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THE APPLICATION OF FORENSIC GEOMORPHOLOGY IN RHINOCEROS POACHING (SOUTH AFRICA)

by
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ABSTRACT

A prevalence of wildlife poaching with escalations has occurred since 2008, especially regarding rhinoceros poaching. It is essential to protect southern Africa's heritage by developing/adapting new research methods and techniques that can assist prosecutors to improve their successes in achieving convictions. The aim of the study was to investigate the use of forensic geomorphology in the context of a poached rhino to assist in the prosecution of suspected poachers. This study was conducted at two experimental study sites which mimicked the aspects of the landscape of rhinoceros by utilising the landscape through a variety of physical, chemical and biological techniques. Trace evidence was removed from the suspects that moved through the mimicked landscape in order to verify if any significant similarities could be identified. The study concluded that a linkage could be recognized between the selected landscape and the trace evidence collected from the suspects' belongings in both experimental studies. The results from the first experimental study site illustrated that a definite linkage could be made between the suspects and the landscape, whereas the second experimental study site suggested that there was a possibility that a linkage could be made.

CHAPTER 1: Introduction

1.1 Background

The wide range of wildlife in large nature conservation areas as well as private owned wildlife farms forms part of southern Africa's proud heritage. South Africa is home to 83% of Africa's rhinoceros and 73% of all wild rhinoceros worldwide and is an exceptionally important country for rhinoceros conservation (EWT, 2014 & CITES, 2013). However, by 2015 rhinoceros poaching reached a crisis point. South Africa has continued to experience the highest absolute levels of poaching, and in 2010/11 these losses represented a 1.9 % average yearly mortality against the country's historical (1992-2010) rhinoceros population growth rate of +6.9 % per annum (CITES, 2013). If poaching were to continue to increase between +34 % to +46 % a year, as it has done in South Africa since 2010, it is estimated that deaths could begin to exceed births as early as 2015-2016 (Montesh, 2012), meaning the rhinoceros may possibly go extinct in the near future.

Despite intensive conservation efforts, poaching of this iconic species is dramatically increasing, forcing the remaining rhinoceros towards extinction. The Western Black Rhinoceros was declared extinct by the IUCN (International Union for Conservation of Nature) in 2011, with the primary cause identified as poaching (DEA, 2014). All five remaining rhinoceros species are listed on the IUCN Redlist of threatened species, with three out of five species classified as critically endangered (EWT, 2014). This poaching is predominantly motivated by the illegal trade in rhinoceros horn. Globalisation and economic growth has made it easier to establish illegal trading routes (TRAFFIC, 2012). The current poaching crisis is attributed to the growing demand for rhinoceros horn in Asian countries, mainly China and Vietnam, where the horn is perceived to have medicinal properties and serve as a sign of wealth (TRAFFIC. 2012). The high price fetched for the horn has attracted the involvement of criminal syndicates who use advanced equipment to track and kill rhinoceros. The Rhinoceros horn trade is estimated to be the third biggest illegal industry internationally after drugs and human trafficking, and often has its roots in structured, trans-boundary crime (EWT, 2014). Addressing the rhinoceros poaching problem in South Africa is a complex task with an organised mesh of activities that involves uneducated poor poachers from rural villages, professional individuals (veterinarians, pilots, park officials, *etc.*) as well as corrupt public officials (Eloff, 2012).

Despite an array of preventative measures, the frequency of rhinoceros poaching in South Africa is daily: A rhinoceros was poached every eight hours in 2014 (EWT, 2014). Field protection measures such anti-poaching patrols, dehorning and horn poisoning are all costly and the costs are increasing. Measures such as increasing penalties (fines and prison sentences) are perhaps the most effective manner to combat the upsurge of rhinoceros poaching. However, even these measures may be ineffective as prosecuting authorities typically demand better evidence to successfully prosecute the most serious cases. The current case backlog and low prosecution rate in South Africa typifies the limitations of this approach (EWT, 2014). New prosecution methods are needed to curb the on-going killing of South Africa's rhinoceros. It is vital to protect southern Africa's heritage by developing and adapting new research techniques and methods that can support prosecutors and police to improve their successes in achieving convictions. Forensic geoscience can provide additional physical evidence to assist in prosecuting suspects.

The landscape in which the rhinoceros habitat exists makes it difficult for investigators to conduct forensic analysis. Geomorphology reveals a fundamental principle in forensic analysis: namely that shape of the land influences or controls human activity, and this can be applied to forensic geoscience in order to convict suspects (Ruffel & McKinley, 2013). Forensic geoscience is a field of analysis that utilises methods developed in the geoscience, such as geology, geomorphology, botany, biology and statistics, for civil and criminal judicial proceedings (Morgan & Bull, 2007). It is gradually being recognized that much potentially valuable information is potentially available even in small amounts of soil. This can be attributed not only to its occurrence at crime scenes and its transferability between the scene and the criminal, but also to the fact that soils/sediments are comprised of not only naturally occurring rocks, minerals, fauna and flora but also anthropogenic components such as paint fragments, glass or metallic particles (Gallop & Stockdale, 1988). Thus, a sample of soil/sediment recovered from clothing, a vehicle or crime scene has a large, almost limitless number of characteristics which make it unique to specific locations (Saferstein, 2004). The value of soils/sediment analysis in providing useful evidence in forensic enquiries lies with the ability of a forensic practitioner to identify and make comparisons between samples (Morgan & Bull, 2007). Approaching a crime scene, such as a poached rhinoceros, from a geomorphic perspective allows an investigator to analyse the landscape to identify the samples necessary to serve as useful evidence.

1.2 Problem statement

There are no precise methods in dealing with wildlife crimes. Perhaps this is due to the fact there have not previously been a high demand for wildlife objects such as rhinoceros horn or elephant tusks, as well as such an established system in the illegal trade of ivory and rhinoceros horn (Eloff, 2012). This means that there are no efficient measures to connect or exclude suspects from a specific wildlife crime scene.

Suspected poachers (especially rhinoceros poachers) often escape prosecutors due to a lack of evidence to connect or exclude the perpetrator/s to a crime scene such as a poached rhinoceros. Forensic geomorphology research allows the development of important techniques that can assist prosecutors and police to improve their success in achieving convictions. However, even though forensic geoscience is an established and widely used discipline in Europe and the Americas, it is still unclear how effective it may prove in South Africa's rhinoceros' habitats. The question arise; to what role can Forensic Geomorphology play in successfully prosecuting rhinoceros poachers? It remains unclear if soils and sediments can be routinely analysed in order to compare crime sites with items belonging to a suspect and their vehicles, and whether the analysis will enable a very detailed characteristics of sediment to be identified from large numbers of samples, and thereby accurate results. Is it, or could it be, unique to a crime scene or unique to circumstances under which a criminal act was committed? Questions such as these, paired with the geological context of the crime scene and what are the consequences of this context relative to the containment, preservation, and retrieval of evidentiary material that may include weapons, remnants, and personal objects are still unclear. Therefore, the overall objective of this research is to determine how effectively and accurately soils and sediments can link a person to a wildlife crime scene through forensic geomorphology.

1.3 Aims and Objectives

The aim of the study is to investigate the use of forensic geomorphology in the context of a poached rhino to assist in the prosecution of suspected poachers. The aim is achieved by achieving the following objectives (Figure 1.1):

Objective 1: Undertake experimental studies to investigate the processes of reincorporation and redistribution;

Objective 2: To identify the ubiquitous nature of soils, sediments and the rest of the landscape found in association with specific wildlife sites where rhinoceros occur in South Africa; and

Objective 3: verify how accurately these certain geomorphic aspects, namely trace evidence, at the scene of the crime can be linked to a suspect/s (shoes, vehicles, house, clothing *etc.*) and have a final comparison of the results gained from experimental studies.

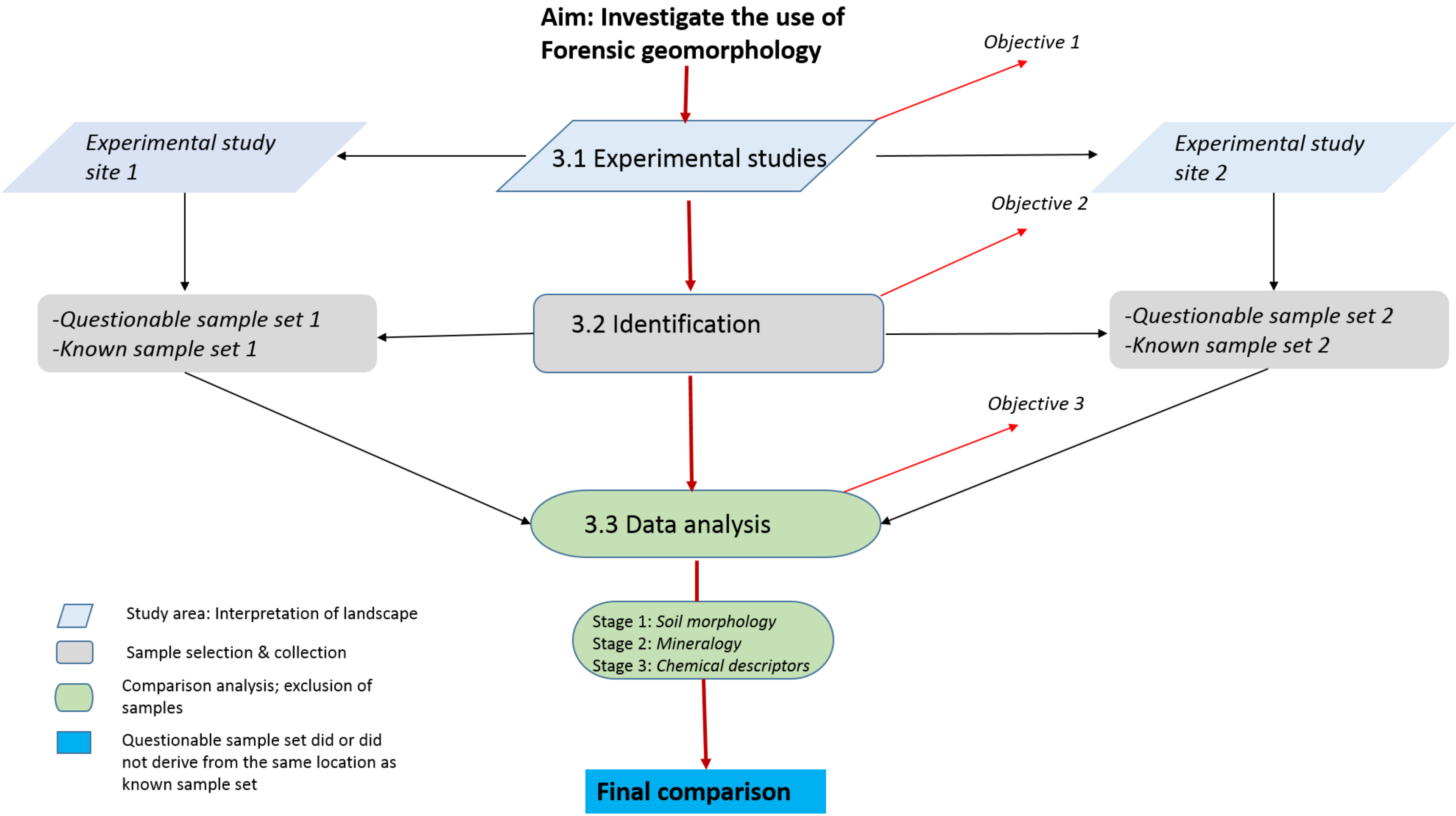

FIGURE 1.1: Flow diagram of aims and Objectives

1.4 Thesis statement

Based on the aim and the objectives, the thesis of this work is to test, through a geomorphic perspective, how accurately and effectively soils and sediments found in a landscape can be identified and linked to a suspect/s and their belongings that have passed through that particular landscape. Morgan's *et al*. (2006) research indicates that soil and sediment characteristics are variable over short distances and thus applicable for forensic purposes. With Morgan's research in mind, Locard's exchange principle states: "whenever two objects come into contact, there is always a transfer of material" which suggests that some form of trace evidence will be obtainable once a suspect/s makes contact with soil (Locard, 1930 as referenced in Morgan & Bull, 2007; p79). This establishes the fact that a linkage can be found between a person and a specific area. The thesis aims to create experimental studies to mimic that of an actual wildlife crime scene in order to evaluate how successfully one can investigate the processes of reincorporation and redistribution of soils and sediments identified and sampled.

1.5 Delineations and limitations

Following Locard's general principle that 'every contact leaves a trace', it would be tempting to consider that the analysis of sediment and soils taken from possessions of a suspect would show how much similarity with that of a specific crime site where the suspect moved around in and paths considered to be walked (Morgan *et al*., 2006). However, when investigating the similarities or differences of materials found on shoes compared to the comparator site it is clear that the supposed simple relationship is not as straightforward (Fitzpatrick, 2006). The main problem when trying to find similarities between a suspect's belongings (such as shoes) and the crime site itself is that the supposed route of the suspect/s is often unclear and uncertain (Ruffel & McKinley, 2013). Regarding wildlife crimes, the natural barriers surrounding the crime scene can prove as much a disadvantage as an advantage (Morgan *et al*., 2006). Killam (2004) refers indirectly to numerous aspects of geomorphology from murderers using 'paths of least resistance', so when considering a natural landscape, routes can occasionally be obvious and sometimes unclear. Another problem encountered when analysing and interpreting material from a suspect's belongings is that the belongings are worn for some designated period of time, quite a long time after the crucial event. Thus the materials may well fall off shoes, or be added to by materials from elsewhere during subsequent activity. Compounding this problem is the fact that a person's outfit and/or belongings and the amount of material obtainable for analysis can be highly variable.

