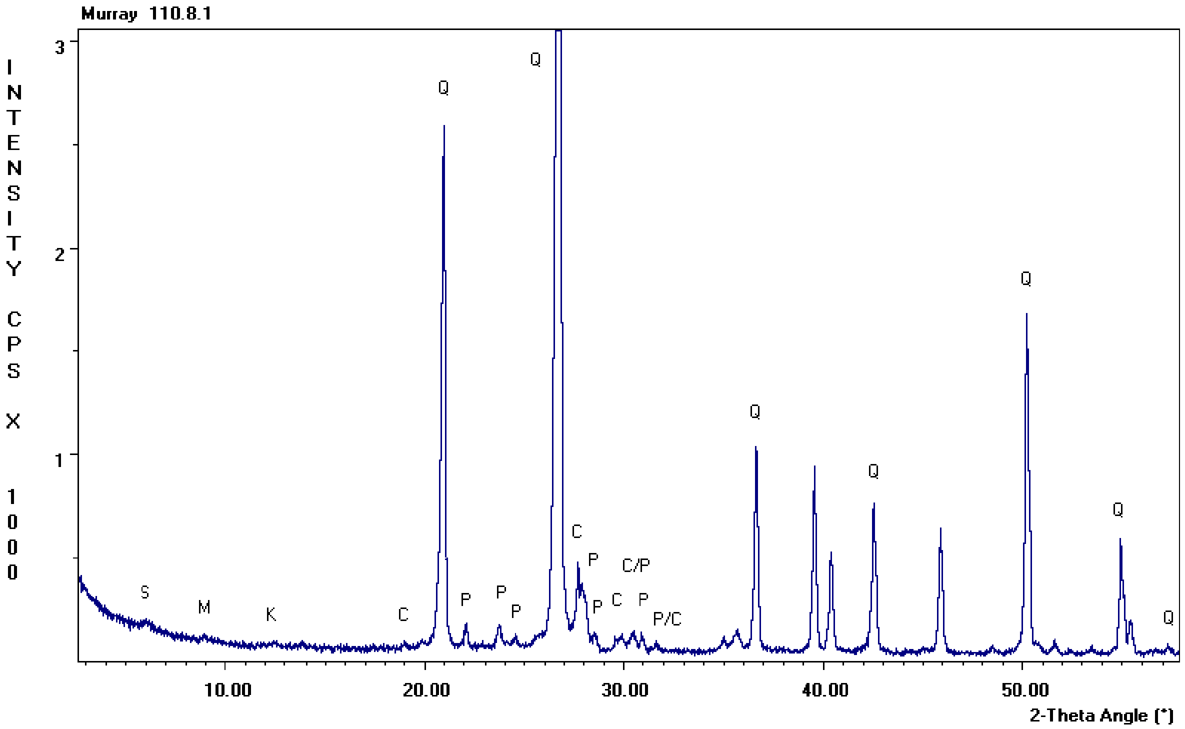
Sample no. 110.6.1: Site 6 Rose Garden path, RTBG, Queens Domain, Hobart Dark Brown soil



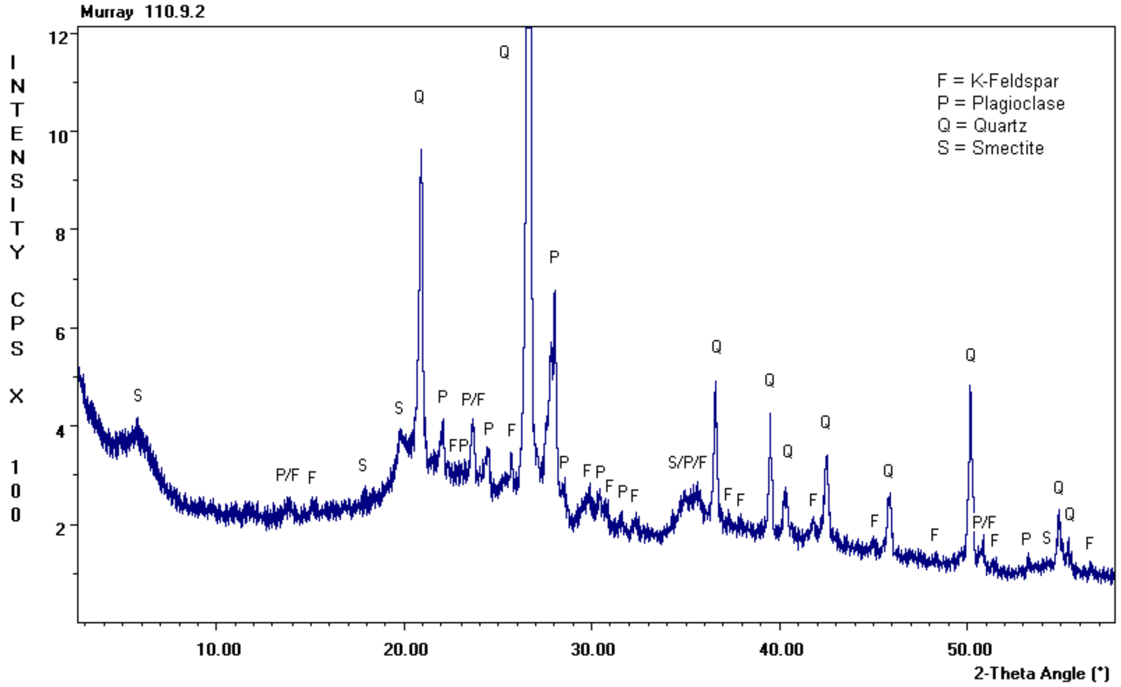
Sample no. 110.6.2 Site 6 Rose Garden path, RTBG, Queens Domain, Hobart Red Soil



Sample no. 110.7.1: Site 7 Rose Garden path, RTBG, Queens Domain, Hobart. Black Soil



Sample no. 110.8.1: Site 8 Rose Garden path, RTBG, Queens Domain, Hobart Dark reddish gray Soil



Sample no. 110.9.2: Site 9 Natural soil SE boundary, RTBG, Queens Domain, Hobart Very dark brown soil