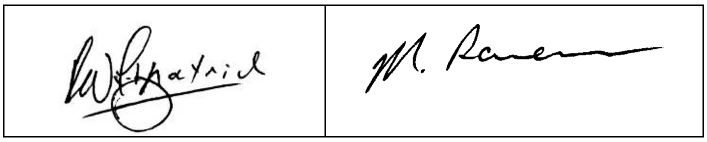
Centre for Australian Forensic Soil Science

Guidelines for Conducting Criminal and Environmental Soil Forensic Investigations: Version 10.1

R.W. Fitzpatrick and M.D. Raven



Centre for Australian Forensic Soil Science (CAFSS)

Client Report: CAFSS_076 (Version 10.1)

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Cover Photographs:

From left to right photographs of: (a) top of rubber shoe sole with tooth-like edge moulding showing brown (7.5YR4/4 moist) clayey soil (Questioned soil), (b) brown (7.5YR4/4 moist) clayey soil in wooded area at crime scene (Control soil), (c) reddish brown clayey soil with white quartz and dolomite gravel (Reference soil) from road-verge at victim's house (from Fitzpatrick and Raven, 2009; Fitzpatrick *et al.* 2012)

Executive Summary

The experience gained from conducting over 155 case studies, together with research by the *Centre for Australian Forensic Soil Science (*CAFSS) has led to the development of **"broad guidelines for conducting criminal and environmental soil forensic investigations".** This guideline document has been produced to update the earlier publications, which has incorporated information from case investigations conducted by CAFSS. The Guidelines were developed and designed to provide: (i) basic background information on the use of soils and geological materials to discriminate between soil samples from different locations (ii) a systematic approach to examining soils for forensic comparisons and (iii) appropriate methods, which are standardized, inexpensive, accurate and applicable to sampling and characterising small and large samples. The Guidelines are not intended as an authoritative scene of crime manual or laboratory methods manual, but rather as a source of information of approaches in which forensic examinations of soils and related geological materials can be applied to crime investigations, terrorist casework and where environmental incidents occurred.

The aim of this guideline document is to provide the basic rationale and define a set of data requirements that will be used by staff in CAFSS to conduct soil forensic investigations.

The forensic investigation of soil usually involves the following two main activities:

(1) Soil collection and sampling of one or more locations.

(2) Soil characterization and evaluation.

Of paramount importance in both activities, is continuity of evidence or the chain-of-custody, which must be maintained and documented at all times throughout the entire investigation. Consequently, all sampling methods, sample storage security, soil characterization and analytical methods must be subject to the most rigorous procedures of sample/data handling available so they can be discoverable and questioned in court.

Soil collection and sampling of one or more locations

Samples are categorised in two ways:

1. Questioned soil samples whose origin is unknown or disputed - often from a suspect or victim and

2. Known soil samples that are grouped into the following **three** groups of origin in association with the matter under investigation: (i) control soil samples whose origin is known - often from locations such as the crime scene, (ii) Reference soil samples whose origin or type is known and may comprise: (a) type samples held in a museum or soil/geological archive collection, (b) samples collected from known sites linked to a victim or (c) sites/areas from soil or geological maps that can be used to assist in making soil comparisons; (iii) Alibi soil samples are those of known origin - often from locations suggested by a suspect or linked to a suspect (e.g. backyards or driveways at the suspect's home).

Alibi and reference samples provide a measure of the uniqueness of the questioned and control samples hence providing a more comprehensive analysis of the targeted comparator samples to provide a more accurate picture of the within-site heterogeneity.

Forensic soil comparisons of a questioned sample with one or more samples of known origin are usually based on several pedological, physical, mineralogical and biological properties to evaluate the significance of observed similarities and differences in order to arrive at a conclusion regarding a possible association. Soil can be used to indicate or compare provenance, and therefore be used as intelligence and subsequently evidence to narrow areas of search during an investigation. Evaluative comparison of soil on one article of evidence compared to another, or compared to a known location, can and has been used as evidence in courts of law.

Soil characterization and evaluation

Soil characterization requires a multidisciplinary approach, which combines descriptive, analytical, and spatial information (e.g. mapping). This approach involves subdividing approaches and methods into the following 4-stages each comprising several steps and involving a combination of techniques:

1. Initial characterization for screening of samples, which involves morphological characterisation of bulk or whole soil samples.

2. **Semi-detailed characterization**, which involves identification, semi-detailed characterisation and semi-quantification of minerals and organic matter in bulk and on individual soil particles following sample selection and size fractionation (< 50 µm or 100 µm).

3. **Detailed characterization**, which involves using additional analytical techniques and/or methods of sample preparation, separation or concentration (e.g. size or magnetic or heavy mineral fractionation) to characterise and quantify minerals and organic matter in bulk and on individual soil particles.

4. **Integration and extrapolation of soil information from one scale to next.** This final stage involves building coherent soil-landscape models of information from microscopic observations to the landscape scale, which may involve soil classification and use of soil, geological and vegetation maps; terrain analysis, remote sensing and geophysics.

The progression of a soil forensic examination through each of the four stages will depend on a number of factors such as the amount of sample available and the results from the early stages of the examination.

The broad guidelines describe best practice for field (collecting, identifying and describing soil samples) and key laboratory techniques, which requires consistent and correct use of terms and standard methods. This approach has enabled soil properties to be successfully used to discriminate between or compare soils for critical evidence to solve overwhelmingly complex criminal and environmental forensic cases.

The guidelines are incorporated in all case investigations conducted by CAFSS. These investigations have included several homicide cases that have been presented before several Supreme Courts in Australia.

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1 Introduction

The aim of soil forensic analysis is to associate soil, altered rock particles or mineral samples taken from an item, such as shoes, clothing, shovel or vehicle with a specific location or common origin. This transfer of "soil trace evidence" is governed by what has become known as the Locard Exchange Principle (Chisum and Turvey, 2000), which states that when two surfaces come into physical contact there is a mutual exchange of trace evidence between them (Figure 1). According to Fitzpatrick (2009) soil materials and minerals are powerful, perhaps ideal, pieces of contact trace evidence to help in forensic investigations. Examination of soil is concerned with detection of both naturally occurring soils (e.g., minerals, organic matter) and anthropogenic or human-made soils that contain manufactured materials (e.g., brick fragments). Hence, forensic soil examination can be complex because of the diversity and heterogeneity of soil samples. However, such diversity, heterogeneity and complexity enables forensic soil examiners to distinguish between soils that may appear to be similar (e.g. Bull *et al.* 2004; Dawson and Hillier 2010; Fitzpatrick and Raven 2012; Ritz et al. 2009; Fitzpatrick et al. 2009; 2012; Fitzpatrick 2009, 2012, 2013a,b,c). In essence, forensic soil scientists and geologists must determine if there are unique features of soils or geological materials crucial to an investigation that enables these soils to be compared with soils from known locations. To achieve these objectives, there are various approaches, stages and steps for ensuring that this is achieved but there is no "authoritative scene of crime manual or laboratory methods manual". The approach and method of each forensic situation has to be taken on its merits according to existing conditions but must involve using standard approaches to record, describe and analysis materials.

The experience gained from conducting over 155 case study investigations, together with research by the *Centre for Australian Forensic Soil Science* (CAFSS) has led to the development of these "broad guidelines for conducting criminal and environmental soil forensic investigations". This particular document has been produced to update earlier publication versions, which was incorporated in the Appendices of case investigations conducted by CAFSS (e.g. Fitzpatrick and Raven 2008; 2009, 2012; Fitzpatrick 2013d,e, 2015a,b).

The aim of this guideline document is to provide the basic rationale and define a set of data requirements that will be used by the staff of CAFSS to conduct soil forensic investigations. These broad guidelines were developed and designed to provide a more "systematic approach and use of appropriate standard methods" for chain-of-custody of samples, sampling, characterising and examining soils for forensic comparisons. It is suggested, that this approach and the procedures recommended are a preliminary set of broad guidelines, which provides a guideline framework for adoption as current best practice. Where detailed information is required reference should be made to other relevant and/or individual organisational procedures. This guideline document does not cover search methods (e.g. Donnelly, 2003; Harrison and Donnelly. 2009; Ruffell and McKinley 2008).

Soil forensic investigations generally involve three major steps:

(1) Soil collection and sampling.
(2) Soil sample chain-of-custody protocols.
(3) Soil characterisation and evaluation.

2 Soil sample collection

This section briefly summarizes the general procedures that ensure that collected soil samples are appropriate for the specific objectives of the forensic soil investigation.

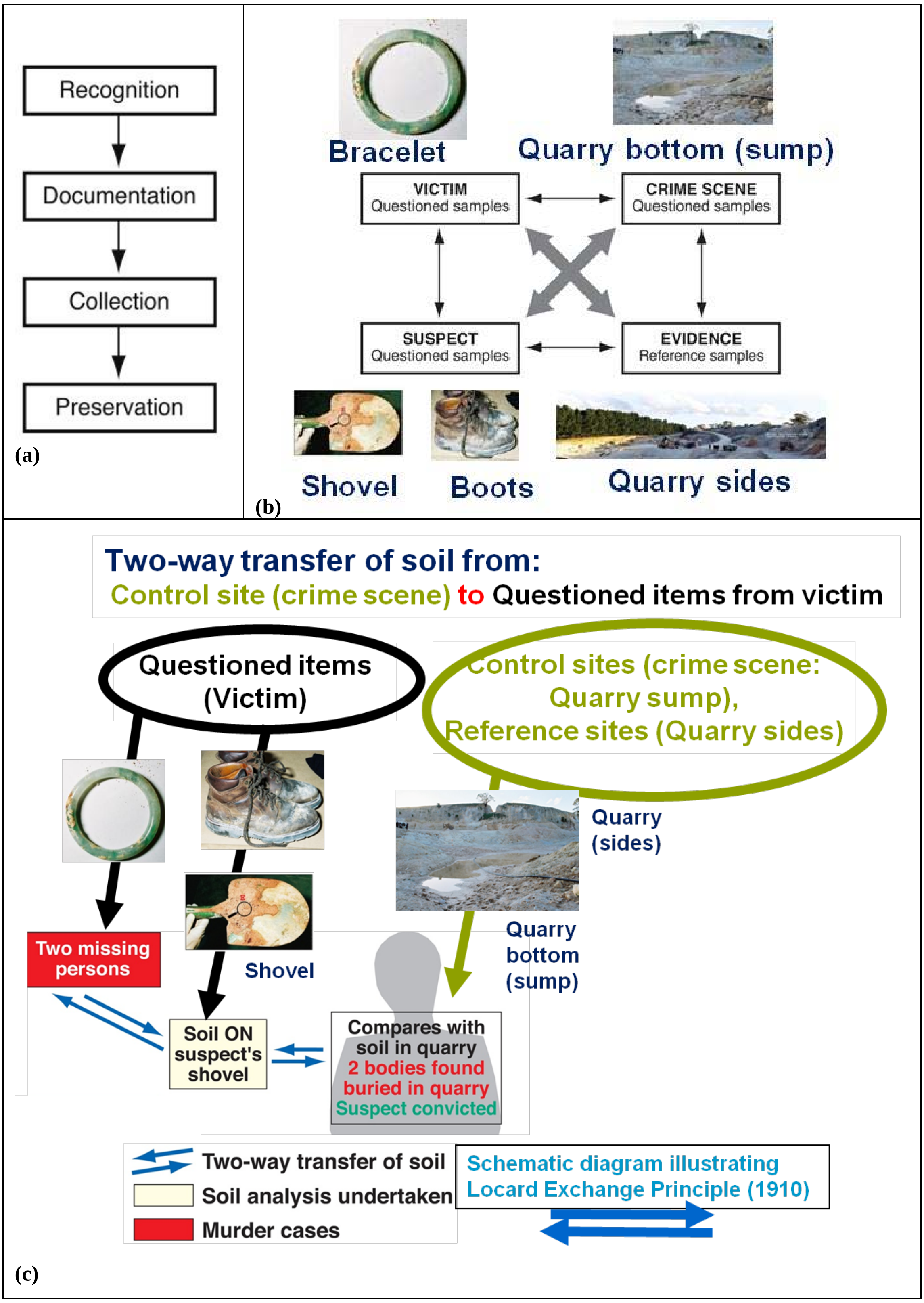


Figure 1. Schematic diagrams illustrating: (a) Correct sequence for conducting soil forensic investigations; (b) and (c) Soil forensic evidence from *known* control "collected" sampling sites (crime scene) and *known* reference sites (e.g. quarry sides) or alibi sites, which may be used to associate questioned soils on items that are linked to the suspect (i.e. shovel), victim (i.e. bracelet) and crime scene (i.e. sump in quarry) using a two way or four-way linkage (modified from Fitzpatrick and Raven 2012; Fitzpatrick 2013b). NOTE: Reference soil sites/areas from soil or geological maps and soil archive/museum collections can also be used to assist in making soil comparisons (see Fitzpatrick and Raven 2012).