Analytical techniques available to the forensic scientist are numerous if one considers the range of techniques accessible in botany, sedimentology, geochemistry, and geomorphology. A crucial problem here is to employ methods with forensic perspectives rather than using purely geological and geomorphological procedures of interpretation (Bull *et al*., 2006). Analysis may provide descriptive qualities of the soil or sediment which may, or may not, be diagnostic. If two samples possess similar descriptive attributes in any number of physical, chemical or biological characteristics, they may have derived from one common source, but equally they could have derived from separate sources of similar features (Fitzpatrick, 2009). Therefore, it will be important when interpreting the results from the physical trace evidence analysis that due care is given to the exclusion of samples rather than trying to match samples. The work of Walls (1968) was the first mention of excluding rather than matching a sample. Walls suggested that one should exclude all samples unless the samples show such similar characteristics in the context of distinctiveness or rarity of their particular attributes that they cannot be denied of originating from the same geographic location.

Therefore, it will be important when interpreting the results from the physical trace evidence analysis that due care is given to the exclusion of samples and that the sample which shows very similar characteristics in the context of distinctiveness or rarity of their particular attributes be handled accordingly (Bull *et al*., 2006).

1.6 Significance of the study

It is essential to protect South Africa's heritage by developing and adopting new research methods and techniques that can assist prosecutors and police to place a person/s at a crime scene or to exclude them. Wildlife crimes are considered to be vaguer than urban crimes due to the ubiquitous characteristics of a natural environment, it becomes more difficult to obtain the correct samples as suspects can move more freely than in an urban environment. Proper landscape interpretation allows an investigator to accurately determine the most likely route taken by a person/s, and thereby identifying valuable areas for sample collection that may exclude or connect a person/s to a crime scene. Forensic geoscience is an increasingly important discipline, based upon well-established ideas and analytical techniques developed throughout the 20th century (Murray, 2004). This type of forensic analysis is a rapidly developing division of criminal investigation utilising the analysis of rocks, sediments and soils by studying the physical, chemical and biological components of a sample found within a landscape (Ruffel & McKinley, 2013). Soils and sediments are now routinely analysed to compare crime sites with items belonging to a suspect and their belongings (Bock & Norris, 1997). The prompt development of systematic techniques and machinery enables detailed characteristics of a sediment to be identified from large numbers of samples. Soils and sediments are now routinely analysed to compare crime sites with items belonging to a suspect and their vehicles. It is clear that the use of forensic geoscience's independent techniques in wildlife crime detection has great potential given the unique nature of soils, sediments and the rest of the landscape found in association with wildlife sites. (Morgan *et al*., 2006)

Poaching is, unfortunately, a daily occurrence and the research conducted is aimed at determining whether a person or persons were present at a specific location to establish their connection to, or exclusion form a poaching incident. This project will support the existing collaboration between research and criminal prosecution and to enhance the collective knowledge with regards to poaching, which will enable southern Africa’s game farms and nature reserves to deal with the scourge of poaching in a more scientific and effective manner.

CHAPTER 2: Literature overview

Rhinoceroses were once abundant throughout Africa and Asia with a worldwide population of approximately 500 000 in the early twentieth century (Montesh, 2012). The largest population of white rhinoceroses in the world are found in the Kruger National Park (KNP). In 2010, estimates indicated the presence of 10,621 white rhinoceroses in the park (Ferreira *et al*., 2012). Since the late 1990's, white rhinoceroses have been trans-located from the KNP for biodiversity and conservation reasons and sold to generate conservation revenue. By 2010, 1 402 had been removed, largely to other conservation areas, with no adverse effects on the population, and numbers continued to increase in the park. However, the number of poached white rhinoceroses is now exceeding the birth rate which the SANParks white rhinoceros running model requires for a healthy species, which is 4.4 per cent of the standing population at any given time. At these increasing rates of poaching the number of surplus rhinoceroses available in the next few years will reduce, and the overall population is expected to decline in 2016 (Ferreira *et al*., 2012).

The KNP is also home to over 627 black rhinoceroses, estimated during a census in 2008, with an annual population growth rate of approximately 6.75 per cent (Ferreira *et al*., 2011). At least eight black rhinoceroses have been poached in the KNP since 2008, but the exact number, and therefore the impact on this critically endangered animal, is not known as there have been no census of this species in the park since October 2008 (DEA, 2014 & Ferreira *et al*., 2011). South Africa has continued to experience the highest absolute levels of rhinoceros poaching in the world. Figures compiled by the South African Department of Environmental affairs (2014) show the dramatic escalation in poaching over recent years as illustrated in Figure2.1. This has occurred despite CITES bans on legal horn trade, increased law enforcement effort in the field (South African National Defence Force and police personnel being stationed in Kruger National Park since August 2011), increasing arrests, as well as a good conviction rate in cases that come to court with some significant sentences being handed down and in other cases asset forfeiture being imposed (CITES, 2013).

In spite of measures taken to deter rhinoceros poaching and rhinoceros horn trade, losses in South Africa continue to drive the escalating trend with record poaching deaths from 2008 to 2013 (as indicated in Figure 2.1). High prices in illegal Asian markets, criminality in the wildlife industry, government policy lapses and occasional complicity, and Asian-run criminal syndicates stand behind the continuing attrition in South Africa (Milliken & Shaw, 2012). While the majority of rhinoceroses poached shot, in some cases poachers are using quieter methods to avoid detection including the use of firearm silencers, veterinary immobilizing drugs and poison (CITIES, 2013).

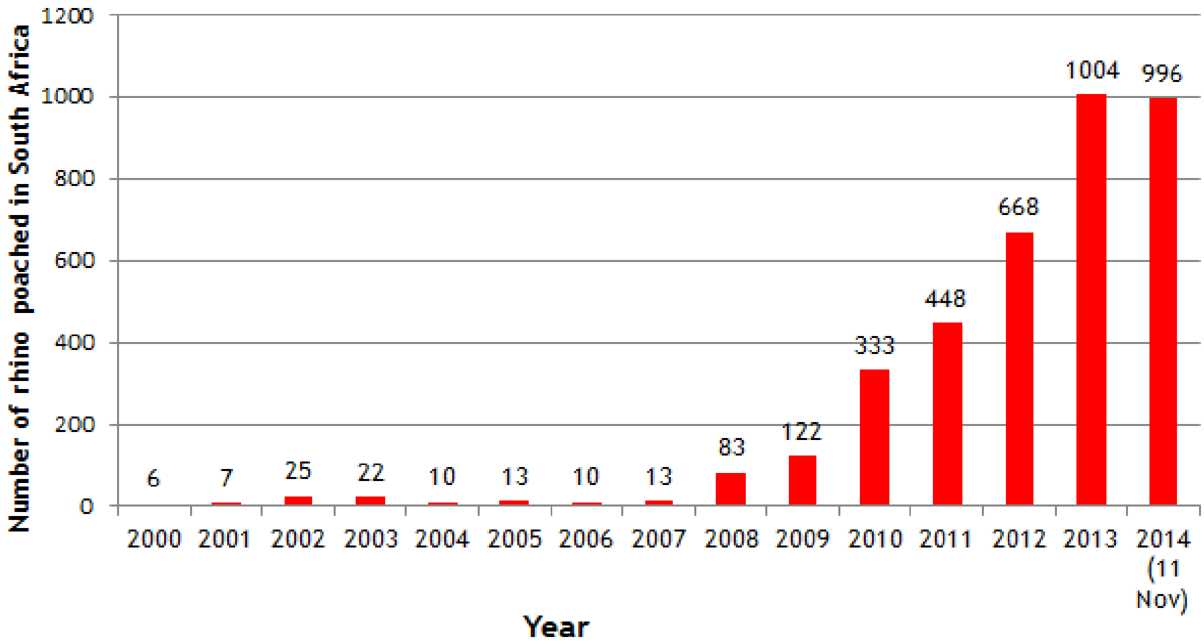

FIGURE 2.1: Annual recorded rhinoceros poached in South Africa since 2000 (DEA, 2014)

Whilst crime syndicates become more elusive and rhinoceros poaching increases, it becomes more important to be able to link a suspect to a crime scene in order to cripple the rising network of rhinoceros horn trade. The concept of using soil as evidence has a long history, which will further be discussed in Section 2.3. Modern soil analytical methods in forensic investigations is, however, a moderately recent development (Fitzpatrick, 2009). Currently, soil analyses for investigative intelligence gathering are generally only performed in cases of serious crime, whereas they may be used in the evidential phase of many less serious cases (Fitzpatrick, 2009). There is an opportunity, however, for the development of a soil forensic approach that would permit a greater use of soil information in the intelligence phase of police operations as well as the evidential phase (Barclay *et al.*, 2006). In this context, soil comparisons may be used not only to associate but to eliminate areas of land and/or suspects from further police enquiries, thus permitting the reassigning of limited resources.

2.1 Forensic geoscience

As mentioned in Chapter 1, forensic geoscience is a field of analysis that uses techniques developed in geosciences, such as geomorphology, botany, geology, biology and statistics (Morgan & Bull, 2007). This rapidly developing division of criminal investigation utilises the analysis of rocks, sediments and soils by studying the physical, chemical and biological components of a sample. The rapid development of analytical techniques, machinery and, to some extent, automation enables detailed characteristics of sediment to be identified from large numbers of samples (Morgan & Bull, 2007). Soils and sediments are now regularly analysed to compare crime sites using items belonging to a suspect and their vehicles (Morgan *et al*., 2006). Geological trace evidence involves the collection, analysis, interpretation, presentation and explanation of geological evidence. Trace evidence can vary considerably and may include; rock fragments, soils and sediments, which occur naturally in the ground, artificial (anthropogenic) man-made materials derived from geological raw materials such as bricks, concrete, glass or plaster board, or micro-fossils (Morgan & Bull, 2007). The variability of the characteristics of the rocks and soils is helpful in potentially placing an offender or item at a particular location (Woods *et al*., 2014). The value of these inorganic materials is that they are generally inert and not affected by time or sample storage (Dawson & Hiller, 2010).

Soils are complex materials that vary in properties in different areas, and have unique characteristics because of the natural effects and transfers made by human and other living organisms over time (Morgan *et al*., 2010). Forensic examination of soil is not only concerned with the analysis of naturally occurring rocks, minerals, vegetation, and animal matter (Dawson & Hillier, 2010), but also the detection of manufactured materials, such as chemicals from synthetic fertilizers and from different environments (nitrate, phosphate, and sulphate). Environmental artefacts (such as lead or objects as glass, paint chips, asphalt, brick fragments, and cinders) whose presence may impart soil with characteristics, will make it unique to a particular location (Dawson & Hillier, 2010). The environmental artefacts consist of both inorganic and organic components in varying proportions. These components may be naturally occurring or introduced by human activities, and so soils contain a wealth of information of potential forensic use (Morgan *et al*., 2010). In addition, the particulate nature of most soil components and the customary contact of people and objects with the ground surface create numerous opportunities for the transfer and subsequent recovery of soil as potential evidential material. Thereafter, any of the biogeochemical characteristics of soil found on potential evidential items, referred to as the 'questioned' soil, may be used to indicate its provenance, or to compare it with other samples of known provenance. As such, soil may be used for investigative/intelligence purposes during enquiry or for evaluative/comparative purposes which culminate in the presentation of soil as evidence in courts of law (Dawson & Hillier, 2010).

2.2 Where soil may be encountered

Soil may be encountered in many different situations in forensic science, for example: clothing and shoes from a suspect supposed to have walked in a garden bed prior to entering the victim's house; a dirty spade recovered from a suspect's house suspected to have been used to bury resources; and soil from a suspect's vehicle that may have been at a burial site (Fitzpatrick *et al*., 2009) as shown in Figure 2. Ultimately, soil can be used as evidence to exclude a suspect, a victim or an object with a particular scene, assist with identifying the scene of a crime, or contribute to forensic intelligence (Fitzpatrick, 2009).

FIGURE 2.2: Soil adhered to different objects, typical of those which may be associated with a crime including the soles of boots, a spade, and on the tyres and wheel arches of a car (Dawson & Hillier, 2010)

As mentioned in chapter 1, forensic geoscience is a type of geological evidence based on Locard's Exchange Principle (1930): "Whenever two objects come into contact, there is always a transfer of material" (as referred to in Morgan & Bull, 2007; p79). The transfer may be short- lived, or beyond detection, but nevertheless the transfer has taken place (Fitzpatrick, 2009). The trace evidence may then be used to see if there could be an association between different items or objects. Such transfers are referred to as primary transfers (Dawson and Hillier, 2010). An example is evidence that is transferred from the soil surface to the shoe and later recovered from the shoe, such as in the treads of the sole or within the shoe (Dawson and Hillier, 2010). Once a trace material has been transferred, any subsequent actions of that material, in this case from shoes (for example, from the shoe to the carpet in a vehicles foot well) are referred to as secondary transfers. These secondary transfer materials can also be significant in assessing the nature and source(s) of contact. Hence, the surface of soils can provide information linking persons to crime scenes (Fitzpatrick, 2009). Although a suspect may be unaware that soil, especially the fine fractions, has been transferred to the person or surroundings, soil particles are easily located and collected when inspecting crime scenes or examining items of physical evidence (Fitzpatrick, 2009). Traces of soil can easily and quickly be located directly using hand lenses or light microscopes. For example, Fitzpatrick *et al.* (2009) successfully completed a forensic comparison of small amounts of fine yellow–brown soil adhering to a suspect's shoe with a stony/gravelly black control soil submerged in a river where a hit-and-run offender ran through. Hence, if suspects cannot see fine soil materials adhering to their belongings, especially when they impregnate vehicle carpeting, shoes, or clothing, they will often make little effort to comprehensively clean soil materials (Fitzpatrick, 2009).

2.3 Historical overview

The current interest in geoscience and forensic investigations can be better understood in terms of the episodic evolution of scientific applications to domestic, terrorist and international criminal prosecution. In addition, novelists such as Conan-Doyle, Cornwell and Andrews have all made significant contributions to the science, as well as the popularity of the stories behind the investigations, for example the 'Sherlock Holmes' book series (Ritz *et al.*, 2009). It is thus rather unfortunate that a reference to sediment forensics has never been made and the term soil forensics has only recently been used (Ruffell, 2010). The stories of Arthur Conan Doyle (1887–1907), and criminal cases of Hans Gross (1962), Georg Popp (1910, 1939), Oscar Heinrich (active in the 1920s and 1930s) and Edmond Locard (1930), established the study of soil, sediment and landforms as being useful in forensic science and criminal investigations (Ruffel, 2010, Crelling, 1998, and Ruffel & McKinley, 2004).

None of the above authors created a term for their work as they were investigators first and foremost using all the evidence available, as opposed to Earth scientists (Ruffel, 2010). Forensic work on soil and sediment continued through the inter-war years, and between 1945 and the 1960s; the FBI, starting in the 1930s, and Camps (1962) used soil and sediment in cases of comparison/exclusion, intelligence gathering and substitution (Murray & Tedrow, 1975, and Ruffel, 2010). Consequently, a review of the literature from 1965 to 2000 in Murray's (2004) bibliography shows 24 articles on the use of soil and/or sediment in criminal investigations. As a term, this was first used to name a commercial consultancy named geoforensics, and by Ruffel & McKinley (2008) to encompass all that had gone before; pedology; geology; geoscience, but also including geomorphology; geography; geostatistics; remote sensing; and human geography/sociology. Just as Pye and Croft (2004) used 'forensic geoscience' and included more disciplines (detailed chapters on geophysics, unusual applications [e.g. spacecraft surfaces], statistics) than in Murray (2004), so Ruffell and McKinley (2008) expanded forensic geoscience even further, with chapters on remote sensing, geomorphology and GIS, some applied to human geography and sociology. Thus, following the publication of these three books; Murray (2004), Pye & Croft (2004), and, Ruffel & McKinley (2008), an increasing number of the sub-disciplines of the Earth and associated sciences being included.

2.4 The role of geomorphology in forensic geoscience

Although it is possible to accurately link a suspect, clothing or object to a particular scene using geological trace evidence, these techniques are rendered useless if the investigator cannot determine which samples to collect for analysis from a vast landscape. Where geomorphology is the scientific study of landforms and the processes that shape them (Schoeneberger, 2012), the discipline can also be used in forensics to trace a suspect's movement and to collect samples. The term "Forensic" is taken to be pertaining to the law, and thus frequently includes criminal investigations into homicide or murder in some countries, kidnap, theft, rape, smuggling, and extortion to give a few examples, but also scientific investigations that may come before a court of law (Schumm, 2005). The word 'forensic' has been positioned in front of almost every area of study one can imagine, from the firm forensic chemistry or biology to geology and pedology, but rarely to geomorphology. The application of forensic geomorphology is somewhat unfamiliar, this is to some extent surprising, given that one of the earliest handbooks on forensic science or criminalistics, included sections on geography and geomorphology (Gross, 1893, translated by Morgan & Bull, 2007). Geomorphology reflects a fundamental principle in Gross' (1893) work: that the shape of the land influences or controls human activity such as in natural areas, nature conservation areas or game farms and that this can be applied to geoforensics. Black (1979, cited in Schumm, 2005; p42) states that forensic medicine involves the "application of every branch of medical knowledge to the purpose of the law." If we substitute geomorphic knowledge for medical knowledge, we have a definition of forensic geomorphology that applies to both criminal and civil litigation.

Ruffell and McKinley (2004) used some examples to demonstrate how Geomorphology has been used in several famous cases, they include the following examples: In the case of the hunt for Osama bin Laden, the geological succession exposed in a cave from which bin Laden made his famous 'post 9–11' broadcast, was critical in identifying his approximate whereabouts in northern Afghanistan. Karst features also figure prominently in the description of how solution hollows (dolines) were misinterpreted by Allied Reconnaissance as bomb craters prior to the D-day Landings. D- day was also used to show how important an understanding in coastal geomorphology was in negotiating rocky reefs, steep cliffs and soft sand from beach assaults. The invasion force undertook extensive studies from submarines, aerial photography and covert landings, prior to the invasion in order to plan the best locations for landing craft, parachute drop zones, battleship gunnery and cliff-scaling assault to cope with the variable coastal geomorphology of the Normandy coastline (Ruffel & McKinley, 2004). These cases reinforce the early work of Gross (1893, cited in Ruffel and McKinley, 2004), and the sociological context of Rossmo (2000), where both show how people operate within a landscape. Covert locations, line of sight, ease of access and digging all play a strong role in criminal behaviour, as shown by many publications mentioned in Section 2.3. Killiam (2004) refers indirectly to various aspects of geomorphology from murderers using 'paths of least resistance'. The criminal, victim, law enforcer and investigator all interact with a landscape and thus forensic work will be advanced by the input of a geomorphologist.

The traditional view of science has had a physics bias emphasizing experimentation, quantification, and prediction as its essential and fundamental attributes (Bull *et al*., 2006). In contrast, forensic geomorphology tends to be conceptual, observational, and largely descriptive. It is a philosophical and intellectual science (Ruffel & McKinley, 2004). Schumm (2005) implores his geomorphologist colleagues to not be afraid of being involved in cases of litigation, they being the most capable scientists available to comment on changing water courses, the sources of landslides or environmental pollution and the reasons for building failure on unstable ground. This thesis may reinforce and perhaps expand on Schumm's (2005) statement. In this project, forensic aspects of physical geography, geomorphology and landform mapping are considered.

In summary, geomorphology plays a critical role in two areas of geoforensics, namely searching the land for surface or buried objects and sampling scenes of crime and control locations as evidence (Ruffel & McKinley, 2013). Associated geoscience disciplines have substantial bodies of work dedicated to their relevance in forensic investigations, yet geomorphology (specifically landforms, their mapping and evolution, soils and relationship to geology and biogeography) has not had similar public exposure. This is can be viewed as peculiar considering how fundamental to legal enquiries the location of a crime and its evolution are (Ruffel & McKinley, 2013). The geomorphology of a crime site is basically "the lay of the land" and what controls the character of the land surface: its topography and it is to focus the on the ground search as dictated by a broad range of forensic circumstances.

2.5 The application of forensic geomorphology on rhinoceros poaching

As forensic soil examinations have proven prominent in providing valuable physical evidence in previous cases (see Petraco *et al*., 2008), the question has been raised as to whether it can be applied to wildlife crimes such as rhinoceros poaching to assist in prosecutions. Based on the Locard Exchange Principle (1930), poachers that have ventured into the natural environment are likely to pick up traces of soil, as a transfer is inevitable to happen. However, the different landscapes of the environment of the rhinoceros provides difficulties in selecting the correct samples from the crime scene to use for comparison. Figures 2.3 and 2.4 illustrate a typical scenario where two white rhinoceroses were poached separately whilst grazing in two different landscapes. Both landscapes in these figures present different features regarding its geomorphic setting which influences accessibility and movement in the area, which also require different approaches regarding sample identification for comparison analysis.

FIGURE 2.3: Rhinoceros poached in watering hole (Save the rhino, 2013)

FIGURE 2.4: Drone photograph of rhinoceros poached in a savannah landscape (Save the Rhino, 2013)

Many people focus on the surface expression of a poached rhinoceros naturally because they are fixating on the crime scene itself. As Boyd (1979) states, the succession of activity prior to, during, and after a crime is critical, both as events alter the landscape and give rise to the observed surface expression. It is, therefore, essential to be able to reconstruct what has happened at the specific area, when and how. The fundamental question is asked in geomorphology. Protocols in forensic geomorphology consist of identifying the features of an area as well the activities that occurred there, because it is difficult for example, to get into a position, where a clean, killing shot is possible. Thus geomorphology allows the investigator to identify the activities that most likely to have occurred at specific sites in the landscape and with that knowledge determine where necessary samples need to be collected. With the correct samples gathered, a conclusion can be reached through proper geoforensic techniques to whether or not a suspect or belongings can be excluded from a crime scene.

Forensic soil examination can be complex, because of the variety and heterogeneity of soil samples. However, such variety and complexity allows forensic examiners to distinguish between soils, which may appear to be alike (Fitzpatrick, 2009). There is an overall lack of expertise in this relatively new area among soil scientists. For research and application in this area to grow appreciably, it will need to be considered and taught as a fundamental part of soil science (Fitzpatrick, 2009). Finally, an attempt should be made to develop and refine methodologies and approaches to develop a practical “soil forensics manual with soil kit for sampling, describing and interpreting soils” as noted by Fitzpatrick (2009; p4).

CHAPTER 3: Methodology

As outlined in Chapter 2, attempts should be made to develop and refine methodologies for soil forensics and this chapter aims to test a suitable methodology that can be applied to a scene where a rhinoceros has been poached.

In order to provide accurate forensic geoscientific interpretations from the analysis of sediments and soil, it is important to recognise the difference between geomorphic and forensic procedures. The primary aim of geomorphic analysis is to study the landscape in order to gain an understanding of the processes and activities that shaped the area. Forensic investigation in this project will involve the comparison of samples taken from a crime scene with those samples recovered from a person or their belongings. Sometimes the forensic aim is determining the provenance of material. The forensic geoscience rationale is to exclude a sample from a comparator sample by means of their physical, chemical or biological characteristics, since the goal of matching a questioned sample to its origin is fundamentally flawed (Morgan & Bull, 2007). A sample of soil, or any other earth material, cannot be said to have come from the same single place (Fitzpatrick, 2009). However, according to Murray & Tedrow (1991; p240), it is possible to establish to a "high degree of probability that a sample was or was not derived from a given place". Thus, this methodology is aimed at determining the probability of which a sample did or did not derive from the same place or landscape.

Although no standard forensic soil examination method exists (Dawson & Hiller, 2010 and Fitzpatrick 2009), a plethora of techniques can be used to analyse the physical, chemical and biological components that make up the landscape of rhinoceroses. As indicated earlier, forensic geomorphology looks at the specific aspects of the landscape, such as topography, vegetation, drainage patterns, and land uses which can be linked to suspects with regards to poaching incidents; this will be done through analysis of traces of soil and sediment (Morgan et al., 2006). A specific set of protocols and techniques were used to unpack the application of forensic geomorphology at a wildlife crime scene in order to meet the aim and objectives as set out in Section 1.3, and illustrated in Figure 1.1.

3.1 Experimental studies

Morgan & Bull (2006) emphasize the role of experimental studies in that they are crucial to establish the nature, transfer, tenacity, and method of collection of trace evidence in order to be able to carry out appropriate analysis, interpretation and presentation. Therefore, two experimental studies were undertaken to investigate the processes of reincorporation and redistribution of trace physical evidence on a suspect or a crime scene known as reincorporation and the possible links and analysis that could be made, meaning redistribution.

The experimental studies were created to depict the aspects of an actual wildlife crime scene. The experiments involved a specific location that was selected and a marker placed which under conditions mimicked that of forensic reality typically encountered at a wildlife crime scene. A person enacted the same movements of an actual suspect at and in the vicinity of the selected location. An axe and a machete were doused in water and placed on the ground to mimic how soils usually stick to the blood found on axes and machetes at a poached rhinoceros site. Soils and sediment were then routinely analysed to compare the simulated crime incident with items belonging to the person's simulating as poachers, and their vehicles. The study areas have already experienced high levels of poaching and were thus perfect for the experimental studies. The two studies were conducted in separate landscapes with unique attributes to ensure a wider based application of the study.

Before any of the other objectives could be reached, it is important to note that all materials and sites be approached from a forensic point of view. The researcher determined the scale of the area as soon as the designated 'crime scene' has been selected.

3.2 Identification for sample selection

A number of areas were identified for sample selection at each experimental study site depending on the probable routes taken by the suspects. The routes of the suspects have been determined using the work done by Killam (2004) which refers indirectly to various aspects of geomorphology from murderers using 'paths of least resistance' and Rossmo (2000) also stated and showed how criminals operate with regard to a landscape. Once an inventory of landforms, processes, and landform systems in the study area were carried out, the experimental study sites were analysed, assessing each for the intrinsic value of each element or shape, alongside possible routes and areas of movement. Landforms and landform systems are analysed and assessed by means of the enumeration of intervening elements in the morphogenetic system. A sampling grid was established in each of the areas to identify where samples need to be collected from. Two types of sample sets were gathered; the first sample set from the suspects' and their belongings (comparator/questionable sample set). The second sample gathered from the crime scene, which includes the selected location as well as the area surrounding the marker (known sample set).

During forensic analysis, large amounts of material were not gathered as would have been the case using geological analysis (Lindemann, 2001). Rather a smaller amount, particularly from anthropogenic sources, on only trace amounts of soil and sediment. The physical trace evidence, such as soil and sediment, were mostly gained from the persons' belongings and mimicked crime scene itself. However, a successful analysis cannot be based on single locations, therefor samples will also be gathered from the geographical route the 'suspects' travelled to reach the crime scene. The methods of Petraco *et al*. (2008) were applied, which involved sixteen field samples. These samples did not exceed 50mg each as they were gathered from the persons and their belongings. This is a small quantity comparison according to Morgan & Bull (2007).