First and foremost, soil evidence must be recognized for all possible items relating to the investigation (Figures 1a, b and c). Secondly, evidence must be well documented. Finally, the meticulous collection and preservation of soil samples must be maintained so as to preserve the integrity of the soil evidence (Figure 1a) - followed by soil characterization.

Soil samples must be carefully collected and handled using established sampling approaches and then examined by a Soil or Earth Scientist with forensic science experience to ensure that the soil samples can be useful during an investigation.

In general, soil analysis begins with the sampling and describing of the following two distinct categories of samples:

Questioned soil samples

Questioned soil samples are the main focus of most soil forensic examinations. These samples are those samples of unknown or disputed origin. Questioned soil samples are often collected from a suspect or victim or may be soils that have been transported by a shovel, a vehicle or shoes (e.g. Figure 2).

Known soil samples

Known soil samples are grouped into the following **three** established groups of origin, which are associated with the matter under investigation (e.g. Figures 2 and 3).

Control soil samples are those of known origin - usually from specific sites directly related to the investigation such as the known or proposed crime scene (e.g. Figures 2 and 3).

Reference soil samples are those of whose origin or type is known. They may comprise: (i) type samples held in a museum or soil/geological archive collection (e.g., dinosaur nest materials: see Raven and Fitzpatrick 2005) or (ii) samples collected from known sites linked to a victim (e.g. Figures 2 and 3). Reference soil sites/areas from soil or geological maps can also be used to assist in making soil comparisons (Fitzpatrick and Raven 2012).

Alibi soil samples are those of known origin - often from locations suggested by a suspect or linked to a suspect (e.g. backyards or driveways at the suspect's home: see Figures 2 and 3).

The ***alibi*** and ***reference*** samples provide a measure of the uniqueness of the questioned and control samples and therefore provide: (i) a more comprehensive analysis of the targeted comparator samples, (ii) a more accurate picture of the spatial soil heterogeneity of a site or set of sites and locations that may have been visited by the suspect (e.g. Figures 2 and 3) and (iii) possible "alibi" locations suggested or linked to the suspect.

The role of the forensic soil scientist is to compare materials from these three groups of samples and draw conclusions about the origins of the questioned soil samples.

Knowing how many questioned, control (e.g. possible scene of a crime), reference (e.g. victim's house), alibi (e.g. suspect's house) to collect is often difficult. The number, size and type of samples to be taken are strongly dependent on the nature of the environment being investigated, especially the type of soil (e.g. wet or dry soil) and nature of activity that may have taken place at the sampling location (e.g. suspected transfer of soil from the soil surface only or from a depth in the case of a buried object or body – or both). Usually the number of samples should never be less than three, preferably at least five. Large or more variable crime scenes will require a larger number of samples (e.g. a complex scene could require more than fifty samples). However, the main purpose in all soil forensic investigations is to collect a set of samples that is representative and unbiased.

Figure 2. From left to right photographs of: (a) top of rubber shoe sole with tooth-like edge moulding showing brown (7.5YR4/4 moist) clayey soil (**Questioned soil**), (b) brown (7.5YR4/4 moist) clayey soil in the wooded area at crime scene (**Control soil**), (c) reddish brown clayey soil with white quartz and dolomite gravel (**Reference soil**) from the road-verge at victim's house (from Fitzpatrick and Raven, 2009; Fitzpatrick et al. 2012).

***Background information*:** When possible, obtaining background information prior to the collection of any samples will be beneficial for the purpose of ensuring that appropriate samples are collected. The types of background information, which can be gathered include case information, soil survey information, geological survey information, appropriate maps (including geo-political, topographical, road, geological, and soil survey maps), and the exact location of the collection site (Figure 3), including GPS coordinates or equivalent.

To obtain maximum information and an optimum sampling program it is preferable that a forensic soil examiner should visit sites and take samples in person. However, if it is not possible for a forensic soil examiner to visit a scene or scenes, a suitably trained scene of crimes officer should take samples using the standard protocols detailed in these Guidelines and ensure that:

- Documentary record of each individual sampling location is obtained (see Appendix 1; Table A1.1). This includes geographical coordinates using a hand-held GPS instrument. The Easting, Northing and elevation of each sample site is recorded as a waypoint in the GPS as well as written into a log book. The WGS-84 map datum and UTM (meters) coordinate system is used by CAFSS.
- Diagrams or sketches that include measurements of distances made using tape measures are made.
- Samples are labelled at the scene: case name, person collecting, date, and time.
- Standard procedures are used for site location, site description, observation, upper and lower depth of sampling, soil morphology (see Appendix 2).
- Adequate photographic record is made in accordance with the *Australasian Guidelines for Digital Imaging Processes* (EESAG 2004). This includes close-up views (e.g. of specific and general features) and perspective views from some distance away to provide information about the environmental context. Photographs must be labelled with case name, person collecting, date, and time. A scale such as a special CAFSS 10 cm scale (see Figures 2, 5, 6 and 7) or 2m scale (see Figure 8) is used in the photographs where appropriate.

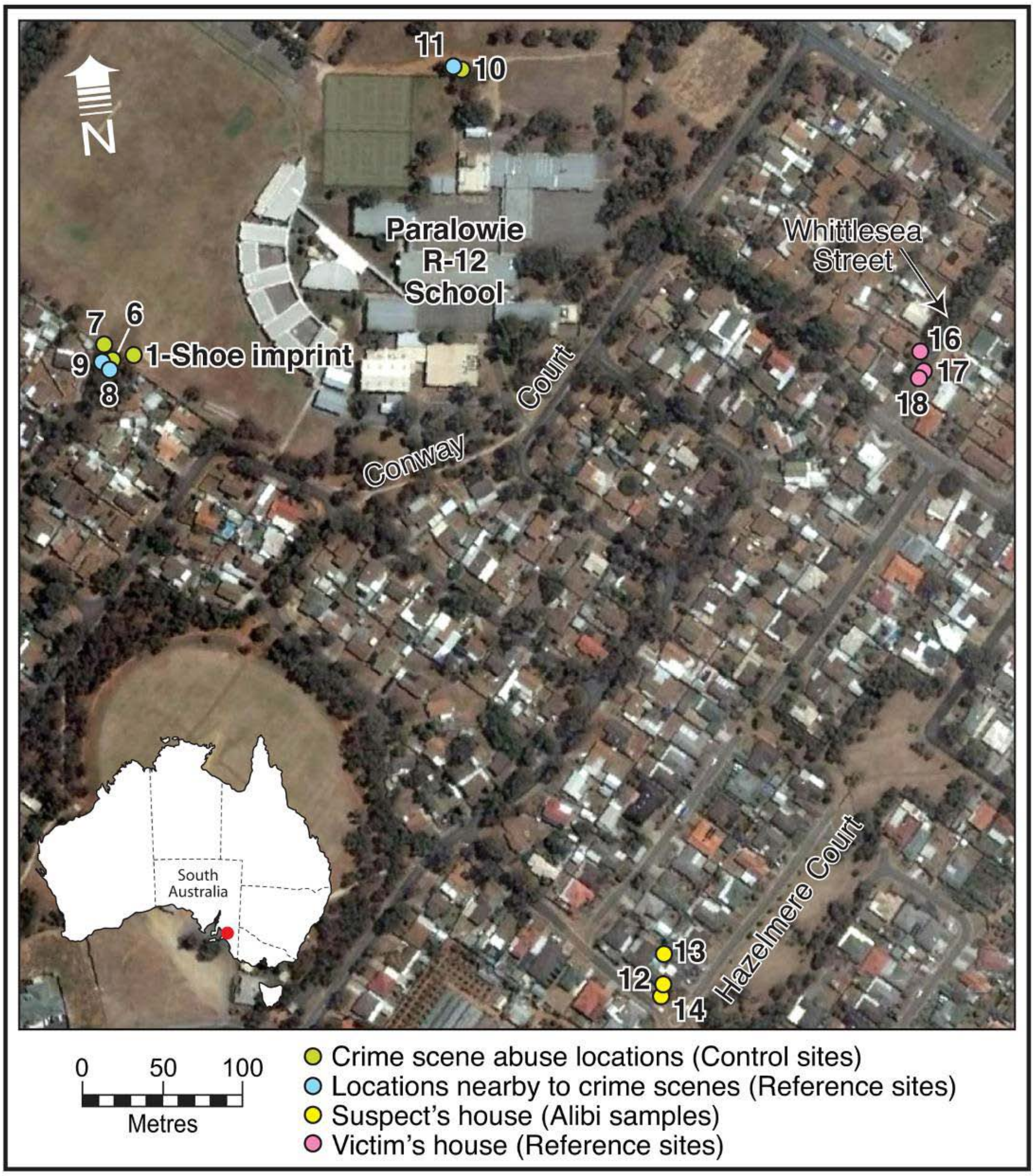


Figure 3. Google Earth image showing thirteen representative localities where soil materials were sampled at: (i) Crime scene abuse locations (Control sites), (ii) locations nearby to crime scenes (Reference sites where samples of loose - possibly transferable soil taken in pathways and under trees:), (iii) Suspect's house (Alibi sites where samples were collected on the surface (0 to 3 cm)] and (iv) Victim's house (Reference sites). Additional samples were collected to determine whether or not the suspect had transferred soil materials to his shoes from near his house or near the house of the victim or near/at the crime scenes. The reference and alibi samples were used to determine differences or similarities with the control samples (Modified from Fitzpatrick and Raven, 2009; Fitzpatrick *et al.* 2012).

***Considerations of environmental alteration*:** Soil evidence from moist or wet samples containing: (i) fine-grained pyrite, which can rapidly oxidize in air to form sulfuric acid and (ii) other materials, such as botanical or human remains (e.g. from an excavated human body or human hair; Figure 4) may be subject to environmental alteration or degradation over time.

Moist samples should be transferred to Petri dishes with extreme care and dried 60^{o}C before being photographed or characterised. If the samples pose a biohazard appropriate personal protection equipment (e.g. face mask, hair cover and latex gloves: Figure 4) should be worn. Suitable precautions must be taken to avoid cross-contamination between forensic scientists and samples during the drying (Figure 4).

For this reason, such soil samples should be preserved and collected as early as possible in the course of an investigation. This does not preclude the possibility of collecting additional samples at a later date, but it should be noted that these samples may not represent the materials that were present at the time of the crime.

Figure 4: Photographs showing precautions taken to avoid cross-contamination between forensic scientist and samples during the drying of moist questioned samples taken from: (i) the excavated body deposition site, (ii) head/face of deceased (obtained at post mortem) and (iii) body bag of deceased, which contained soil and human hair (samples were received from the South Australian Police in marked containers labelled "BIOHAZARD"). Samples were placed in covered glass petri dishes and oven-dried for two days at 60 degrees centigrade. (From Fitzpatrick 2013e)

***Exhibit triage*:**
Exhibits must be kept at the original property point until such time as the following acceptance criteria are met:

I. Discussions have occurred with the relevant scientist regarding the probative value of these exhibits.

AND

II. Suspect's (names and DOB supplied) are known at the time of intended lodgement and samples have been taken from the suspect or items linked to the suspect.

OR

An Investigator has been directed by the Court to supply a full brief of evidence and the scientist has advised the analysis is likely to reveal evidence of significant probative value.

OR

The samples provided may provide a link between two scenes, which may assist in identifying the suspect.

AND

III. All questioned and known soil samples are submitted together and are appropriately packaged with clear information outlining the exhibits taken (Figures 5 and 6) and the reasons for soil analysis.

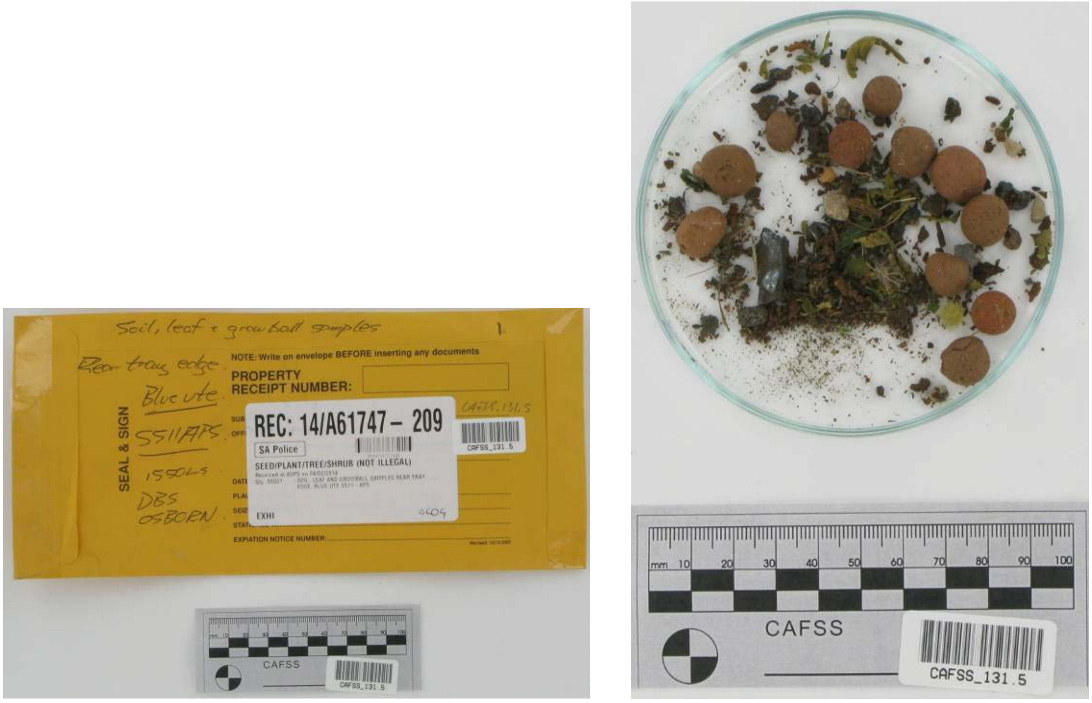


Figure 5: Photographs of the questioned soil sample (CAFSS_131.05; 14/A62160 – 209) sampled from a from the tray of a utility vehicle S511APS: (i) Top Left - “as received” from police and photographed using a Canon 40D 10 MP digital SLR camera with a Canon EF 100mm macro lens and Canon MT-24EX macro twin light flash unit and (ii) Top Right transferred to Petri dish and photographed in the Ortery Photosimile light box showing the dark brown human-made organic-rich soil, which has an artefact coir fibre matrix with red rounded porous scoria fragments (from Fitzpatrick 2015). Samples are given a unique numeric CAFSS code (i.e. CAFSS_131.05) that is printed onto an adhesive bar coded label, which is fixed on: (i) the “as received” sample container and (ii) the CAFSS 10 cm scale bar marker. (From Fitzpatrick 2015a)

Figure 6: Photographs of control soil sample (CAFSS_131.02; 14/A62160 – 177) from a cannabis plant: (i) Top Left - “as received” from police and photographed using a Canon 40D 10 MP digital SLR camera with a Canon EF 100mm macro lens and Canon MT-24EX macro twin light flash unit and (ii) Top Right - transferred to Petri dish and photographed in the Ortery Photosimile light box showing the dark brown human-made organic-rich soil, which has an artefact coir fibre matrix with red rounded porous scoria fragments (from Fitzpatrick 2015). Samples are given a unique numeric CAFSS code (i.e. CAFSS_131.05) that is printed onto an adhesive bar coded label, which is fixed on: (i) the “as received” sample container and (ii) the CAFSS 10 cm scale bar marker. (From Fitzpatrick 2015a)

3 Questioned soil sample collection

A soil profile usually consists of a number of different soil layers or horizons each with different properties. Consequently, observation of depth changes in soil morphological characteristics is critical. A layer structure is also found in other forensic situations such as the soil accumulated on the soles of shoes or on shovels. Consequently, it is recommended that wherever possible each layer be carefully sampled and characterised.

- It is critical to wear clean latex gloves (Figure 4). Do not use powered gloves or talcum powder in the gloves because the layer silicate mineral talc will contaminate the soil sample.
- Always use clean non-porous tools (e.g., shovel, trowel – Figure 2, artist's palette knife), which are made of stainless steel (for harder materials) or plastic tools (for softer materials). Plastic spades and trowels generally lack the strength required to dig soils, especially for most Australian soil conditions. Artist's palette knives are useful for sampling very thin layers of mud or dust on surfaces.
- Preferably place soil samples in a rigid container rather than polythene bags or paper bags because the packaging must keep soil lumps intact. Do not use paper envelopes for soil samples because they tear and leak.
- Large lumps of soil should be kept in one piece if possible by wrapping in cotton wool or bubble wrap. Documentation should be taken to indication the outer layers of the soil piece.
- Trace samples of soil can be collected using a dry swab or with a small brush into a container.
- Store dry samples at room temperature.
- Samples must be labelled with the case name, person collecting the sample, date and time (e.g. Figures 5 and 6).
- Sample packages must be secure with the dry soil samples sealed in sample bags or bottles with tamper-indicating serrated evidence tape (Figure 7).

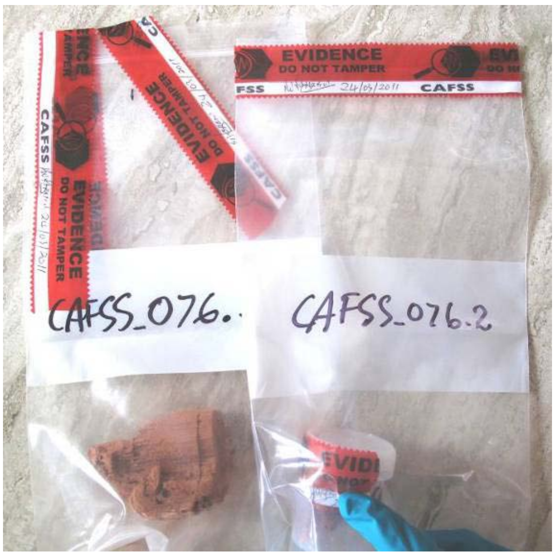


Figure 7. Photographs showing bulk CAFSS soil sample in sealed plastic bag (Left hand side) and soil sub-sample placed in a sealed plastic bottle using CAFSS red/white stripe tamper-indicating serrated evidence tape with CAFSS logo imprint in black.

Collection of soil from clothing, shoes, tools and other items

- If the soil adhering to an item of clothing, shoes, shovel or tool is wet or moist then air dry the whole item and then package the whole intact sample and item.
- In the case of sequential/chronologically deposited layers of soil being present first remove the 'surface layer' and then air dry.
- If other examinations are required on the item, remove as much of the soil material as possible, labelling the location the soil was collected and then package.

Collection of soil from vehicles

- If the soil is wet/moist or adhering in a wet/moist condition to objects (e.g. tyres of a vehicle) first air dry then collect the soil.
- Ensure that sequential/chronological deposited layers of soil are documented.
- Samples from underneath a vehicle to ensure samples are collected from the front and rear of the vehicle separately.
- Examine other areas such as wheel arches, inner wheel-rims (Figure 8), fender wells and other catchment areas under the vehicle for potential soil samples. Document the location of the different location of samples.
- Samples from the vehicles dust film should be considered. The dust film is an area approximately 10cm to 20 cm above the outside bottom of the vehicle doors and is where soil is flicked up onto the vehicle from the tyres (Figure 8). This can be sampled using a dry swab or if copious soil deposits then a brush into a rigid container.

Figure 8. Photographs showing: (i) Top Left - dry soil adhering to rear inner wheel-rim on drivers side of car driven by suspect; Bottom Left: close-up view of dried soil after removal from wheel-rim, scale bar indicates 10 mm (Questioned soil sample, CAFSS_088.02) and (ii) Top Left - dry soil adhering to the back door on the passenger side of police vehicle after having driven along the stretch of moist unsealed roads in the national park within the Dandenong Ranges along Georges track - Olinda Creek Road – Barbers Road and very short section of Silvan Road to site CAFSS_088.5; Bottom Right: close-up of dried soil sample, scale bar indicates 10 mm (Control soil sample,CAFSS_088.17). (From Fitzpatrick 2013d)

4 Known soil sample collection

In major crime investigations, such as murder scenes, known control soil samples must be conducted after the removal of the body and before major disturbance of the site (e.g. removal of vegetation).

The exact nature of sampling will vary from situation to situation and this should be considered when determining the number and location of known samples. Soil sampling can be divided into two classes: (i) targeted sampling and (ii) random sampling.

Targeted sampling

Sampling localised areas: If distinguishing features are evident in the soil or on some other surface (e.g. flooring), then samples from the areas containing these features should be taken directly but only after photographing and other appropriate forensic sampling has been applied. For example, if a distinguishing feature is an indentation made by footwear or vehicle tyres, soil samples should be recovered after a plaster cast of the indentation is taken. The soil can be collected both directly from the indentation and the plaster cast.

Targeted soil samples should also be taken from locations deemed to be of high relevance. For example, samples should be taken near or below a widow where forced entry has taken place and where an offender is most likely to have stood or kneeled. Similarly, fallen lumps of mud or muddy potholes and the areas around them should be sampled.

For example, if the upper of suspect footwear is heavily coated with mud and the ground to be sampled for comparison with the mud on the footwear is wet and soft, then soil samples should be collected to a depth of around 0–10 cm. If the material to be sampled for comparison with the mud is a subaqueous soil or sediment from the bottom of a river channel, stream, pond, lake, or dam then a sample can be obtained by pressing a plastic tube or container into the soft submerged soil/sediment and removing it with a scooping action. In deeper water, subaqueous soils/sediment samples can be taken using specialized sampling devices such as the Russian D-auger or an Undisturbed Wet Sampler (UWS) (made by Dormer Engineering: http://www.doreng.com.au). The latter has been extensively tested, modified (e.g. connected to concrete vibrator) and used by CAFSS and CSIRO staff to collect subaqueous soil cores (Baker *et al.* 2011).

In contrast, if only the shoe tread was in contact with the soil and the soil is very hard and dry, then the upper 0–0.5 cm or thinner of the soil should be carefully collected.

Sampling across a region/wider area: The first step in sampling wide regions is to consult available soil or geological maps of the region of interest (if necessary in conjunction or with help from CAFSS). Using these maps, areas of broadly similar soil type can be identified and sampled. Clear features such as footpaths or tracks close to the location of interest should be sampled at several places along the feature (e.g. Figure 3). Urban soil and roadside sediments or gravel are important soil evidence in crime investigations. However, these features have not been considered in detail in traditional soil science and geology, but have been investigated quite extensively by forensic, archaeological and environmental scientists.

Random sampling

In the absence of obvious features at or around a location of interest, systematic sampling of the location should be conducted to obtain an unbiased sample (e.g. sampling on a cross-pattern grid to fully characterise the soil patterns in the area).

A quadrant such as that shown in Figure 8 can be used by placing it on the ground to determine where sampling would take place. Samples can then be collected from the top left hand quarter of the quadrant. This would involve sampling a 200mmx200mm area initially to a depth of 2cm and then separately and directly beneath the first sample, to a depth of 5cm. A minimum of two samples at depth interval of 0-2cm and 2-5cm should be taken at each sample site. Samples should be collected with the use of a stainless steel spade. The majority of the sample (approximately 1kg for each depth interval) should be placed in labelled (e.g. bar coded) plastic zip-lock bags with a portion being placed into a soil chip tray for easy visual morphological characterization and comparison (see Fitzpatrick *et al.* 2010).

Figure 8. Photos showing: Top left and right - quadrant used in random sample collection (from Creeper 2008).