Soil collected for comparative purposes must be able to be traced to the soil that was removed from the suspects. In most cases, this is the surface topsoil since this this is the part of the soil layer that is in contact with persons and their clothing. Consequently, care needs to be taken in avoiding contamination of the soil surface with deeper soil horizons. Saferstein (2004) notes that the whole item should be collected and bagged, and examined in *situ* with an appropriate technique for the amount of soil available.

3.3 Data analysis

Using the Munsell colour classification system, samples from the suspect and crime scene were matched to the reference colour codes, and these must all be found to be within a very similar range. As soon as all the samples have been selected and gathered, two analyses were used, namely to include and to exclude, as was done in the methodology described in Ruffel & McKinley (2013) and Morgan & Bull (2007).

Once all the samples that show very similar characteristics have been identified, a range of independent techniques were required before a meaningful interpretation of results could have been provided. The physical and chemical characteristics of the soil and sediment samples taken from the selected location were compared to the material taken from the persons' belongings using the same analysis that has been used on actual criminal investigations. The methodology analysis of characterizing soils for forensic comparison involve three stages: (i) descriptive, the morphological, profile of soil samples, (ii) mineralogical summary of each sample, (iii) and detailed chemical characterization of soil particles. These stages have been used by the staff in the Centre for Australian Forensic Soil Science (CAFSS) to identify similarities between soils in order to solve a double murder case (Fitzpatrick *et al*., 2007).

3.3.1 Stage 1: Soil morphology

The identification of soil differences using various morphological attributes such as colour, texture, consistency and structure, on whole soil samples is an important first step for using soil information to help investigators at a crime scene (Dawson & Hiller, 2010). Soil morphology is defined as the branch of soil science and pedology that deals with the description, using standard terminology, of in situ spatial organization and physical properties of soils regardless of potential land use (Fitzpatrick, 2009). Soil morphological interpretation provides a visual, quick, and non-destructive approach to screen and discriminate among many types of forensic soil samples (Fitzpatrick, 2009).

Morphological soil descriptors are arguably the most common and probably the simplest and it is for this reason that all samples are characterized first using the four key morphological descriptors of colour; consistency; texture and structure, as described in the analysis of Fitzpatrick (2009). These soil morphological descriptions follow strict conventions whereby a standard array of data is described in a sequence, and each term is defined according to the USDA Field Book (version 3.0) for describing and sampling soils. Samples taken from surrounding areas were analysed for their grain size distribution characteristics using a Granulometer (Malvern Mastersizer 2000). However, due to the limited amount of soil available for analysis, simple sieving measures were used to determine the dominant particle size. Every sample was processed through a standard sieve series: 4 mesh (4.76mm), 8 mesh (2.38mm), 10 mesh (2mm) and 20 mesh (0.5mm) in order to obtain the basic particle size in each sample. The rationale behind this analysis was to see if any samples could be excluded from having derived the area around the crime site. Grain size analysis is a tool best suited for description and possible exclusion, rarely can it be used as a diagnostic tool (Fitzpatrick, 2009). Further, when grain size analysis is undertaken on soil collected from a suspect's artefacts such as shoes, clothing, vehicles, etc. the very homogenisation required of the sample prior and during analysis, by whatever technique, prevents any idea of previous or post event contamination from being considered and inevitably leaves exclusion or association an untested result. It may appear that there is some 'contamination' or mixing of soils from different sources on the suspect's belongings, especially boots. This admixture is not surprising due to the nature of footwear and highlights the necessity for great care to be taken in the interpretation of results produced from techniques that require homogenisation of the sample prior to analysis (Morgan *et al.,* 2006).

3.3.1.1 Binocular microscopy

Binocular microscopy of all the soil samples will reveal a very distinctive assemblage of particle mineralogy and petrology (Fitzpatrick, 2009). The assemblages found in each sample are similar to each other, and are noteworthy due to the small number of constituents present. These assemblages are of very local origin and their presence in all of the samples analysed can be deemed significant (Morgan & Bull, 2007).

3.3.1.2 Scanning electron microscopy

The textures of individual grains of quartz within the samples were the most important step as it enables samples to be accurately compared and exclusions to be identified; this were done by viewing the samples under high magnification by a scanning electron microscope (SEM) (Morgan *et al*., 2006). A Scanning Electron Microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons (Hafner, 2007). The electrons interact with atoms in the sample, producing signals that can be detected and that contain information about the sample's surface topography and composition (Hafner, 2007). The signals that derive from electron-sample interactions reveal information about the sample including external morphology (texture), chemical composition, and crystalline structure and orientation of materials making up the sample (Hafner, 2007).

SEMs have been more commonly used in forensic science for the identification of fibres, hair, paint, fossils and any other 'unusual' objects, but many of the more common mineral particles of soil may also display a variety of distinctive attributes, such as size, shape, surface texture and chemical composition, that enable samples to be compared. Additionally, the individual particles in a soil are frequently associated into aggregates, and these associations and other textural data can be observed.

The SEM is critical in fields that require characterization of solid materials (Hafner, 2007 and Pye & Croft, 2006). The samples gathered in the field were analysed under a SEM to assess the quartz grain surface textures as well as shape of the particles. Using a JEOL 5800 with EDAX scanning electron microscope, samples of between 50 and 100 nanometres. Prior to analysis, the grains were coated in gold to aid picture resolution. All samples were characterised using the four morphological descriptors of colour, texture, consistency and structure (Fitzpatrick, 2004).

3.3.2 Stage 2: Mineralogy

The mineralogy content of the samples were analysed by using X-ray diffraction (XRD). In many soil forensic case investigations, the amount of soil available for analyses, for example on clothing or soles shoes, may preclude routine bulk analyses (Fitzpatrick, 2009). In such situations, it is best to use a XRD fitted with a system for analysis of extremely small samples, such as thin coatings or single particles of the order of 2-10mg, loaded onto silicon (Si) low background holders for XRD analysis. According to Murray (2004), "Quantitative XRD could possibly revolutionise forensic soil examination". For example, XRD patterns can also be likened to finger print comparisons between soil samples and how closely they relate to each other.

3.3.3 Stage 3: Chemical characteristics

After all the samples that fail to show physical and mineralogical properties as well as spatial organization characteristics have been excluded, the remaining samples underwent a chemical analysis to determine the link between the trace evidence. Chemical analyses of the samples were undertaken through X-ray fluorescence (XRF). XRF spectrometer is an X-ray instrument used for routine, chemical analyses of rocks, minerals, sediments and fluids. XRF works on wavelength-dispersive spectroscopic principles that are similar to an electron microprobe. The samples were milled in a tungsten-carbide milling pot to achieve particle sizes <75micron. These milled samples were then dried at 100°C and roasted at 1000°C to determine Loss On Ignition (LOI) values. A 1g sample had been mixed with 6g Lithiumteraborate flux and fused at 1050°C to make a stable fused glass bead. For trace element analyses the sample must be mixed with PVA binder and pressed in an aluminium cup @ 10 tons. The Thermo Fisher ARL Perform'X Sequential XRF with OXSAS software has been used for final chemical analyses of the soil that which allowed the researcher to conclude whether the samples derived from the same source.

It is very important when interpreting the results of soil and sediment analyses that due care is given to the exclusion of samples and that samples which show very similar characteristics are viewed in the context of the distinctiveness or rarity of their particular attributes (Morgan & Bull, 2006). Provided that there is sufficient material available for analysis, and given that the samples analysed are both of the material found on the suspect's possessions, and also representative of the source sample, it should be possible to afford meaningful analysis, comparison and interpretation of results (Pye *et al*., 2004). There are three conclusions to be drawn from the results obtained, the questioned sample definitely did not come from the location of interest meaning it is excluded; the questioned sample could have come from the location of interest; and the questioned sample almost certainly did come from the location of interest. As Kirk (1974; p2) stated; "physical evidence cannot be wrong; it cannot perjure itself; it cannot be wholly absent. Only in its interpretation can there be error", it can be said that the success of forensic analysis depends on the manner it was conducted.

CHAPTER 4: Study area

As indicated in Section 3.1, experimental studies are crucial to establish the nature, transfer, tenacity, and method of collection of trace evidence which assist Objectives 2 and 3 that consist of appropriate analysis, interpretation and presentation of the trace evidence. The use of landform mapping, allied to other assets such as vegetation, soils, and anthropogenic features, allows the investigator to accurately select areas where samples should be gathered. In order to demonstrate this process from landscape interpretation, Figure 4.1 shows the area under investigation and the two specific study sites.

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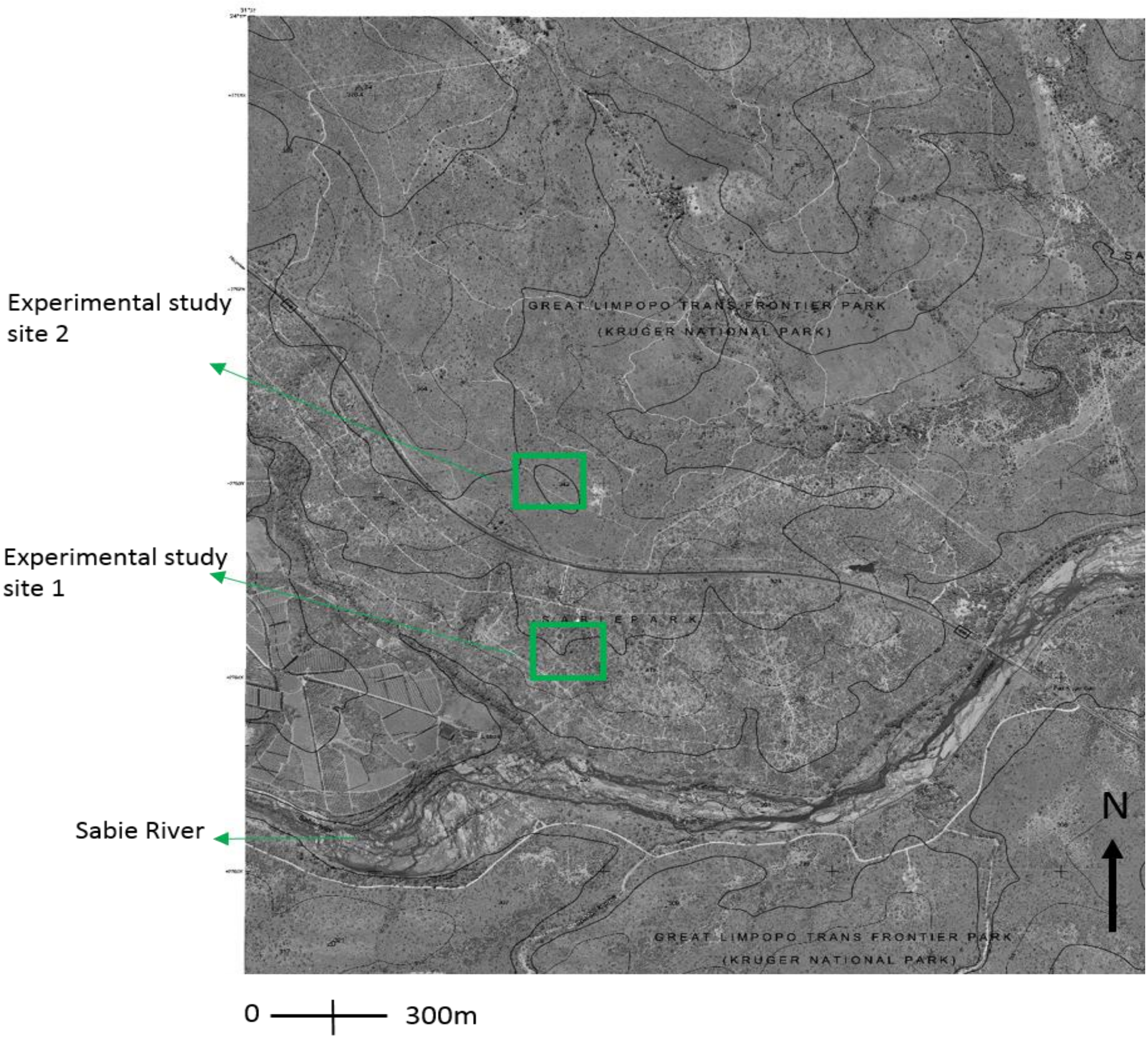


FIGURE 4.1: Overall study area where experimental studies were conducted (NGI, 2013). Topographic map available in Appendix 1

4.1 Study areas

The study areas are located between 24 57' and 25S, and 31 27' and 31 30' E at an altitude of approximately 320m above sea level. Hot summers and mild winters, with an average maximum temperature of 32.9° C and an average minimum temperature of 16.2° C characterize the climate. The overall vegetation of the study areas consist of mixed *Terminalia sericea* (combretum), woodland occurring on sandy granite soil forming part of plains or lowlands (Munyati & Ratshibvumo, 2010). On a regional scale the Lowveld forms the footslope of the Drakensberg escarpment and can be classified as a pediplain with a gentle slope towards the east (Heritage & Moon, 2000). The area underlain by granitoid rocks is characteristically gently to moderately undulating with scattered inselbergs occurring in certain areas, sometimes in clusters (Heritage & Moon, 2000 and Munyati & Ratshibvumo, 2010). The inselbergs are the result of locally higher resistance against weathering caused by dome-like structures in the granitoid rocks (Munyati & Ratshibvumo, 2010).