- Documentary record of each individual sampling location should be obtained. This includes geographical coordinates using a hand-held GPS instrument. The easting, Northing and elevation of each sample site should be recorded as a waypoint in the GPS as well as written into the exhibit notes.
- Samples should be labelled at the site location with the case name, person collecting the sample, date and time.
- A scale should be used in photographs were possible.
- If sampling on a dirt roadway samples should be taken from the centre of the road as well as the tyre tracks.
- Collect approximately 100-200 mL of soil from each likely point source. Due to the variation in soil, not only across the surface of the land, but also in a vertical direction (the soil "profile"), multiple samples may have to be taken from a grave site wherever the colour or texture (granularity) changes.
- Package each point source sample in a specimen jar and label with a suitable descriptor. Record in detail via notes, diagrams and/or photographs the relationship between samples.
- If possible, take further soil samples from some distance away from the scene. These could be taken at compass points (N, E, S, and W) and at a distance ranging from 25 to 100 metres, depending on soil variability and geographical constraints.
- The purpose of these samples is to potentially demonstrate that soil at the scene has a localised distribution; that is to say, soils from the compass points differ in many respects from each other and also from soil at the scene. Submitting a suspect soil sample with only a single control soil sample has

very little evidentiary potential (even if the two can be shown to be similar) because it cannot be established how widespread the occurrence of this soil type is.

- Document collection of these samples using a hand-held GPS instrument. The easting, Northing and elevation of each sample site should be recorded as a waypoint in the GPS as well as written into the exhibit notes. Also a diagram showing significant geographic features and relative positioning of sample sites greatly assists the analyst in the analysis and ability to form an opinion (Appendix 1).
- Moist soil samples that cannot be immediately transferred to the laboratory must be dried at room temperature in a secure location while covered with a breathable material (e.g. a lint-free wipe) so as to prevent environmental contamination of the sample.
- Wet or subaqueous (i.e. submerged under water) soil samples, especially [1]subaqueous acid sulfate soil materials (i.e. contain pyrite, which will rapidly oxidize to form sulfuric acid if dried slowly at room temperature) must be dried rapidly in an oven at 80 degrees centigrade.

  [1]Subaqueous acid sulfate soils that contain hypersulfidic material have a field pH of 4 or more (i.e. contain pyrite with low neutralising capacity with a low amount of lime/calcite) - and is identified by experiencing a substantial drop in pH to 4 or less (in a minimum of water to permit measurement) when a 2 - 10 mm thick layer is kept moist (not wet) at room temperature for a period of 8 weeks until the soil pH changes by at least 0.5 pH unit to below 4.

- Ensure all samples are packaged separately including outer packaging and labelled appropriately.

Analysis

A separate portion of the dried soil sample should be sieved to less than 2mm with a nylon sieve (so called "Fine Earth Fraction" – e.g. McDonald and Isbell 2009; Schoeneberger et al. 2012). The nylon sieve consists of a nylon net, with 2mm spacing's and a plastic casing, plastic lid, and plastic collection bucket. Very firm soil peds can be broken up with a plastic coated steel mallet. All other implements used to fracture and crush any very firm soil features must be either plastic or plastic coated.

The Fine Earth Fraction (<2mm fraction) is used for routine soil chemical and physical analyses (Rayment and Higginson, 1992; see also section 3 / Step 3.5 below) and also for magnetic susceptibility measurements (e.g. Thompson and Oldfield 1986; see section 2 / Step 2.3 below). Magnetic susceptibility measurements are extremely sensitive to metal contamination. Hence, metal contact with these samples post collection must be completely eliminated. The only contact between these samples and metal is during the digging of the samples from the ground with a stainless steel spade. The nylon sieve must be cleaned between each sample sieving with compressed air and wiped with a lint-free cloth. Once sieved, the sample must be placed into a new, labelled, plastic zip-lock bag and stored in the laboratory until needed for analysis.

If more detailed information and assistance is required contact:

Professor Rob Fitzpatrick: Director, Centre for Australian Forensic Soil Science,

Phone: 08 8303 8511; Mobile 0408 824215; Email: rob.fitzpatrick@csiro.au. Intact samples should be submitted to Prof Fitzpatrick (CAFSS).

5 Soil sample chain-of-custody and quarantine approval

Of paramount importance in both soil collection/sampling and soil characterisation/ evaluation is continuity of evidence or the sample chain-of-custody, which must be maintained and documented at all times throughout an entire soil forensic investigation (see Appendix 2 for CAFSS Chain-of-Custody form). Secure sealing of dry soil samples in sample bags or bottles with tamper-indicating serrated evidence tape (see Figure 7 showing soil samples in plastic bag sealed using the red/white stripe tamper-indicating serrated evidence tape with CAFSS logo imprint in black routinely used by CAFSS) and sample storage is vital.

The procedures for sampling, soil characterisation (Appendix 1) and analytical methods must be rigorous and well documented. Secure sample storage and rigorous procedures ensures that information about each sample is unambiguously retrievable and can be presented in Court with absolute certainty. All CAFSS samples are stored in a steel cabinet that is kept locked in a secure room (Dr R.W. Fitzpatrick and Mr M.D. Raven are the only persons able to gain entrance to the room via magnetic card reader system) until required for characterisation. The secure room is also a registered Quarantine Approved Premise (QAP), which is a specific facility registered by CSIRO and approved by DAFF Biosecurity (Department of Agriculture, Fisheries and Forestry Biosecurity) to receive quarantine goods of a high risk nature and the storage, use or further processing of products that are subject to quarantine. CSIRO Land and Water Flagship at the Waite Campus has DAFF Biosecurity approval as a class 5.1 facility (DAFF Biosecurity premise approval number S0116), which is managed by a Quarantine officer in accordance with the CSIRO Land and Water Quarantine Approved Premise Management Manual (Cozens 2012; Appendix 3).

If several items have been collected or submitted for soil forensic examination, anti-contamination protocols must be followed. Such protocols must also be implemented during the arrest/seizure phase of items by police or environmental agencies. Laboratory protocols should be strictly implemented to ensure that examination of the items (e.g. shoes or clothing) are suitably separated from other items for examination. Particularly in ongoing forensic investigations, where the clothing of further suspects and/or items that may be submitted subsequent to the initial submission of samples, detailed records must be kept of locations of item examination (e.g. laboratory room numbers – as per CAFSS Chain-of-Custody form – see Appendix 2).

6 Characterization Methods and Evaluation

Characterising soils for a forensic comparison, broadly involves the division of methods into four stages each comprising several steps and involving a combination of techniques (e.g. various descriptive or morphological and analytical methods listed in Figure 9). Consequently, soil characterisation requires a multidisciplinary approach, which combines descriptive, analytical and spatial information (e.g. mapping) steps in the following four stages:

Stage 1 Initial characterization for screening of samples.

Stage 2 Semi-detailed characterization.

Stage 3 Detailed characterization.

Stage 4 Integration and extrapolation of soil information from one scale to next.

The progression of a soil examination through each of the four stages will depend on a number of factors such as the amount of sample available and the results from the early stages of the examination (see Table 1; Figure 9). Not all stages may be required for all investigations. However, in some investigations it may be necessary to repeat all four stages during the course of a soil investigation to sequentially examine various questioned (Q), control referenced (R, maps or archived), control collected (C) or alibi (A) samples (Table 1).

Table 1. Recommended stages for sequential examination of questioned, control (collected), reference (via maps, soil/geological archives and collected from known sites) and alibi samples during an investigation (modified from Fitzpatrick and Raven 2012).

Type of forensic soil sample	†Stages for sequential examination of questioned (Q), control collected (C), referenced from: maps/archives or collected (R), and alibi collected (A) samples
Questioned samples (Q) *Collected* samples of unknown or disputed origin (e.g. from shovel, shoes, clothing etc.)	Stage 1Q. Initial characterization for screening of sample Stage 2Q. Semi-detailed characterization Stage 3Q. Detailed characterization Stage 4Q. Comparisons between various *collected* questioned samples and construction of generalised soil models (e.g. using soil classification, small-scale soil maps, landscapes).
Control samples (C) *Collected* samples with a known and undisputed origin (e.g. proposed crime scene)	Stages 1C to 3C (As for Stages 1Q to 3Q) Stage 4C. Comparisons between questioned samples and *collected* known control samples and construction of detailed soil-landscape models (e.g. using soil classification, large-scale soil maps etc.)
Reference samples (R) *Reference* samples from known maps, collections, archives, museums *Collected reference* samples from a known locality linked to a victim provide a measure of the uniqueness of the questioned and control samples	Stages 1R to 3R (As for Stages 1Q to 3Q) Stage 4 R. Comparisons between questioned samples and known *reference* archived samples / soil maps and construction of generalised soil-landscape models (e.g. using soil classification, small-scale soil maps etc.) Stage 4 R. Comparisons between questioned samples and known *collected reference* samples and construction of more refined or detailed soil-landscape models to illustrate uniqueness of the Q and C samples (e.g. using soil classification, large-scale soil maps etc.)
Alibi samples (A) *Collected alibi* samples from a known locality linked to a suspect to provide a measure of the uniqueness of the questioned and control samples	Stages 1A to 3A (As for Stages 1Q to 3Q) Stage 4A. Comparisons between questioned samples and *collected* known alibi samples and construction of more refined or detailed soil-landscape models to illustrate uniqueness of the Q and C samples (e.g. using soil classification, large-scale soil maps etc.)

† Not all forensic investigations will require this sequence of examining questioned, control, reference and alibi samples (e.g. control, reference and alibi sampling may not be possible in counter terrorism investigations). In previous editions of these Guidelines and several CAFSS reports, alibi and reference samples were grouped as “alibi samples”. The division into alibi and reference samples has been made to be more specific about linking suggested locations to a suspect (alibi) or victim (reference).

Several forensic practitioners have suggested a similar sequence or succession approach of sediment/soil analysis for exclusionary/comparative forensic investigations (e.g. Sugita and Marumo 2004; Murray 2004 illustrates the examination sequence developed and used by the forensic scientist Skip Palenik). However, there is no “authoritative” scene of crime manual or laboratory methods manual that prescribes approaches, stages and steps for soil forensic examinations. The approach and method of each forensic situation has to be taken on its merits according to existing conditions but must involve using standard approaches to record, describe and analyse materials. However, the preferable approach is to characterise samples using non-destructive methods (e.g. using visual or X-ray diffraction methods), especially during the screening stage of investigations (e.g. Stage 1) rather than destructive methods [e.g. thermal analysis using Differential Thermal Analysis (DTA) in Stage 3; Figure 9)].

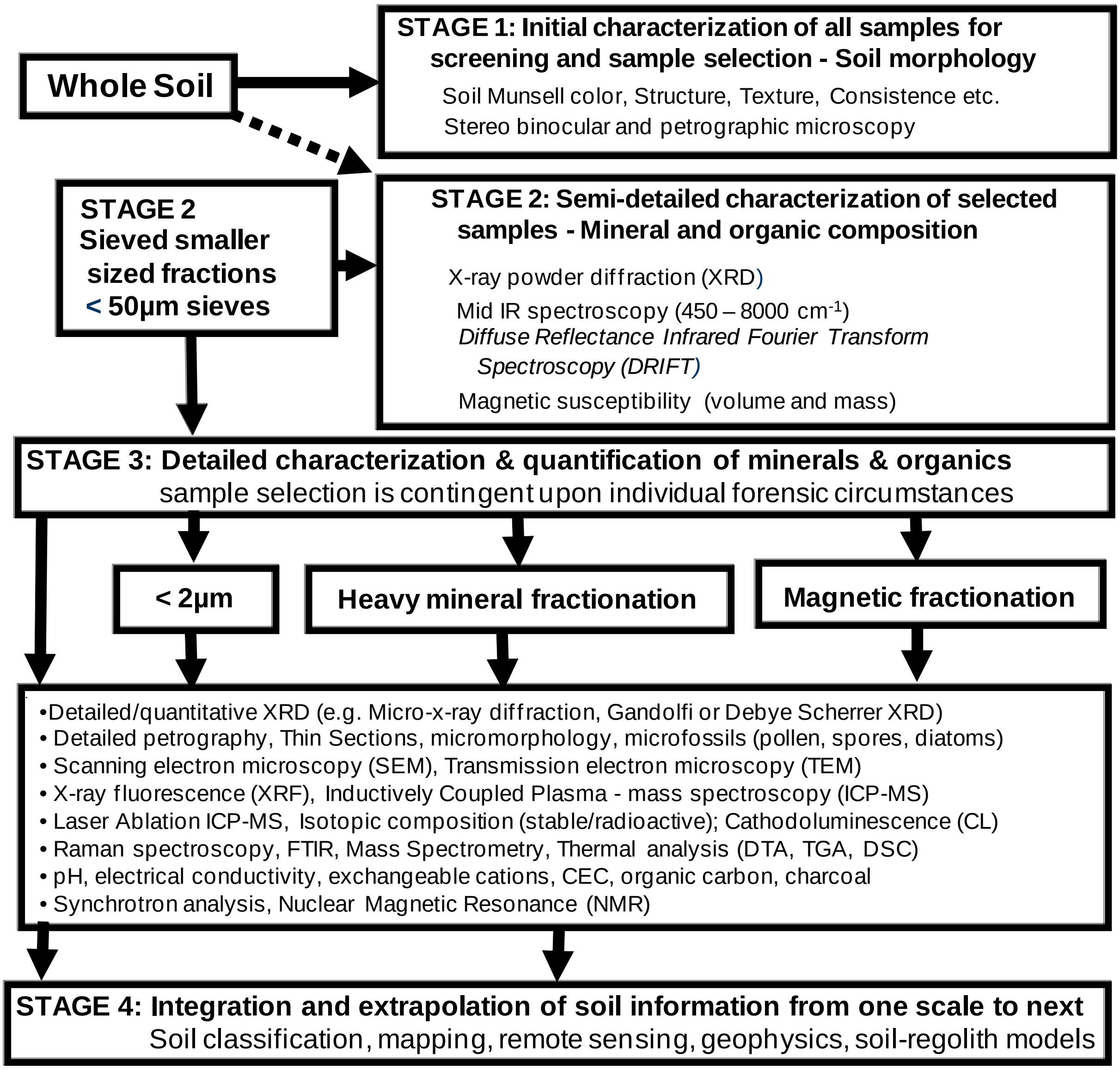


Figure 9. A systematic approach to discriminate soils for forensic soil examinations where, FTIR is Fourier Transform Infrared spectroscopy, DTA is Differential Thermal Analysis, TGA is Thermogravimetric Analysis, DSC is Differential Scanning Calorimetry and CEC is Cation Exchange Capacity [Modified from Fitzpatrick 2008; 2009, 2013c; Fitzpatrick *et al.* 2009].

6.1 Stage 1: Initial characterization for screening of samples

Stage 1 – Morphological characterisation of bulk or whole soil samples for screening of samples (Fitzpatrick *et al.* 2009; Fitzpatrick 2008, 2009, 2013b; Figure 9).

Initial screening (i.e. morphological comparison examination) of whole soil samples is to visually compare samples (i.e. hand held samples/specimens, soil profiles and samples/specimens by eye or under a stereo binocular light microscope). To do this properly, the soil must first be systematically described and characterised using standard Australian (McDonald and Isbell 2009) and International (Schoeneberger *et al.* 2012) soil morphological methods; to deduce whether a soil sample can be used as evidence.

Step 1.1 - Morphological characterisation of hand held samples, soil profiles and samples visually with the naked eye and by optical microscopy (stereo binocular light microscope)

Soil morphology is defined as the branch of soil science and pedology that deals with the description, using standard terminology, of *in situ* spatial organisation and physical properties of soils regardless of potential land use. Soil morphological interpretation provides a visual, quick and non-destructive approach to screen and discriminate among many types of forensic soil samples. It is for this reason that all samples are characterised first using the morphological descriptors. A checklist of macro-morphological descriptors and tests has been compiled from standard techniques used in soil science (e.g. McDonald and Isbell, 2009; Schoeneberger *et al.*, 2012) for assessing the soil properties for forensic examinations. These soil descriptors include (Figure 9):

- Colour of soil matrix and segregations using either: (i) Munsell Soil Color Charts (1994; 2000) or a colour spectrophotometer (e.g. Guedes *et al.* 2009a,b).
- Redoximorphic features of pedogenic origin (kind, quantity, size, contrast, colour moisture state, shape, location, hardness and boundary) - Schoeneberger *et al.* (2012)
- Texture (e.g. sand, loam or clay) – McDonald and Isbell (2009)
- Shape of quartz grains - roundness and sphericity (e.g. sub-rounded, rounded) – from McDonald and Isbell (2009)
- Structure [type (e.g. massive, single grain or peds), grade (e.g. weak) and size (e.g. fine)] – McDonald and Isbell (2009)/ Schoeneberger *et al.* (2012)
- Consistence - dry state rupture resistance (e.g. loose, soft to rigid) - Schoeneberger *et al.* (2012)
- Segregations and coarse fragments (carbonates, ironstone and mottles of lithochromic or lithomorphic origin) - McDonald and Isbell (2009); (colour, quantity, size, contrast)
- Roots and Pores (quantity, size and shape) - McDonald and Isbell (2009)
- Water repellence - McDonald and Isbell (2009)
- Effervescence class (reaction to HCl – to estimate presence of carbonates) - Schoeneberger *et al.* (2012)

For questioned soil samples and soil samples from control and alibi sites a complete visual description of the soil is essential because it serves as a basis for soil identification, classification, correlation, mapping and interpretation (e.g. Fitzpatrick *et al*. 1999, 2003; 2007; 2009, 2012; Fitzpatrick 2008, 2009, 2012, 2013a,b,c;

McDonald and Isbell 2009). This is particularly the case where the soil in question may have been transported by, for example, vehicle, foot or shovel.

A soil profile consists of a number of different soil layers or horizons each with different properties. Consequently, observation of depth changes in soil morphological characteristics is also recommended. A layer structure is also found in other situations such as the soil accumulated on the soles of shoes. Again, it is recommended that wherever possible each layer be carefully characterised.

Low magnification light microscopy. The use of petrography is a major and often precise method of studying and screening soils for discrimination in forensic examinations (Figure 9). For example, nearly fifty common minerals (e.g. gypsum) as well as several less common minerals can easily be seen and distinguished by the naked eye, while the use of a hand lens or low power stereo-binocular microscope enables the forensic soil scientist to better detect mineral properties (e.g. particle shape and surface texture) and provide more accurate mineral identification.

The petrographic microscope is also commonly used for identifying microfossils, pollen grains, grass spores, opal phytoliths, diatoms, minerals and rocks. Thin sections of soil materials are mounted on a glass slide and viewed with the petrographic microscope under different incident light conditions through its special attachments. Where possible, such micro-morphological investigations are used to supplement and verify features in macro-morphological descriptions.

Overall, macro-morphological and petrographic descriptors are useful in assessing soil conditions because:

- They involve rapid field and laboratory assessments. Other methods, such as routine semi-quantitative mineralogy (Stage 2) and more detailed quantitative mineralogy and geochemistry (Stage 3) are often complex and costly to carry out.
- They can be used to rapidly evaluate causes for variations in soil condition induced by weathering (that may range from recent, to thousands to millions or even billions of years), anthropogenic activities, land management, hydrology and weather conditions.

6.2 Stage 2: Semi-detailed characterization

Stage 2 – Identification, characterisation and semi-quantification of minerals and organic matter in bulk samples and on individual soil particles following sample selection and size fractionation (usually < 50 μm).

Once a familiarity with the morphology of the materials has been achieved using visual and light microscopic methods, most of the mineralogical and organic matter components in a particular whole or bulk soil sample can be rapidly identified and semi quantitatively characterised using the following three selected methods:

- X-ray powder diffraction (XRD),
- Diffuse Reflectance Infrared Fourier Transform (DRIFT) and
- Mass and volume magnetic susceptibility methods.

Step 2.1 - X-ray powder diffraction (XRD). XRD methods are arguably the most significant for identification, characterisation, semi-quantitative and quantitative analyses of minerals in forensic soil science (Kugler 2003; Fitzpatrick *et al.* 2009; Fitzpatrick, 2009, 2013b,c; Fitzpatrick and Raven 2012). Extremely small sample quantities (e.g. a few tens of milligrams) as well as large quantities can be successfully analysed using XRD. The critical advantage of XRD methods in forensic soil science is based on the unique character of the diffraction patterns of crystalline and even poorly crystalline soil minerals. Elements and their oxides, polymorphic forms (e.g. anatase and rutile, the polymorphic forms of TiO_2) and mixed crystals can be distinguished by this non-destructive examination. Part of the comparison involves identification of as many of the crystalline components as possible, either by reference to a database of XRD data (e.g. the ICDD Powder Diffraction File, Rendle 2004), or to a local collection of standard reference diffraction patterns, coupled with expert interpretation (e.g. Fitzpatrick *et al*. 2009; Kugler 2003).

XRD patterns can be likened to finger print comparisons between soil samples that delineate how closely the samples relate to each other (e.g. Fitzpatrick *et al*. 2009). However, it is crucial to ask "what is the significance of a close similarity in mineralogical composition and therefore a close similarity in XRD patterns?" If, for example, two soil samples contain only one crystalline component such as quartz (i.e. silicon dioxide), which is very common in soils, the significance of the similarity and its evidential value in terms of comparison criteria will be low. If, however, two soils contain four or five crystalline mineral components, some of them unusual, then the degree of similarity will be considered to be high (e.g. Fitzpatrick *et al*. 2009; Fitzpatrick and Raven 2012).

Step 2.2 - Diffuse Reflectance Infrared Fourier Transform (DRIFT). The main advantages of DRIFT spectroscopy are that the analysis is non-destructive and can be rapidly applied. The mid-infrared portion of the electromagnetic spectrum is sensitive to organic materials, clay minerals, and quartz because of the absorption of infrared light at the vibrational frequencies of molecular functional groups constituting these materials (e.g. Van der Marel and Beutelspacher, 1976; Nguyen *et al.*, 1999). As such, mid-infrared spectroscopy is a powerful and rapid qualitative tool, which can be used semi-quantitatively to characterise analytes of interest. This is especially the case when DRIFT is combined with mid-infrared partial least-squares (MIR-PLS) modelling or other chemometric techniques such as principal components analysis (PCA). MIR-PLS modelling has been developed and applied to soils to predict soil physicochemical properties (e.g. see Janik and Skjemstad, 1995; Janik *et al.* 1998) and has been routinely applied to rapidly screen and compare crime scene samples (Figure 9). PCA, which models the spectral signatures from the various components in a sample, is also a powerful discriminatory tool, providing an objective method of comparing the mid-infrared spectra of the soil samples being examined.

Step 2.3 - Mass and volume magnetic susceptibility. Mineral magnetic techniques are a relatively recent development and have now become a very powerful and widely used research tool to characterise natural materials in landscapes (e.g. Thompson and Oldfield 1986). Mass and volume magnetic susceptibility measurements provide a very rapid assessment of the magnetic properties of a soil. Susceptibility measurements can be used to detect magnetic materials in a soil (e.g. maghemite, magnetite) that are present at amounts below the detection limits of both DRIFT and XRD. Where appropriate, the use of magnetic susceptibility methods should be used before moving to the more costly detailed analytical methods (Stage 3), which generally require sample separation (Figure 9).

6.3 Stage 3: Detailed characterization

Stage 3 – Detailed characterisation and quantification of minerals and organic matter in bulk and on individual soil particles using additional analytical techniques and/or methods of sample preparation, separation or concentration (e.g. size or magnetic or heavy mineral fractionation) (Figure 9).

Step 3.1 - Advanced X-ray diffraction (XRD) methods. Forensic evidence is often only available on questioned items as small submillimetre particles (<0.5mm diameter) with the amount of material weighing less than a milligram. In addition, forensic materials may contain trace amounts of mineral particles, such as: (i) rutile or anatase within small paint or plastic flecks, (ii) polycrystalline minerals, cristobalite and mullite in small brick or burnt regolith particles and (iii) poorly-crystalline hydroxylapatite and well-crystalline hydroxylapatite in unburnt and burnt small bone fragments respectively. Such situations may preclude use of routine bulk XRD analyses and it is best to use an XRD fitted with a system for analysis of extremely small samples. For example, traditional X-ray diffraction (XRD) techniques using low-background Si wafer holders are extremely useful for measuring XRD patterns from samples with weights as low as several milligrams. However, these techniques are generally too insensitive to measure XRD patterns from samples weighing less than a milligram or individual submillimetre particles. Consequently, the mineralogy of small fragments (<0.5mm) can be determined with micro-XRD techniques using fine (submillimetre) monocapillary attachments on laboratory XRD instruments. For analysis in a Gandolfi or Debye-Scherrer powder camera, extremely small specimens (e.g. single mineral particles and paint flakes) can be mounted on the end of glass fibres.