The division of matter (the fractiontion of sediments from the parent body) is necessary for the generation of physical evidence (Inman & Rudin, 2002). In the forensic context it is necessary for the transfer of evidence to take place from the forensic event site to either another location, or clothing or objects associated with the perprator such as shoes, clothing, vehicles and so forth. (Fitzpatrick, 2009). It is then not only important for the evidence to persist upon the personal items associated with the perpatrator, but also for the evidence to be recognized and collected in both studies. Finally this transferred evidence, trace evidence, is required before an interpretation statement can be provided for the court (Inman & Rudin, 2002). This is of course the idealised scenario. In reality, there are significant complexities concerning the transfer, persistance and tenacity of trace evidence, and proper knowledge of the area is required in order to effectively face these complexities (Figure 4.2 and 4.3).

4.2 Experimental study site 1

The location is set around a 25m^2 watering hole located approximately 300m above sea level. This location was selected owing to a poached impala that was seen at this location during site visits, thus ideally mimicking a rhinoceros poaching site. Two people, whom will be referred to as the 'suspects' mimicked the movements of poachers around the watering hole carrying an axe, a standard tool used by rhinoceros poachers. Both suspects wore khaki short pants and cotton t-shirts, footwear will be used with cotton socks. At the selected location the suspects lightly doused the axe with water to mimic the blood fluids as was explained in Chapter 3.

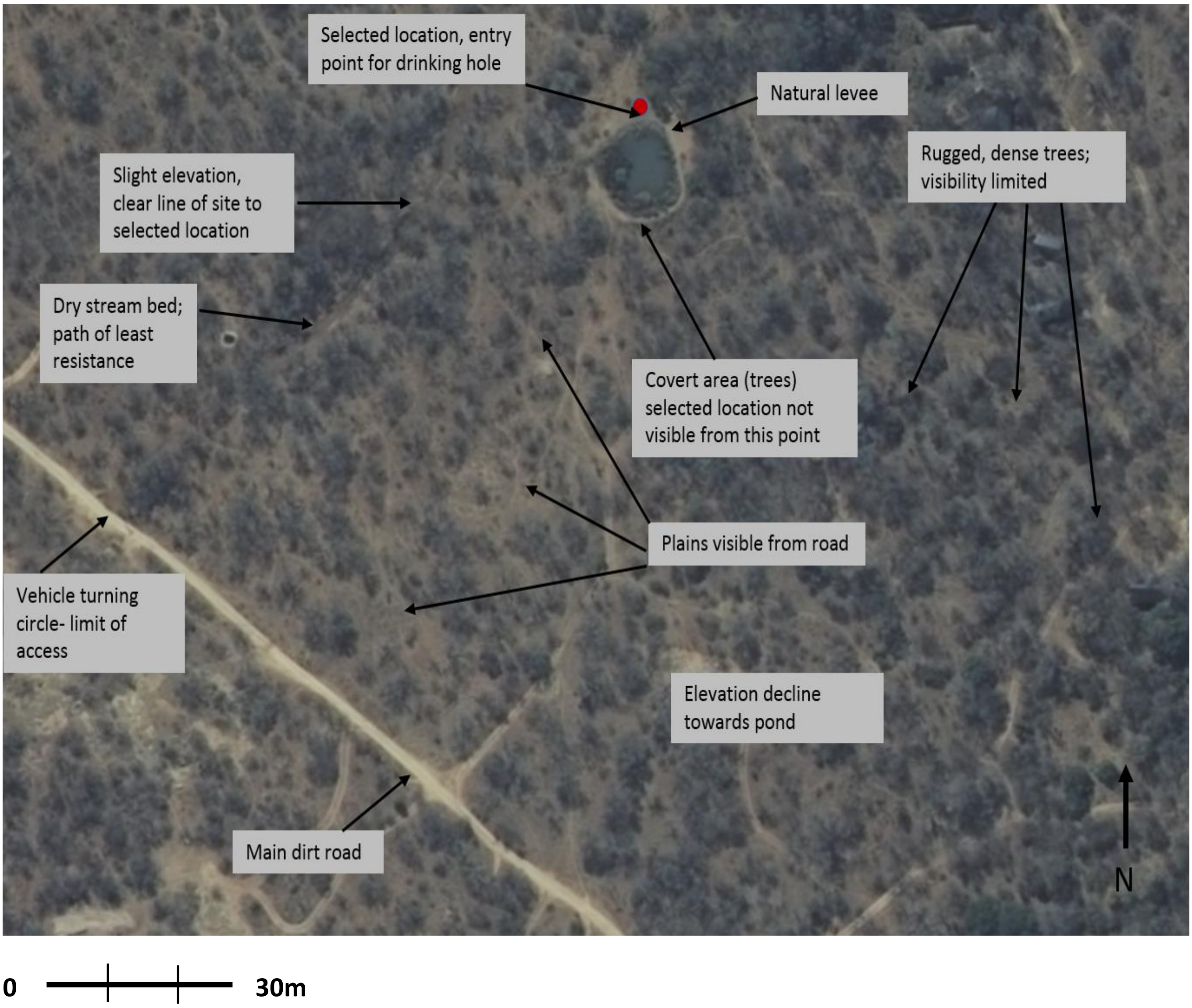


FIGURE 4.2: Landscape and behavioural interpretation of experimental study site 1 in selecting samples (NGI, 2013). Location and raw data shown in Figure 4.1

Through analysing the landscape on foot and by aerial photographs, geomorphic descriptions can be identified and classified in four basic geomorphic categories listed below;

A) LANDSCAPES

The landscape at study site 1 comprises small scale plains: A plain is a broad area of relatively flat land. Plains are one of the major landforms, or types of land, on Earth (Schoeneberger, 2012). As illustrated in Figure 4.2, grasslands are the predominant type of plain. *Euclea undulate* (gwarriebos) and *Spirostachys Africana* (tambotie) are the predominant vegetation of the area. The area presents a centripetal drainage pattern, as most of the accumulated precipitation flows down towards the watering hole.

B) LANDFORMS

A natural levee, low hill, and a stream were identified at the study site. A natural levee is a deposit of sand or mud, built up along or sloping away from, either a floodplain, stream, or in this case, a pond (watering hole) next to the selected location. The main gravel road runs parallel to the pond, as can be seen in Figure 4.2, and deescalates from Southeast to Northwest by about one meter. An episodic stream channel that lack surface flow during most parts of the year is present on the western side of the area and is visible from the main dirt road as well as the selected location. Soil that is rich with nutrients and not exposed to over-grazing occurs to the east side of the area, allowing for a larger and more dense vegetation.

C) POINT FEATURES

An open depression, pond, tree tip mound, and tree tip pit were among the geomorphic point features present. A Slight depression around the watering hole, a dry stream and multiple footpaths linking up at watering hole were also evident features. Recent tree tips, which refer to trees overturned by elephants, were scattered across the landscape, some tree tips from previous years have led to new types of vegetation growth such as *Terminalia sericea* (combretum).

D) ANTHROPOGENIC FEATURES

Anthropogenic features are limited although it is important to note the gravel road. The main gravel road of game reserve which is also the only road within the area, stretches across the lower part of the study area.

The landscape descriptions identified under the four basic geomorphic categories allowed the researcher to conclude a proper interpretation of the area. A watering hole is common spot for rhinoceroses to be poached (as mentioned in Chapter 2 and illustrated in Figure 2.3). However, as illustrated in Figure 4.2, the line of sight is limited due to natural obstructions. Therefore, it can be assumed that if poachers were to shoot a rhinoceros at this watering hole, they would have to travel by foot to a certain point where they had a clear line of sight towards the rhinoceros as well as maintaining a safe distance to prevent detection. Figure 4.2 illustrates that the most likely route for a poacher to take would be along the dry stream bed, as it provides the least natural obstructions, and at a certain point the route presents a clear line of site towards the watering hole. Studying the geomorphic observations made above, the most practical area to collect samples were in and around the stream bed and obviously around the selected location.

4.3 Experimental study site 2

The selected location is in a rocky, exposed area (Figure 4.3) where rhinoceros poaching incidents have occurred before. Two people, which will be referred to as the 'suspects' mimicked the movements of poachers by driving along the main dirt road to a selected point from where they will continue on foot about 50meters into the bush and return to the vehicle. Both suspects will be wearing khaki short pants and plain cotton t-shirts, footwear such as boots and sandals will be used with cotton socks.

FIGURE 4.3: Landscape and behavioural interpretation of experimental study 2 (NGI, 2013). General location shown in Figure 4.1

Through analysing the landscape on foot and by aerial photographs, geomorphic descriptions were identified and classified into four geomorphic categories;

A) LANDSCAPES

Plains are the dominant landscape feature of study site 2. *Sclerocarya birrea* subsp. *Caffra/Acacia nigrescens* savannah occurring on clayey gabbro derived soils are the predominant type of plain. Alternate *Combretum apiculatum* woodland/Coloph. (mopane tree savannah) are the predominant types of vegetation. The landscape experiences high levels of large herbivore grazing, for example buffalo and elephant herds, resulting in very limited vegetation due to over trampling of the surface and also resulted in rills and evident sheetwash across the landscape. The area presents a parallel type of drainage pattern eastwards toward the river.

B) LANDFORMS

A low hill is the only major landform type. Based on the contour map of the area (Appendix 1) there is a twelve meter decrease in the elevation from south to north, in which sheet-wash erosion becomes a dominating geomorphic process in the area. Regular site visits made it clear that precipitation has led to thin layers of water removal of most of the regolith in the area. Due to the lack of vegetation in the area, wind has also become in increasing important factor in removing the loose, heterogeneous material across the landscape, resulting in a very rocky exterior.

C) POINT FEATURES

An open depression, tree tip mound, and tree tip pit were the dominant geomorphic point features in the area. There was a slight depression next to a vehicle drop of point as shown in Figure 4.3 that are dominated by loose sandy soils. Multiple footpaths are scattered across the landscape as well as large granite boulders. As with experimental study site one, recent tree tips, caused by elephants, are scattered across landscape.

D) ANTHROPOGENIC FEATURES

A main gravel road that stretches for 10km and a secondary dirt road approximately 2km were the only two anthropogenic features present in the area.

From Figure 4.3 it can be observed that the suspects have an increased line of view compared to experimental study site one, owing to the nature of the landscape, which would allow a perpetrator to shoot a rhinoceros with ease from a distance as the area does not present many natural barriers. However, through landscape interpretation, it became clear that one specific footpath were the most likely route for a suspect to take; although there are many footpaths (Figure 4.2), the specific footpath is clearly visible from the road and it would be very unlikely for a poacher to pursue a target on a path that presents some obstacles. Still, a wider base of sampling needed to be collected as a suspect could move more freely than the landscape referred to in study site one.

An analysis of the geomorphology of the area allows for, as Hunter *et al*. (2013; p94) stated: "an assessment of what is or what is not likely to have been possible, and the subsequent delimitation of target areas", meaning what would be the most efficient and accessible path taken by a suspect. Through this knowledge, it was possible to effectively and accurately identify areas for sample collection. The two experimental studies took place in different landscapes in order to re-enact actual rhinoceros poaching scenes (as illustrated and explained in Chapter 2, Figures 2.3 and 2.4).

After successful landscape interpretation were conducted of both experimental study sites in order to correspond with Objective 1 (as set out in Section 1.3), the selection and proper collection of samples could have been made (Chapter 5) in order to identify the ubiquitous nature of soils and sediments found in each landscape and so doing achieve Objective 2.

CHAPTER 5: Results and analysis

5.1 Experimental study site 1

5.1.1 Sample identification

As discussed in Chapter 3, two sample sets are needed for comparison analysis; the known sample set which is collected from the site itself, and the comparator sample set which is obtained from the suspects' belongings. The landscape interpretations in Chapter 4 (Figures 4.2 and 4.3), allowed the effective identification of the most prominent areas in each study site for sample collection that forms part of the known sample set.

5.1.1.1 Known sample set

It is crucial for the success of subsequent geoforensic analysis, interpretation and presentation that the collection of soil/sediment samples is carried out accurately, appropriately and effectively.

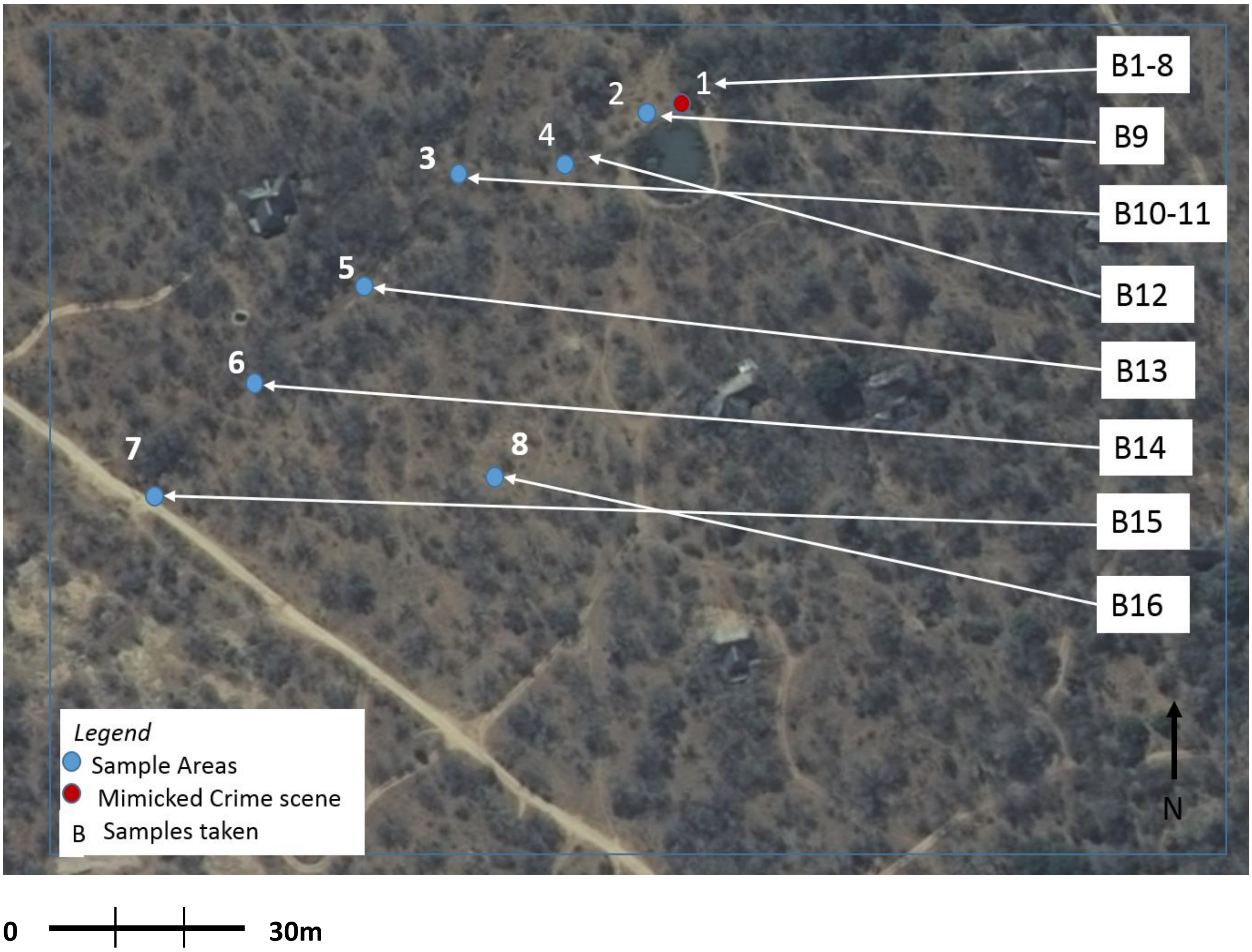


FIGURE 5.1: Points represent the eight areas that were selected for sample collection as well as the sample numbers collected at each of the eight areas at study site 1

The landscape interpretations (Figure 4.2) illustrated the limited movements available for a person moving from the dirt road towards the selected location.

Eight areas were selected from the landscape for sample collection and approximately sixteen samples were gathered altogether depending on the area identified for collection (Figure 5.1). The weight of each sample taken from the eight areas is illustrated in Table 5.1.

Around the selected location that serves as the mimicked crime scene, a sample grid was purposefully located next to the pond where footprints were visible around the location selected based on Pye *et al* (2006). Eight samples were collected from each of the nodes within each grid surrounding the selected location. Each sample was taken from an area of 10cm by 10cm (0.1m by 0.1m) on the surface as illustrated in Figure 5.2. Samples were sequentially taken and numbered clockwise from B1 to B8 as displayed in Figure 5.2.

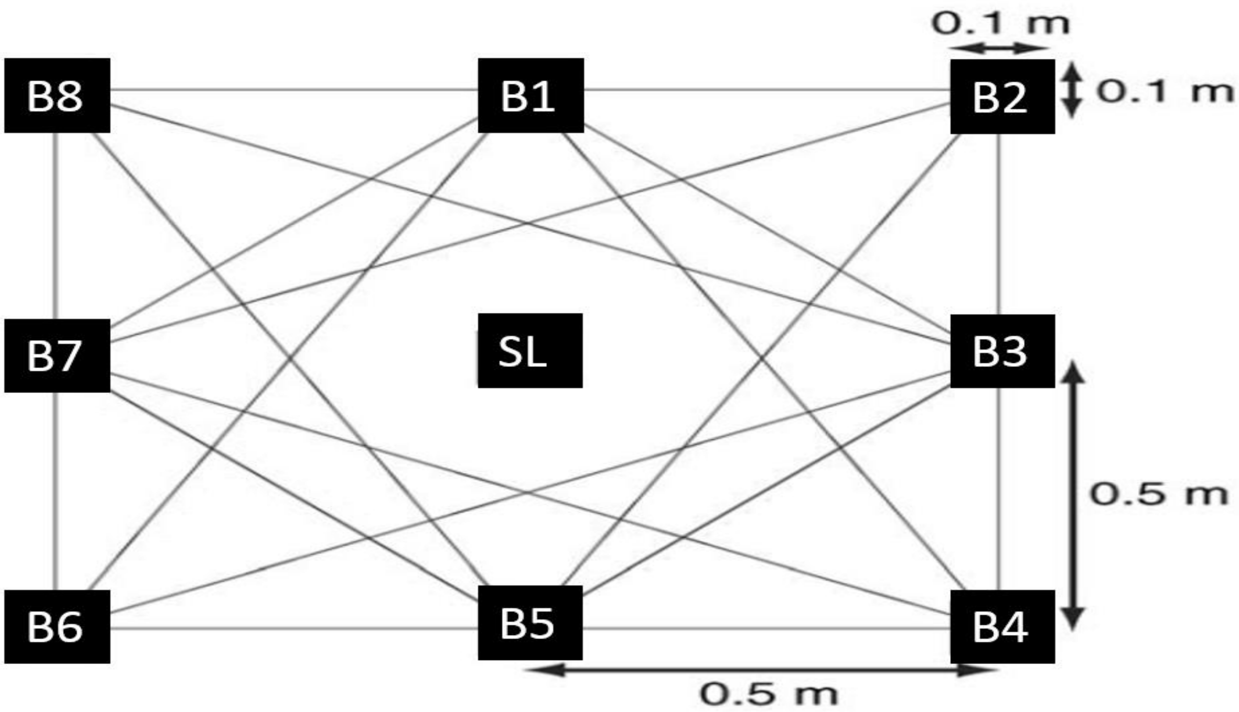


FIGURE 5.2: Sampling grid at experimental study site 1 around selected location represented by 'SL'. B1-B8 represent samples taken

Figures 5.3, 5.4 and 5.5 display the selected location indicated by a red pole to designate where the sampling grid was established. Samples were taken around this location as it was noted previously from the samples gathered in the comparator sample set that the soil displayed a moist texture that easily adhered to the suspects' boots, suggesting that in all probability it originated from a water source, such as the pond.

FIGURE 5.3: Red pole represents selected location that serves as the mimicked crime scene. Photo was taken in a South-Western direction

FIGURE 5.4: Part of the samples gathered in the sample grid (Figure 5.2), the plastic bags represent samples B5 and B7. Notice the difference in soil colour towards the watering hole, emphasising the importance in sample interpretation.

FIGURE 5.5: Samples were taken direct from the footprints next to the marker which represented a mimicked poached rhino

TABLE 5.1: Samples gathered from the landscape of study site 1 for the known sample set

Area	Location	Samples	Weight
1	Selected location, crime scene	B1	50mg
		B2	50mg
		B3	50mg
		B4	50mg
		B5	50mg
		B6	50mg
		B7	50mg
		B8	50mg
2	Footpath	B9	50mg
3	Dry stream bed	B10	50mg
		B11	50mg
4	Footpath	B12	50mg
5	Footpath	B13	50mg
6	Footpath	B14	50mg
7	Entry point	B15	50mg
8	Plains	B16	50mg

5.1.1.2 Comparator/questionable sample set

This sample set refers to the any trace evidence that could be gathered form the suspects' clothing or belongings that might have derived from the crime scene after they were apprehended. Both primary and secondary trace evidence was collected from the suspects. The suspects' clothing and items were analysed, upon turning over the one of the suspect's shoes, a small quantity of soil was detected adhering to the inside portion of its heel (Figure 5.6). Another portion of soil was present within the sole of another shoe worn by the suspects (Figure 5.7). Perhaps the most valuable traces of soil were retrieved from the axe carried by the suspects (figure 5.8).

FIGURE 5.6: Traces of soil adhered to the heel of the boot of one of the suspects were collected, the moist soil sticking more prominently than dry particles

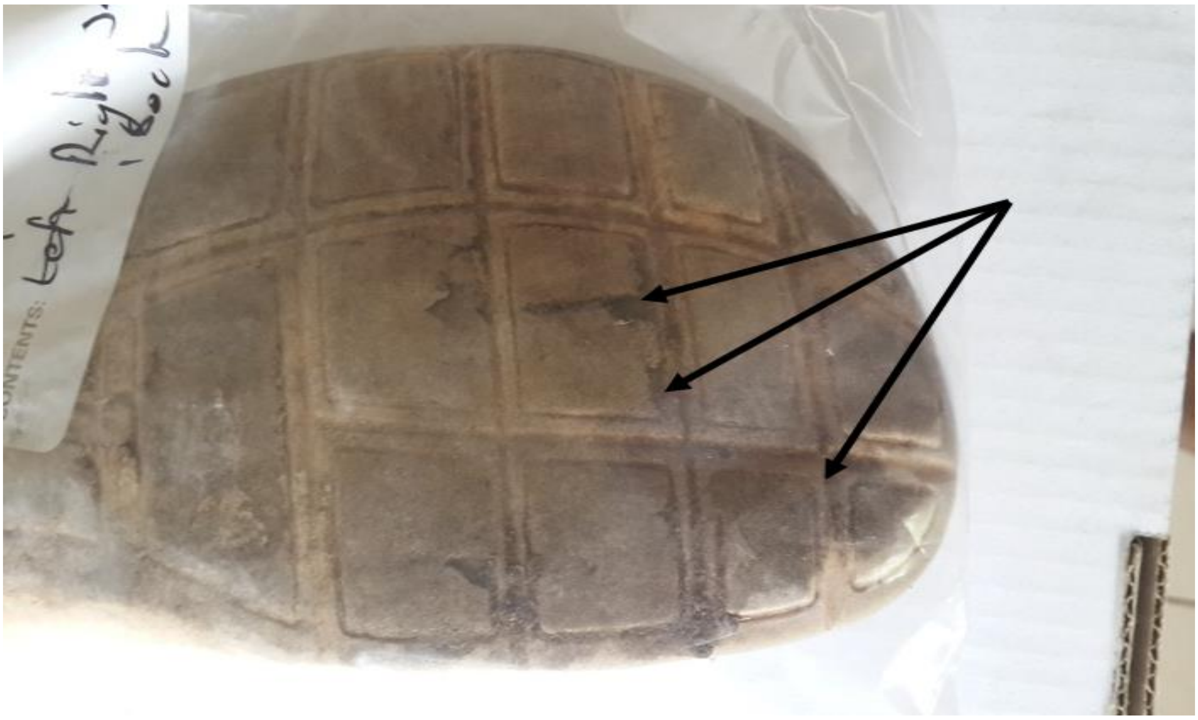


FIGURE 5.7: Finer particles of soil were collected in the cracks of the worn out sandal, possibly silt from the dry riverbed

FIGURE 5.8: the axe used by the suspects presented the most valuable traces of soil. In actual cases soil and other trace evidence easily stick to a blooded axe.

Three samples (Table 5.2) could be gathered from the suspects' clothing and belongings, no sufficient secondary trace evidence could be identified within the vehicle used.

TABLE 5.2: Samples gathered from apprehended suspects that wandered through study site 1

Comparator/questionable sample set	Location gathered	Weight
A1	Axe	15mg
A2	Right shoe	15mg
A3	Left sandal	10mg

With the completion of sample identification and collection, comparison analysis of the sample sets commenced to establish whether the comparator sample set could be excluded from the study site

5.1.2 Analysis

Morgan & Bull (2006) note that it is very important when interpreting the results of soil and sediment analyses that due care is given to the exclusion of samples, and that samples which show very similar characteristics are viewed in the context of the uniqueness or rarity of their particular attributes. After all soils and sediments have been gathered from the known (Section 5.1.1.1) and the suspects (Section 5.1.1.2), analysis was done to determine how accurately the geomorphic trace evidence, could be used to link the evidence. As illustrated in Figure 1.1 and explained in Chapter 3, the analysis consists of three stages in order to establish if there are a significant linkage between the sample sets.

Munsell colour analysis indicated that each sample of the comparator sample set is a 7.5YR 4/2 category, which approximates a reddish, grey brown colour and is one of the categories of the 80 or more recognised by the Munsell system of classification (Morgan & Bull, 2007). Eight samples of the known sample set displayed the same colour as the comparator sample set which indicates that the samples in Table 5.2 cannot be excluded from the investigation. Sample colour can only be used as an exclusionary and descriptive technique, since the homogenisation required to prepare the sample will inevitably fail to identify mixing and contamination around a forensic incident.

Stage 1- Soil morphology

Soil morphological; descriptors such as texture, consistency, structure, colour, and abundance of vegetation are the most useful properties to aid the identification of soil materials and to assess practical soil conditions (Bull & Morgan, 2006).

TABLE 5.3: Soil texture of each sample in the known and comparator sample set

	Specimen	Morphology	Size +/- (mm)	Consistency	Vegetation	Roundness	Sphericity
Comparator/ questionable Sample set (QS1)	A1	Medium sand	0.25-0.5	Loose	Yes	Rounded	Sub-discoidal
	A2	Medium sand	0.25-0.5	Very friable	No	Rounded	Discoidal
	A3	Fine sand	0.1-0.25	Soft	Yes	Angular	Sub-prismoidal
Known sample set (KS1)	B2	Silt	0.002-0.05	Loose	Yes	Angular	Sub-prismoidal
	B3	Silt	0.002-0.05	Loose	Yes	Sub-angular	Prismoidal
	B4	Coarse sand	0.05-1.00	Loose	Yes	Well-Rounded	Sub-discoidal
	B5	Medium sand	0.25-0.5	Very friable	No	Sub-angular	Discoidal
	B6	Fine sand	0.1-0.25	Loose	No	Rounded	Discoidal
	B7	Medium sand	0.25-0.5	Loose	Yes	Rounded	Discoidal
	B8	Very fine sand	0.05-0.1	Very friable	No	Very angular	Sub-discoidal

The known and comparator sample sets were sieved, weighed, and finally viewed under a scanning electron microscope to establish the morphology of the samples. The results are displayed in Table 5.3.