While these instruments are adequate for determining dominant components, synchrotron XRD with high X-ray intensity provides far greater sensitivity and resolution than laboratory source XRD systems (Raven et al. 2011; Fitzpatrick et al. 2011). This enables identification of minute amounts of mineral components.

According to Kugler (2003), X-ray methods are often the only ones that will permit further differentiation of materials under laboratory conditions. Furthermore, with the appropriate calibrations, XRD can be used to quantitatively determine the mineral composition of a soil (as opposed to the qualitative XRD used in Step 2.1). According to Murray (2004) "Quantitative XRD could possibly revolutionise forensic soil examination".

Step 3.2 - Scanning electron microscopy (SEM) and transmission electron microscopy (TEM). SEM and/or TEM are frequently used to examine the morphology and chemical composition (via Energy Dispersive X-ray Spectroscopy) of particles magnified to over 100,000 times making SEM and TEM very useful for particle discrimination (e.g. Smale, 1973; Pirrie *et al.,* 2004; McVicar and Graves, 1997). Soil minerals, fossils and pollen spores that occur in soils (Marumo and Yanai, 1986) can be described and analysed in detail by SEM and TEM and therefore provide very useful indicators when studying soil samples.

Step 3.3 - Elemental analyses. The following range of more prevalent instrumental techniques are frequently used to determine the inorganic constituents in soil samples: X-ray fluorescence (XRF), atomic absorption spectroscopy (AAS), inductively coupled plasma (ICP) spectrometry, ICP-OES (optical emission spectrometry or sometimes called ICP-AES), ICP-MS and neutron activation analysis (NAA) (e.g. Pye 2007; Pye and Croft 2004). Several geochemical techniques, using isotope ratios, and geochemical signatures have been utilised in forensic work (e.g. Trueman *et al.*, 2003).

Step 3.4 - Biological methods. Fossil pollen grains and grass spores are preserved in many soils that are not strongly acidic (pH < 4) or alkaline (> pH 6). These reproductive particles are produced in large amounts by trees, shrubs and grasses and can be readily be used for soil comparisons (e.g. Bruce and Dettmann, 1996; Garrison, 2003; Mildenhall et al. 2006; Murrray, 1982, 2004; Pye, 2007; Wiltshire, 2009). Opal phytoliths (silica-rich) and calcium phytoliths are mineral deposits that form in and between plant cells. Marumo and Yanai (1986) used opal phytoliths to differentiate soils with similar mineralogy. Fourier-Transform infrared (FTIR) spectroscopy can be used to characterize soil organic constituents (fats, waxes, proteins, cellulose, hemicellulose and lignin) in soils. Other emerging soil forensic methods for soil comparison are: (i) Plant Wax Markers Analysis (summarised in Dawson *et al.*, 2008; Dawson and Hiller, 2010), (ii) Plant Fragment DNA Analysis (Dawson *et al.,* 2008) and (iii) Microbial Fingerprinting using a variety of molecular biological techniques to analyse the diversity in soil microbial communities (Dawson et al., 2008; Petrisor et al., 2006). Several soil forensic studies have been reported in Petrisor et al. (2006) to show that a soil bacterial community DNA profile can be obtained from small samples of soil recovered from potential crime scenes (e.g. shoes or clothing) with the profiles being representative of the site of collection.

The recent development of advanced DNA sequencing technologies provides the potential to identify individual species or taxa (e.g. bacteria, plants, animals and fungi) present in a soil sample, which will permit improved discrimination between soil samples. Young et al (2014a,b, 2015a,b 2016) recently examined and demonstrated the practical application of the use of DNA metabarcoding (PCR amplification of DNA mixtures using universal primers) combined with high-throughput sequencing (HTS) technology to distinguish soils from different locations in a forensic context based on the soil biota detected. However, However, before this approach can be employed as an additional tool in actual forensic soil science cases, additional studies are required to assess and quantify the vast “soil community” variation in different locations and habitats, and especially in soils that are subjected to seasonal variations (e.g. wetting and drying of acid sulfate soils).

Step 3.5 - Routine soil chemical and physical analyses. Laboratory analyses for standard routine or conventional soil chemical (e.g. pH, electrical conductivity, exchangeable cations, cation exchange capacity analyses, organic carbon, total carbonate using methods from Rayment and Higginson, 1992) and physical (particle size analyses) analyses must be conducted at either: (i) recognised laboratories that maintain appropriate standards or (ii) accredited laboratories for the particular parameters and methods required (e.g. National Association of Testing Authorities - NATA). In general, these methods require large amounts of sample (e.g. 10 to 50 gm) and are destructive. For all tests and analyses, the Quality Assurance and Quality Control procedures will be equivalent to those endorsed by NATA. All data prior to being released will undergo checks and be signed off by the laboratory Quality Assurance/Quality Control manager. In the report section for Quality Assurance and Quality Control a statement will be included that provides a summary of quality control results and any issues arising and details where the QA/QC data is held should a review be necessary.

Step 3.6 - Combined methods. All the techniques mentioned in steps 3.1 to 3.5 and others listed in Figure 9 (e.g. heavy and magnetic mineral separations, routine soil chemical and physical analysis, Laser Ablation, Raman spectroscopy, Thermal analysis, NMR and Synchrotron analysis) in combination achieve reliable, definite and accurate results, and provide additional information about the mineralogical, chemical and physical properties of the suspected soil material.

When used in combination, methods whose results partially overlap (e.g. XRD, XRF and DRIFT spectroscopy) can be used to provide a consistency check of results. The overlap of results from several techniques provides an overall secure result for a forensic examination (e.g. see Bull *et al.* 2004).

6.4 Stage 4: Integration and extrapolation of soil information from one scale to next

Stage 4 – Soil classification; soil, geological and vegetation maps; terrain analysis, remote sensing and geophysics, soil transference testing, soil-regolith models

Landform and soil mapping involves the integration and extrapolation of soil information from one scale to next to build a coherent model of soil information from microscopic observations to the landscape scale (e.g. using existing soil maps or field mapping information, see Table 1). In forensic soil science, a provenance examination or determination, also known as geographic sourcing, has developed to identify the origin of a sample by placing constraints on the environment from which the sample originated.

Step 4.1 – Soil Classification. Classifying soils for a particular purpose involves the ordering of soils into groups with similar properties and for potential end uses. Conventional soil mapping procedures use soil classification systems to produce maps by means of a series of polygons. In general, soil classification systems currently used in most countries involve the use of the following three broad approaches (Fitzpatrick 2004):

- General-purpose broad soil classifications, which communicate soil information at international scales [e.g. Soil Taxonomy (Soil Survey Staff 1999; 2010) and World Reference Base (IUSS Working Group WRB, 2014)] and national scales [e.g. Australian (Isbell and National Committee on Soils and Terrain 2016)].
- 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 [e.g. Hall, Maschmedt and Billing 2009 for South Australia).
- Special-purpose, technical classification systems, which are designed to cover a wide spectrum of practical issues, and are required for finer scales of resolution and use plain language descriptions for soil types (e.g. Fitzpatrick 2013a; see ''user-friendly'' terminology used to classify soils in Figure 10).

Step 4.2 - Soil, geological and vegetation maps, terrain analysis, remote sensing and geophysics. Integration and extrapolation of soil information are necessary because soils from the crime scene and control site may constitute a highly variable continuum.

Hence, integration of published soil maps or field mapping information together with other spatially held information, such as: (i) terrain analysis (DEM), (ii) regolith, geological or vegetation maps and (iii) remote sensing and geophysics data (e.g. Ruffell and McKinley 2005, 2008) are essential to the study of relationships between soils, landforms, and/or the stratigraphy of parent materials. Soil, regolith and geological maps should be used by forensic soil scientists in developing models to predict where sites of particular soil materials are located (e.g. Johnston *et al.* 2003; ASRIS database: http://www.asris.csiro.au/index_ie.html).

An example of this integration of data comes from staff in the Centre for Australian Forensic Soil Science (CAFSS) using soil maps and conducting field soil survey investigations to solve a double murder case (e.g. Fitzpatrick *et al.* 2007; Fitzpatrick and Raven 2012; Zala 2007). Morphological, chemical, physical and mineralogical properties were used to identify similarities between soil found on a shovel taken from the suspect's vehicle and soil subsequently located in a quarry. Samples were indistinguishable or strongly matched in terms of all comparison criteria used, thus revealing the location of two buried bodies.

Step 4.3 – Soil transference testing.
There has been little recent research focusing on the transfer of soil particles onto textile fabrics since Locard (1930). Most testing has involved human-made particles such as powder, glitter, glass fragments, acrylic and wool fibres (McDermott 2013; Roux and Robertson 2013). For example, Bull et al. (2006a,b) built on the experiments of Pounds and Smalldon (1975a,b,c) who had originally explored the transfer and persistence of textile fibres.

Murray et al. (2015, 2016) have recently reported on the development of new image processing software to better interpret a series of soil transference experiments using anthropogenic and natural soil transfer to bra-cups and straps caused by dragging. Murray et al. (2015, 2016) showed that soil type, clay mineralogy and soil moisture were the greatest influencing factors required to explain the eight categories of soil transference patterns that they observed (both naked eye and measured properties).

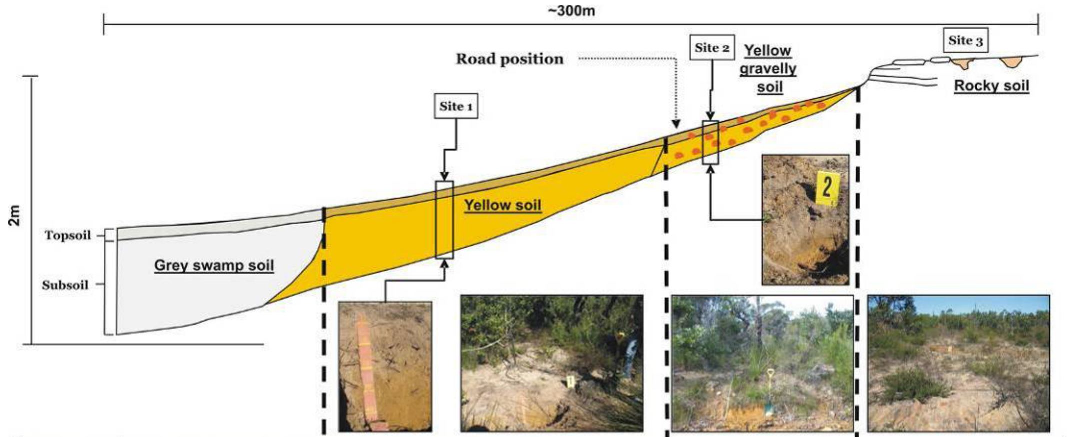
In a homicide case, Fitzpatrick R.W. (2015b) conducted a series of laboratory transference shaking experiments with a clean strip of pyjama top fabric and using scanning electron microscopy (SEM) observed that the mineral particles were dominantly located on the surface of pyjama fabric. However, in the heavily stained seams of the questioned pyjama top the mineral particles were observed by SEM to be mostly deeply impregnated in gaps between the fibres of the fabric, which likely originated under water with some force being applied on the pyjama top.

Step 4.4 - Construction of soil-regolith conceptual models. The integrated and extrapolated soil information (Steps 4.1 and 4.2) is used to ensure:

- better-informed sampling when pedometrically testing, for example, how 'similar' soil on a suspect's shoe is to a scene of crime (e.g. Junger 1996) and
- construction of a coherent model of soil information from microscopic observations to the landscape scale (e.g. physical, chemical or biological mechanistic process models).

Decision making in forensic soil science is sometimes guided by mechanistic process models describing processes with physical, chemical or biological mechanisms (e.g. Ruffell and McKinley, 2005, 2008; Murray, 1982, 2004; 2011; Murray and Tedrow, 1992; Pye, 2007; Pye and Blott 2009; Fitzpatrick *et al.,* 2009, 2012; Fitzpatrick and Raven 2012). Some models use multiple data layers as spatial input. The data required for the analysis are frequently found in and extracted from soil and environmental data bases such as geographic information systems (GIS's).

Soil layers, regolith layers, whole soil profiles, soil-regolith toposequence or cross-sectional models and soil/geological maps are commonly being used by forensic soil scientists in developing conceptual models to predict where sites of particular soil materials are located. An example of these relationships is from an investigation where digging implements (e.g. shovels, mattocks and rake) retrieved from the boot of the suspect's vehicle contained soils that were identified to be unique to a specific soil-regolith province where police investigators had circumstantial evidence that the suspects had buried weapons. To help police in the field to determine if samples from this soil-regolith province "do compare or do not compare" with soils previously identified and characterised on implements retrieved from the suspect's vehicle a soil-regolith conceptual model was constructed (Figure 10), which incorporates a typical sequence of soil subtypes and vegetation found on a slope in a thickly vegetated landscape. The soil-regolith toposequence model uses a plain language special-purpose technical soil classification system, which places strong emphasis on soil colour (e.g. grey swampy wet soil, yellow-brown soil and yellow-gravelly soil) so as to rapidly closely match these various soil subtypes in this complex/rugged terrain to the soil on the digging implements retrieved from a suspect's vehicle.



Soil type	Grey swamp soil	Yellow soil	Yellow gravelly soil	Rocky soil
Brief description	Grey swampy wet soils in low lying areas	Yellow-brown soils	Yellow-brown soils with ironstone gravels	Sandstone outcrops and pavements with pockets of shallow soils and ironstone gravels
Soil of interest?	NO	YES	NO	NO
Vegetation type	Swampy upland open, often treeless areas, dominated by dense vegetation and sedges	Predominantly uncleared open heath, closed-heath and scrub, with patches of eucalypt low-woodland	Predominantly uncleared open heath, closed-heath and scrub, with patches of eucalypt low-woodland	Predominantly uncleared open heath, closed-heath and scrub, with patches of eucalypt low-woodland
Surface soil features	White/grey sand	Yellow-brown with some patches of grey sand accumulated by surface water wash. Charcoal and burnt stumps may be present	As with "**Yellow Soil**", plus ironstone local accumulations of ironstone gravels	Flat and steep areas of sandstone with pockets of shallow yellow gravelly soil
Topsoil	White/grey sand	Yellow-brown sandy loam	As with "**Yellow Soil**", plus ironstone accumulations of ironstone gravels	Pockets of shallow yellow gravelly soil
Subsoil	White/grey sand	Yellow-brown sandy clay loam	As with "**Yellow Soil**", plus ironstone accumulations of ironstone gravels	Pockets of shallow yellow gravelly soil

Figure 10. Typical sequence of soil types and vegetation found on a slope in a densely or thickly vegetated landscape (from Fitzpatrick 2013a).

7 Case Assessment and Interpretation

Guidelines on governing how forensic soil scientists and geologists should write reports have not been issued to date (i.e. to interpret and value soil or geological trace evidence). However, according to Robertson (2009) “it could be argued that the expert should use *none* of the following three words: consistent, similar or match”. He recommends that “the purpose of any scientific examination and comparison should be to use appropriate and discriminating tests aimed at finding differences”. Finally, Robertson (2009) suggests that the application of the Bayesian statistical approach using likelihood ratios (LR) to weighting forensic evidence has: “not yet found wide acceptance in Courts where the judiciary seem certain to take a conservative approach to its adoption. If this approach is to gain acceptance in the future, there will need to be a large body of research to base an informed estimate of the probabilities which make up the LR.” Without further research CAFSS do not recommend the Bayesian approach.

A small working group within the International Union of Geological Sciences (IUGS), Initiative on Forensic Geology (IFG) had constructive discussions on developing a “Terminology Scheme to assess soil and geological evidence” at their inaugural IFG meeting in Rome, Italy on 18th September 2011. As a consequence of constructive discussion during the IFG meeting it was decided **NOT** to use:

(i) the terms “consistent”, “similar” or “match” (Robertson 2009),

(ii) the oversimplified Verbal Terminology scheme used by the U.K. Forensic Science Service to assess evidence relating to footwear marks and various forms of trace evidence other than DNA (Table 2),

(iii) the more complex “Verbal Terminology scheme with 10 Relative Rankings” developed by Pye (2007),

(iv) terminologies that may be associated with statistics such as “probability” or “degrees of probability” or the use of “likelihood ratios” (the Bayesian approach) in the provision of an evaluative opinion.

The main reason for not using the descriptors given in Table 2 is not because the terminology is inadequate but rather because the descriptors require a context.

As a result, CAFSS has developed a terminology scheme, which uses “Categories of Comparability” with defined “Examples of Type of Evidence” for soil or geological evidence interpretation (Table 3). It is hoped this scheme will be refined and developed as guidance for:

(i) interpretation of results and

(ii) meeting admissibility requirements in courts.

Table 2. Simplified Verbal Terminology scheme used by the U.K. Forensic Science Service (from Pye, 2007, page 247).

Verbal Terminology
None
Limited
Moderate
Moderately strong
Strong
Very strong
Extremely strong
Conclusive

Table 3. Terminology scheme used by CAFSS to assess soil and geological evidence (modified from Pye, 2007 and Fitzpatrick 2013c).

Categories of Comparability	Examples of Type of Evidence
None	Different in virtually all aspects
Limited	Some general comparison in terms of soil morphology (colour, texture, and/or relatively common particle types present)
Moderate	General comparison in terms of soil morphology, especially in having a similar assemblage of relatively common particle types in common, some of which may have distinctive textural or chemical features
Moderately strong	Fairly high degree of comparability in terms of soil morphology as well as chemical, mineralogical, and/or biological properties; including relatively unusual particle types in common
Strong ***to*** **Very strong**	High degree of comparability in terms of soil morphology as well as chemical, mineralogical, and/or biological properties; including several relatively unusual particle types present
Extremely strong ***to*** **Conclusive**	Physical fit (rocks) and very high degree of comparability in terms of soil morphology as well as chemical, mineralogical, and/or biological properties; including one or more very unusual particle types present.

8 Practice Direction: Guidelines for Expert Witnesses

"Never write a report, investigate a problem or go to court using methods of which you are not confident, and if such are included, comment on only those aspects of which you have experience" (Ruffell and McKinley 2008, p 11).

It is important for expert witnesses to state their conclusions clearly, logically and without bias. An expert witness should have sufficient knowledge of their subject to state the reasons for their findings in a manner understandable to the Court. In Australia there are Codes of Practice for expert witnesses (Robertson 2009) and standard features of these include:

- An expert witness has an overriding duty to assist the court impartially on matters relevant to the witness's area of expertise and is not an advocate for a party.
- An expert witness must work cooperatively with other witnesses.
- A report by an expert witness must set out all the facts and assumptions on which the expert's opinions are based and must note any matters that qualify those opinions.
- If an expert witness changes opinion, the witness must prepare a supplementary report.

Guidelines for expert witnesses have been issued by the Federal Court of Australia under the authorship of Chief Justice (now former Chief Justice) Black (Black, 2008). These guidelines are reproduced in Appendix 4.

Expert Witness and Report Checking Statements. Example used in all CAFSS reports are reproduced in Appendix 5.

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Appendix 1. Data requirements for site and soil profile descriptions

Table A1.1. Data requirements for site and soil profile descriptions - list of parameters, units of measurement, method or method reference, and objective for conducting field test.

Parameter	Units	Method or Method Code	Method Reference	Objective
Site identification number	Unique numeric code	Unique code CAFSS030.1 etc.	Sequence provided by client (e.g. police)	Uniquely identifies site
Site Location – co-ordinates	Zone, Easting and Northing co-ordinates	Global positioning system (GPS) locate to the Geocentric Datum of Australia 1994	Not applicable	Accurately place the sample site within the investigation or study area
Site Location – map	Map	Locate site on an appropriately scaled map, preferably a photo image	Not applicable	Shows relationship of the sample site to other sites and features of the study area
Site Description (includes general location and position of the known control and/or alibi samples) including surface condition and vegetation.	Text description	Text description for the measured parameters, including a sketch map and cross-section.	Refer for guidance to National Committee on Soil and Terrain (2009)	Places the sample site within the landscape and surrounding environment, to enable extrapolation of the soil sample information and to estimate the proportion that it represents in the study area
Type of soil observation	Categories	Text description	National Committee on Soil and Terrain (2009)	Provides detail on how the sample was obtained
Upper and lower depth of sampled/described layer	cm	Tape measure	National Committee on Soil and Terrain (2009)	Estimating the layer thickness and position in the profile of the soil sample
Soil Morphology Description (colour, field texture, consistence, structure, moisture status, and other unique features if they occur, such as mottling (redoximorphic features), odour, organic material, shell fragments, minerals such as jarosite, crystals, coarse fragments)	Categories	As per the categories listed for the soil morphology description parameters	National Committee on Soil and Terrain (2009); Schoeneberger *et al*. (2012) – for redoximorphic features	For characterisation and classification of the soil. To facilitate understanding of soil variability and transfer of quantitative data between profiles and layers that appear similar through this qualitative description
Photographs - soil profile, soil (or water) surface, surrounding landscape (at a minimum on the 4 opposite points of the compass), and any other features of interest, including chip-tray samples.	Digital	See EESAG (2004) for sufficient quality for reports. Soil profile photographs must have a scale marker on left side.	Photographs saved as JPEG or TIFF format for photographs and required and file naming convention (EESAG, 2004).	Provides a visual record of the sampled site and location.

Appendix 2. CAFSS Chain of custody forms

Chain of Custody

For legal or forensic samples sent to Centre for Australian Forensic Soil Science (CAFSS)

CAFSS Case Number: CAFSS_

1. Courier: - Sample Reception in CAFSS laboratory

Sample released by	Sample received by	Date & Time
Name Section Signature	Name Section Signature	

Condition of sample containers (e.g. bags) and seals inspected and recorded by CAFSS Staff

Outer container condition: ☐Not Sealed ☐Intact Seal ☐Broken

Seal

Date___/___/___Time_____ ☐Not Signed ☐Not Dated

Recorded by: ____

Name *Section* *Signature*

Sample container condition: ☐Not Sealed ☐Intact Seal ☐Broken Seal

Date___/___/___Time_____ ☐Not Signed ☐Not Dated

Recorded by:____

Name *Section* *Signature*

Forms

This form must be stored in the CAFSS storage laboratory/facility until:

- **Opening of sample containers and seals by CAFSS staff (Section 2)**

2. Opening of sample containers (e.g. bags) and seals by CAFSS Staff

Opened by:____
Name *Section* *Signature*

Date___/__/___ Time_______

This form must be stored by the laboratory that performed the tests until:

- **returned / forwarded to laboratory person (Section 3) or**
- **put into storage and re-sealed in CAFSS storage facility (Section 4) or**
- **returned / forwarded to client or courts (Section 5) or**
- **samples have been discarded by CAFSS (Section 6)**

3. Laboratory

Sample released by	Sample received by	Date & Time
Name Section Signature	Name Section Signature	
Name Section Signature	Name Section Signature	
Name Section Signature	Name Section Signature	
Name Section Signature	Name Section Signature	
Name Section Signature	Name Section Signature	
Name Section Signature	Name Section Signature	
Name Section Signature	Name Section Signature	
Name Section Signature	Name Section Signature	

4. Storage and re-sealing in CAFSS storage facility

Re-sealing* and storage: Date___/__/___ Time_______

Sealed* and stored by: ____
Name *Section* *Signature*

*All sample bags and bottles must be sealed using CAFSS red/white stripe tamper-indicating serrated evidence tape with CAFSS logo imprint in black.

5. Returned / Forwarded to client (police)

Re-sealing* and returned / forwarded: Date___/__/___ Time_____

Sealed* and returned/forwarded by: ____
Name *Section*
Signature

*All sample bags and bottles must be sealed using the CAFSS red/white stripe tamper-indicating serrated evidence tape with CAFSS logo imprint in black.