Soil morphology is the numerical proportion (weight percentage) of the sand, silt and clay separates in the fine-earth fraction (<2mm). Soil separates are specific ranges of particle sizes. According to the USDA, the smallest particles are clay particles and are classified as having diameters of less than 0.002 mm. The next smallest particles are silt particles that have diameters between 0.002 mm and 0.05 mm. The largest particles are sand particles and are larger than 0.05 mm in diameter. After sieving the weight percentage was used to determine the dominant texture in each sample using the USDA soil textural triangle (Appendix 2).

Particle size is a physical property of any soil that can provide important clues to the nature and provenance of a sample. As discussed in Chapter 3.3.1, simple sieving measures were used to determine dominant particle size due to the limited amount of soil available for analysis. The comparator soil samples (QS1) show medium sand (particles less than 0.5 mm and greater than 0.25 mm in diameter) to be the dominating particle with fine sand (particles between 0.1 mm and 0.25 mm in diameter) to a lesser extent also found in the comparator sample set.

Images produced by the SEM revealed unique features in some of the samples; the presence of many faint, brown 10YR 4/6 (Musell classification system) moist clay films on all faces of peds (<2um), as can be seen in Figure 5.9, were identified. The clay coatings (< 0.002 mm) are mostly present on the coarse sand edges and illustrate a waxy, exterior coating. The presence of clay minerals within the comparator sample set supports the idea that the suspect must have been near a water source at some stage, as it also bears a similar resemblance to the samples from the known sample set that were collected around the pond (Figure 5.10). The similarity between the sample sets is increased during the winter months when the study was conducted since little precipitation occurs in the area, suggesting that waxy clay coatings will only be present on particles in or near a water source.

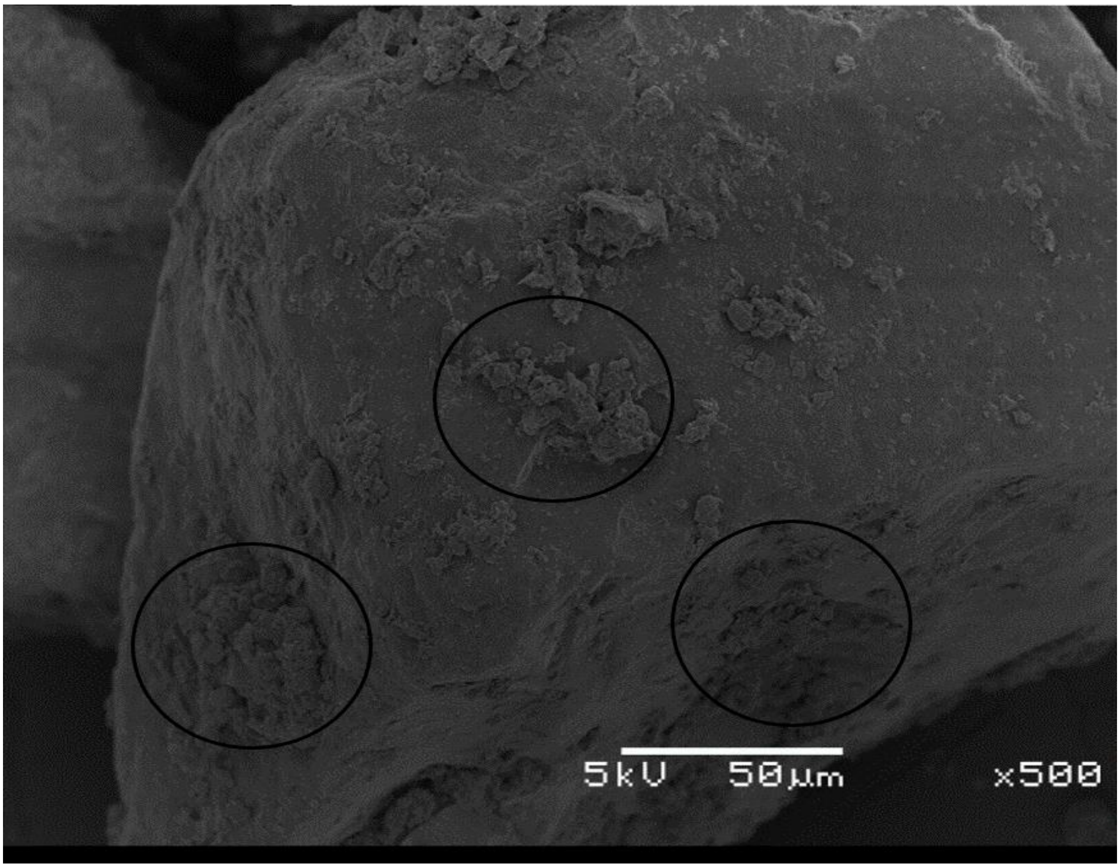


FIGURE 5.9: Sample B4, SEM image of particles displaying clay films on waxy exterior

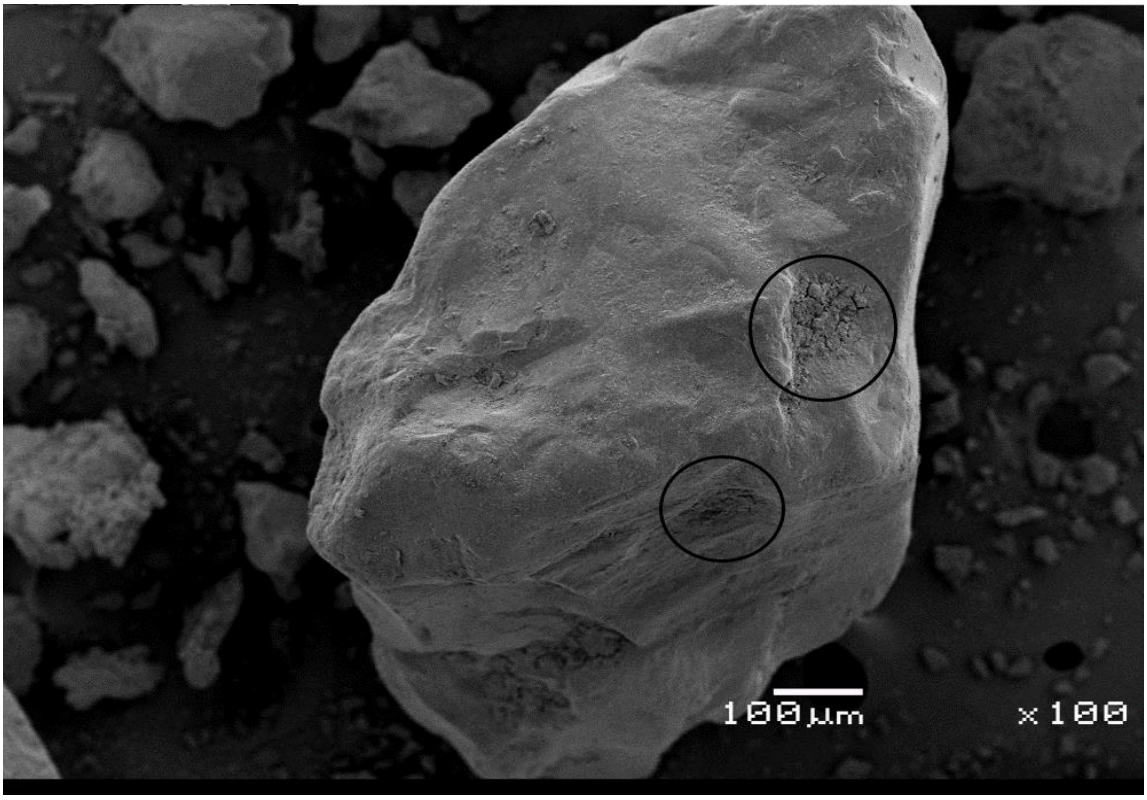


FIGURE 5.10: Sample A1 display the same clay films as B4

Figures 5.9 and 5.10 also illustrate the dominant shape of the soil particles, which was estimated using the USDA (2012) roundness graphic (Appendix 3) in order to get a main physical description of the samples. Rounded particles suggest that some form of chemical or physical weathering (USDA, 2012), possibly caused by the stream and lowland, smoothed out and caused the rounded edges to the particles in the area where samples were collected from.

It is not uncommon to detect plant debris in samples taken in a natural environment and samples could not be excluded on this basis. However it could serve as an informal indicator to the forensic investigator to which samples could be used for biological analysis at a later stage should not enough information be gathered through physical and chemical analysis. Most samples displayed the presence of root fragments and pollen, as can be seen in Figure 5.11. Other soil forensic methods such as plant wax markers analysis, plant fragment deoxyribonucleic acid (DNA) analysis, and microbial fingerprinting using a variety of molecular biological techniques can be used to analyse the diversity in soil microbial communities for forensic soil comparison (Ward *et al*., 2005). The pollen identified in Figure 5.11c could also be used to establish a link between the two sample sets through a proper palynological analysis, if the current analysis provides insufficient results.