Samples received by: ____
Name *Section*
Signature

6. Disposal by CAFSS

Disposal of sample Date___/__/___ Time_______

Disposed by: ____
Name *Section* *Signature*

Appendix 3. Quarantine sample entry pathway approval process within the Quarantine Approved Premises of CSIRO Land and Water

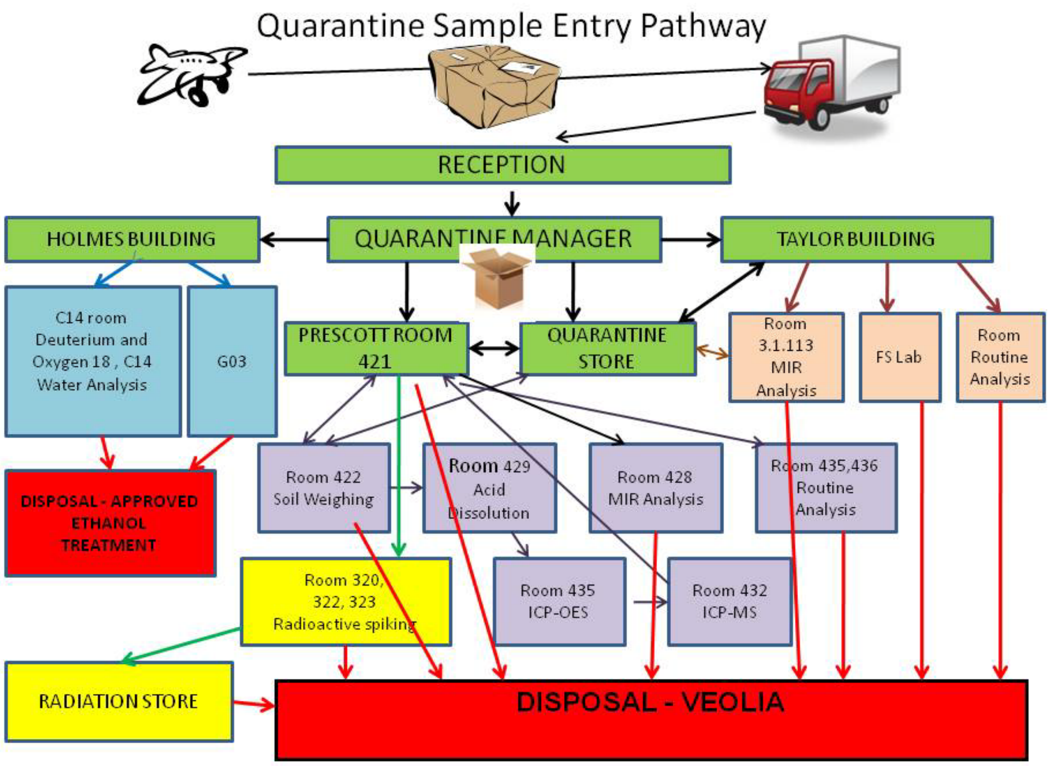

Figure A3.1 Flow diagram illustrating quarantine sample entry pathway approval process within the Quarantine Approved Premises (QAP) of CSIRO Land and Water (where: "FS Lab" denotes the CAFSS Forensic Soil Laboratory (from Cozens, G. (V1 2012 QAP Manager) (2012). CSIRO Land and Water Quarantine Approved Premises (QAP) Management Manual. Department of Agriculture, Fisheries and Forestry (DAFF) Biosecurity Approved Premises – S0116. 43pp

Appendix 4. Justice Black's guidelines for expert witnesses

Reproduced from http://www.fedcourt.gov.au/pdfsrtfs_p/practicedirections_experts.rtf

Guidelines for Expert Witnesses in Proceedings in the Federal Court of Australia

Practice Direction

This replaces the Practice Direction on Guidelines for Expert Witnesses in Proceedings in the Federal Court of Australia issued on 6 June 2007.

Practitioners should give a copy of the following guidelines to any witness they propose to retain for the purpose of preparing a report or giving evidence in a proceeding as to an opinion held by the witness that is wholly or substantially based on the specialised knowledge of the witness (see **- Part 3.3 - Opinion** of the *Evidence Act 1995* (Cth)).

M.E.J. BLACK
Chief Justice
5 May 2008

Explanatory Memorandum

The guidelines are not intended to address all aspects of an expert witness's duties, but are intended to facilitate the admission of opinion evidence[1], and to assist experts to understand in general terms what the Court expects of them. Additionally, it is hoped that the guidelines will assist individual expert witnesses to avoid the criticism that is sometimes made (whether rightly or wrongly) that expert witnesses lack objectivity, or have coloured their evidence in favour of the party calling them.

Ways by which an expert witness giving opinion evidence may avoid criticism of partiality include ensuring that the report, or other statement of evidence:

(a) is clearly expressed and not argumentative in tone;
(b) is centrally concerned to express an opinion, upon a clearly defined question or questions, based on the expert's specialised knowledge;
(c) identifies with precision the factual premises upon which the opinion is based;
(d) explains the process of reasoning by which the expert reached the opinion expressed in the report;
(e) is confined to the area or areas of the expert's specialised knowledge; and
(f) identifies any pre-existing relationship (such as that of treating medical practitioner or a firm's accountant) between the author of the report, or his or her firm, company etc, and a party to the litigation.

An expert is not disqualified from giving evidence by reason only of a pre-existing relationship with the party that proffers the expert as a witness, but the nature of the pre-existing relationship should be disclosed.

[1] As to the distinction between expert opinion evidence and expert assistance see *Evans Deakin Pty Ltd v Sebel Furniture Ltd* [2003] FCA 171 per Allsop J at [676].

The expert should make it clear whether, and to what extent, the opinion is based on the personal knowledge of the expert (the factual basis for which might be required to be established by admissible evidence of the expert or another witness) derived from the ongoing relationship rather than on factual premises or assumptions provided to the expert by way of instructions.

All experts need to be aware that if they participate to a significant degree in the process of formulating and preparing the case of a party, they may find it difficult to maintain objectivity.
An expert witness does not compromise objectivity by defending, forcefully if necessary, an opinion based on the expert's specialised knowledge which is genuinely held but may do so if the expert is, for example, unwilling to give consideration to alternative factual premises or is unwilling, where appropriate, to acknowledge recognised differences of opinion or approach between experts in the relevant discipline.

Some expert evidence is necessarily evaluative in character and, to an extent, argumentative. Some evidence by economists about the definition of the relevant market in competition law cases and evidence by anthropologists about the identification of a traditional society for the purposes of native title applications may be of such a character. The Court has a discretion to treat essentially argumentative evidence as submission, see Order 10 paragraph 1(2)(j).

The guidelines are, as their title indicates, no more than guidelines. Attempts to apply them literally in every case may prove unhelpful. In some areas of specialised knowledge and in some circumstances (eg some aspects of economic evidence in competition law cases) their literal interpretation may prove unworkable.

The Court expects legal practitioners and experts to work together to ensure that the guidelines are implemented in a practically sensible way which ensures that they achieve their intended purpose.

Nothing in the guidelines is intended to require the retention of more than one expert on the same subject matter – one to assist and one to give evidence. In most cases this would be wasteful. It is not required by the Guidelines. Expert assistance may be required in the early identification of the real issues in dispute.

Guidelines

1. General Duty to the Court[2]

1.1 An expert witness has an overriding duty to assist the Court on matters relevant to the expert's area of expertise.
1.2 An expert witness is not an advocate for a party even when giving testimony that is necessarily evaluative rather than inferential[3].
1.3 An expert witness's paramount duty is to the Court and not to the person retaining the expert.

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[2] See rule 35.3 Civil Procedure Rules (UK); see also Lord Woolf "Medics, Lawyers and the Courts" [1997] 16 CJQ 302 at 313.
[3] See *Sampi v State of Western Australia* [2005] FCA 777 at [792]-[793], and *ACCC v Liquorland and Woolworths* [2006] FCA 826 at [836]-[842].

2. The Form of the Expert Evidence[4]

2.1 An expert's written report must give details of the expert's qualifications and of the literature or other material used in making the report.

2.2 All assumptions of fact made by the expert should be clearly and fully stated.

2.3 The report should identify and state the qualifications of each person who carried out any tests or experiments upon which the expert relied in compiling the report.

2.4 Where several opinions are provided in the report, the expert should summarise them.

2.5 The expert should give the reasons for each opinion.

2.6 At the end of the report the expert should declare that "[the expert] has *made all the inquiries that* [the expert] *believes are desirable and appropriate and that no matters of significance that* [the expert] *regards as relevant have, to* [the expert's] *knowledge, been withheld from the Court*."

2.7 There should be included in or attached to the report; (i) a statement of the questions or issues that the expert was asked to address; (ii) the factual premises upon which the report proceeds; and (iii) the documents and other materials that the expert has been instructed to consider.

2.8 If, after exchange of reports or at any other stage, an expert witness changes a material opinion, having read another expert's report or for any other reason, the change should be communicated in a timely manner (through legal representatives) to each party to whom the expert witness's report has been provided and, when appropriate, to the Court[5].

2.9 If an expert's opinion is not fully researched because the expert considers that insufficient data are available, or for any other reason, this must be stated with an indication that the opinion is no more than a provisional one. Where an expert witness who has prepared a report believes that it may be incomplete or inaccurate without some qualification, that qualification must be stated in the report[5].

2.10 The expert should make it clear when a particular question or issue falls outside the relevant field of expertise.

2.11 Where an expert's report refers to photographs, plans, calculations, analyses, measurements, survey reports or other extrinsic matter, these must be provided to the opposite party at the same time as the exchange of reports[6].

3. Experts' Conference

3.1 If experts retained by the parties meet at the direction of the Court, it would be improper for an expert to be given, or to accept, instructions not to reach agreement. If, at a meeting directed by the Court, the experts cannot reach agreement about matters of expert opinion, they should specify their reasons for being unable to do so.

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[4] See rule 35.10 Civil Procedure Rules (UK) and Practice Direction 35 – Experts and Assessors (UK); *HG v the Queen* (1999) 197 CLR 414 per Gleeson CJ at [39]-[43]; *Ocean Marine Mutual Insurance Association (Europe) OV v Jetopay Pty Ltd* [2000] FCA 1463 (FC) at [17]-[23].

[5] The *"Ikarian Reefer"* [1993] 20 FSR 563 at 565.

[6] The *"Ikarian Reefer"* [1993] 20 FSR 563 at 565-566. See also Ormrod *"Scientific Evidence in Court"* [1968] Crim LR 240.

Appendix 5. Expert Witness and Report Checking Statements

Example used in all CAFSS reports are reproduced in Appendix 5.

I *Robert William Fitzpatrick* have made all the inquiries that I believe are desirable and appropriate and that no matters of significance that I regard as relevant have, to my knowledge, been withheld from the Court.

I have read, understood and complied with the “Guidelines for expert witnesses” issued by the Federal Court of Australia under the authorship of Chief Justice (now former Chief Justice) Black (Black, 2008). These guidelines are reproduced in Appendix 4 of the accompanying report by Fitzpatrick and Raven (2016).

The expert opinion in this report is wholly or substantially based upon my specialist knowledge: See Biography, Background and Curriculum Vitae and List of Publications: **Web**: **The University of Adelaide**: http://www.adelaide.edu.au/directory/robert.fitzpatrick

Signed:

Professor Rob Fitzpatrick FTSE; CPSS-level 3
Director: Centre for Australian Forensic Soil Science (CAFSS)
Chief Research Scientist: CSIRO Land and Water
Professorial Research Fellow: The University of Adelaide

Signed:

Mark Raven
Checked by Manager Mineralogical and Geochemical Services
Contaminant Chemistry and Ecotoxicology Program, CSIRO
Water for a Healthy Country Flagship – Healthy Water Ecosystems, CSIRO
Minerals Down Under Flagship – Driving Sustainability, CSIRO
Digital Technologies and Services Flagship - CAFSS (Centre for Australian Forensic Soil Science), CSIRO
Treasurer: Australian Clay Minerals Society

Signed:

Checked by Dr Peter Self
Mineralogical and Geochemical Services
Contaminant Chemistry and Ecotoxicology Program, CSIRO
Water for a Healthy Country Flagship – Healthy Water Ecosystems, CSIRO
Minerals Down Under Flagship – Driving Sustainability, CSIRO
Digital Technologies and Services Flagship - CAFSS (Centre for Australian Forensic Soil Science), CSIRO
Secteratry: Australian Clay Minerals Society