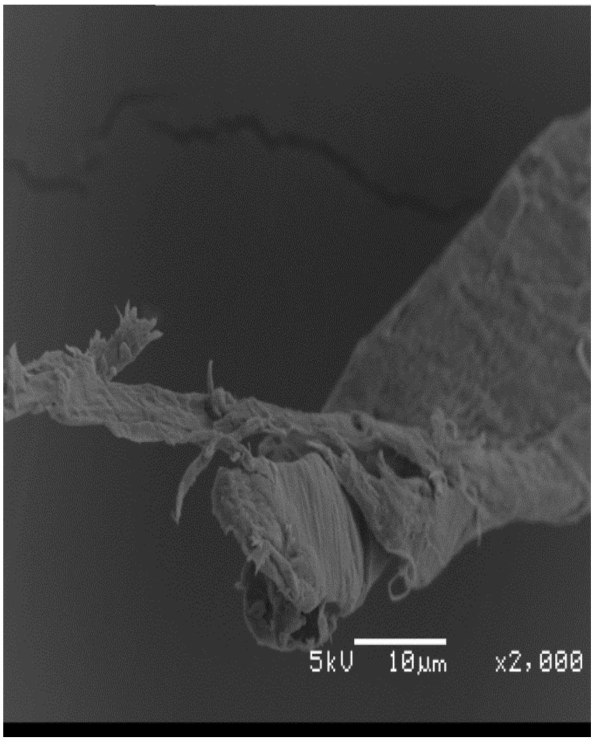


FIGURE 5.11a: Micrograph of a root fragment in sample B7

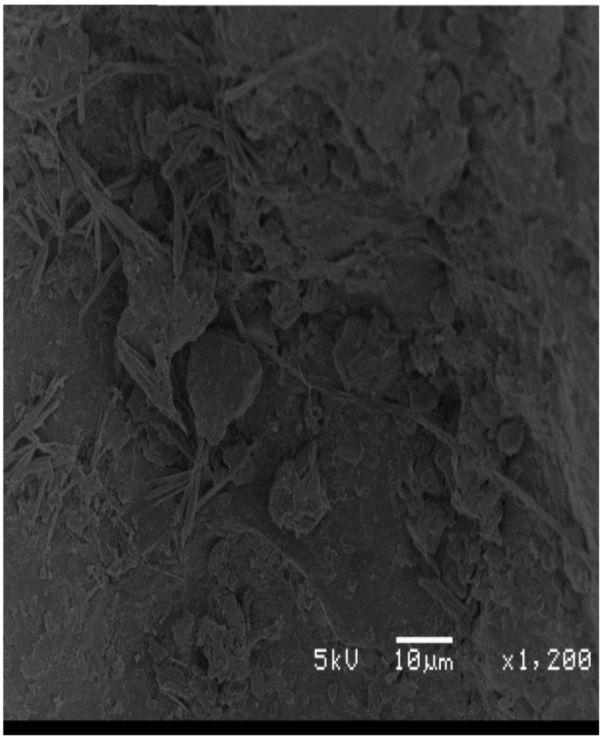


FIGURE 5.11b: Micrograph of the fragments of leaflets in sample A2

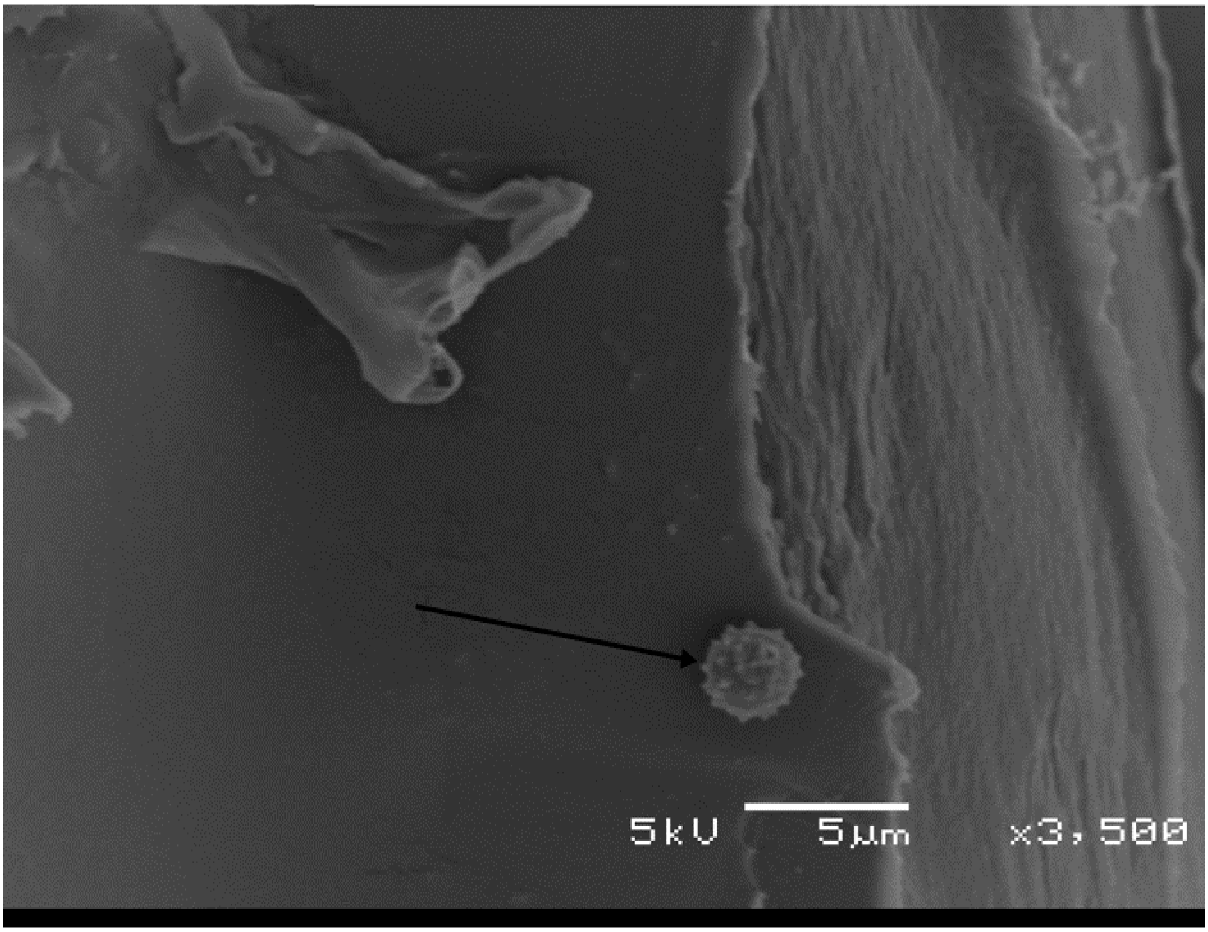


FIGURE 5.11c: A micrograph of a pollen spore in sample B6. Pollen indicated by the arrow.

Samples B4, B5, B6 and B7 of the known sample set illustrate the same soil texture, size, structure, colour as well as the presence of clay films on some of the particles of the comparator soil sample set and can therefore not be excluded from the investigation. It is unlikely that the observed similarity could be from samples from different locations. However, soil morphology is not sufficient enough to be presented in court as valuable evidence. The remaining samples' mineralogical structure and chemical composition needed to be analysed before any further exclusions could be made.

Stage 2- Mineralogy

Soil is generally developed on residual or transported geological material and so may always be traced back to the parent rocks from which it was formed (Dawson & Hillier, 2010). This means that all of the minerals that occur in rocks may also occur in soils, in addition to those formed by soil-forming (weathering) processes. An understanding of how minerals are identified and classified is important because minerals may be distinguished from each other at different levels of detail.

TABLE 5.4: Detailed/quantitative XRD results displaying mineralogy of selected samples

Specimen	Location	Colour	Mineral	%	3 σ error	Vegetable debris
KS1	Selected location B4	7.5YR 4/2	Quartz	39.77	0.96	Medium
			Microcline	14.69	0.84	
			Plagioclase	40.64	1.02	
			Muscovite	1.37		
			Diopside	4.9	0.6	
	Site at surface B5	7.5YR 4/2	Quartz	38.5	0.99	Trace
			Microcline	10.69	0.84	
			Plagioclase	43.64	1.02	
			Muscovite	Trace		
			Hornblende	Trace		
	Site at surface B6	7.5YR 4/2	Quartz	57.96	0.96	Trace
			Microcline	7.33	0.78	
			Plagioclase	33.7	1.02	
			Muscovite	1.89		
			Hornblende	Trace		
	Footpath B14	7.5YR 4/2	Quartz	40.46	0.99	Medium
			Microcline	12.81	0.78	
			Plagioclase	47.73	1.02	
			Muscovite	Trace		
			Hornblende	Trace		
QS1	Axe A1	7.5YR 4/2	Quartz	44.96	0.99	Trace
			Microcline	11.99	0.87	
			Plagioclase	42.05	0.96	
			Muscovite	Trace		
			Diopside	2.8		
	Suspect's socks A2	7.5YR 4/2	Quartz	39.83	0.93	Trace
			Microcline	19.05	1.14	
			Plagioclase	34.36	1.11	
			Muscovite	6.77	0.63	
			Diopside	Trace		
	Suspect's shoes A3		Quartz	44.22	1.14	
			Microcline	10.88	1.08	
			Plagioclase	44.9	1.02	
			Muscovite	Trace		
			Hornblende	Trace		

*Trace refers to less than 1%

*KS1- Known Sample set 1 *QS1- Questionable/comparator sample set 1

The mineralogy component of the remaining samples was analysed through X-ray Diffraction to identify whether there are any unusual mineral components. If the soil samples contain only one crystalline component such as quartz, namely 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. However, as Dawson & Hiller (2010) argue, if the two soils contain four or five crystalline mineral components, some of them unusual, then the degree of similarity will be considered as high.

Both the known and comparator sample sets contain five crystalline mineral components, confirming that a degree of similarity could be considered as mentioned by Dawson and Hiller (2010). Quartz, microcline, plagioclase, muscovite and hornblende are common minerals in southern Africa and are widely spread across the landscape (Cairncross, 2004). Thus, it would not be uncommon to find these minerals in a sample. However, the average mineralogy percentage of all samples appears to be uniform, suggesting that the comparator sample set cannot be excluded. Even though the percentages of minerals in the comparator sample set have some resemblance to the known sample set, it is does not present enough similarity to be used as standalone evidence in court. However, sample B4 contains a small percentage of diopside, which is also present in every sample in the comparator sample set, specifically sample A1. Diopside is fairly common in some of the rocks of the Bushveld Complex (Cairncross, 2004) and more specifically in the south-western areas of the Kruger National Park (Munyati & Ratshibvumo, 2010), which means that it could have originated from the selected location at experimental study site 1 and can therefore not be excluded from the crime scene. The same minerals are rarely identical in detail (Dawson & Hiller, 2010). Therefore, if the samples that show similar mineralogical characteristics display the same pattern during chemical analysis, a possible linkage can be made.

Stage 3- chemical analysis

The final stage in the comparison analysis consist of comparing the remaining samples from stage 2 that cannot be excluded using X-ray Fluorescence spectroscopy in order to determine their chemical composition. If a sample from the comparator sample set were to display a strong chemical composition resemblance to one of the remaining samples from the known sample set, then those two samples most certainly originated from the same area.

TABLE 5.5: Percentage and range of elemental concentrations in comparator- (A1, A2, A3) and known sample set (B4, B5, B6, B14)

%	Certified	Analysed	A1	A2	A3	B4	B5	B6	B14
SiO_2	99.6	99.70	72.75	74.02	71.23	69.50	71.65	71.50	73.65
TiO_2	0.01	0.00	0.24	0.26	0.31	0.27	0.33	0.23	0.23
Al_2O_3	0.05	0.01	10.15	11.39	11.27	12.00	15.11	12.52	13.07
Fe_2O_3	0.05	0.01	1.54	1.65	2.06	1.82	2.00	1.47	1.64
MnO	0.01	0.00	0.01	0.01	0.02	0.02	0.02	0.01	0.01
MgO	0.05	0.01	0.24	0.24	0.32	0.30	0.35	0.20	0.21
CaO	0.01	0.01	4.74	4.71	3.96	3.79	2.18	4.66	1.77
Na_2O	0.05	0.02	4.55	4.55	5.77	4.70	2.25	5.46	1.58
K_2O	0.01	0.01	1.61	2.19	1.38	1.62	1.14	1.35	1.19
P_2O_5	0	0.03	0.05	0.06	0.07	0.06	0.06	0.05	0.05
Cr_2O_3	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NiO	0	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
V_2O_5	0	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01
ZrO_2	0	0.01	0.03	0.03	0.03	0.03	0.02	0.03	0.03
CuO	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LOI	0	0.10	3.33	2.68	4.07	5.70	5.44	3.88	5.54
TOTAL	**100**	**99.92**	**99.26**	**101.80**	**100.50**	**99.80**	**100.56**	**99.37**	**99.00**

Chemical analysis of the seven samples was undertaken to determine the similarity of the chemical composition given in Table 5.5. The percentage of silicon dioxide (SiO_2) appears to be average among the seven samples (well within standard deviation), which could be expected in the bushveld area where granite and gabbro are the dominant geology types and have a high Silica composition. It can be observed how the mean of the comparator sample set (A1, A2 & A3) share a similar pattern with samples B4 and B14 as illustrated in Figure 5.12.

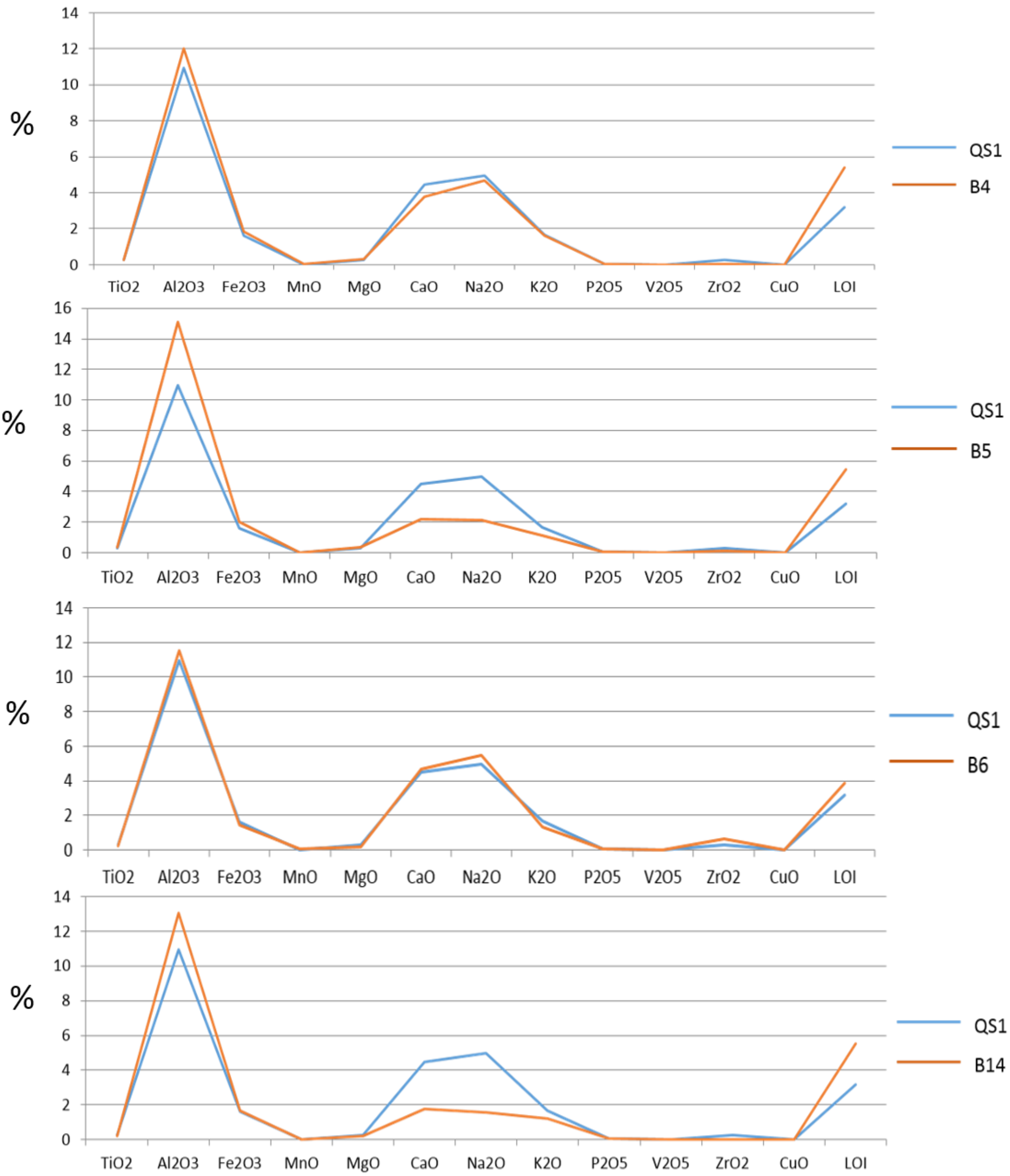


FIGURE 5.12: Graphs displaying the average percentage of the comparator sample set compared to each of the samples from the known sample set. SiO_2 has been excluded from the graphs as it has a similar percentage among all sample sets.

5.2 Experimental study site 2

5.2.1 Sample identification

As with Section 5.1.1 of experimental study site 1, two sample sets were used for comparison analysis; the known sample set which is collected from the site itself, and the comparator sample set which is obtained from the suspects' belongings.

5.2.1.1 Known sample set

This sample set refers to all samples gathered in the selected location where possible suspects moved around. Based on the landscape interpretation set out in Chapter 4 (Figure 4.3), eight areas were selected for sample collection (Figure 5.13). As the landscape in experimental study site 2 allows for more movement by possible perpetrators, more samples were collected than in experimental study site 1 in order to gain a wider range of results. Eight areas were selected to collect samples in the field as illustrated in Figure 5.13. From these eight areas, approximately eighteen samples were gathered altogether depending on the location.

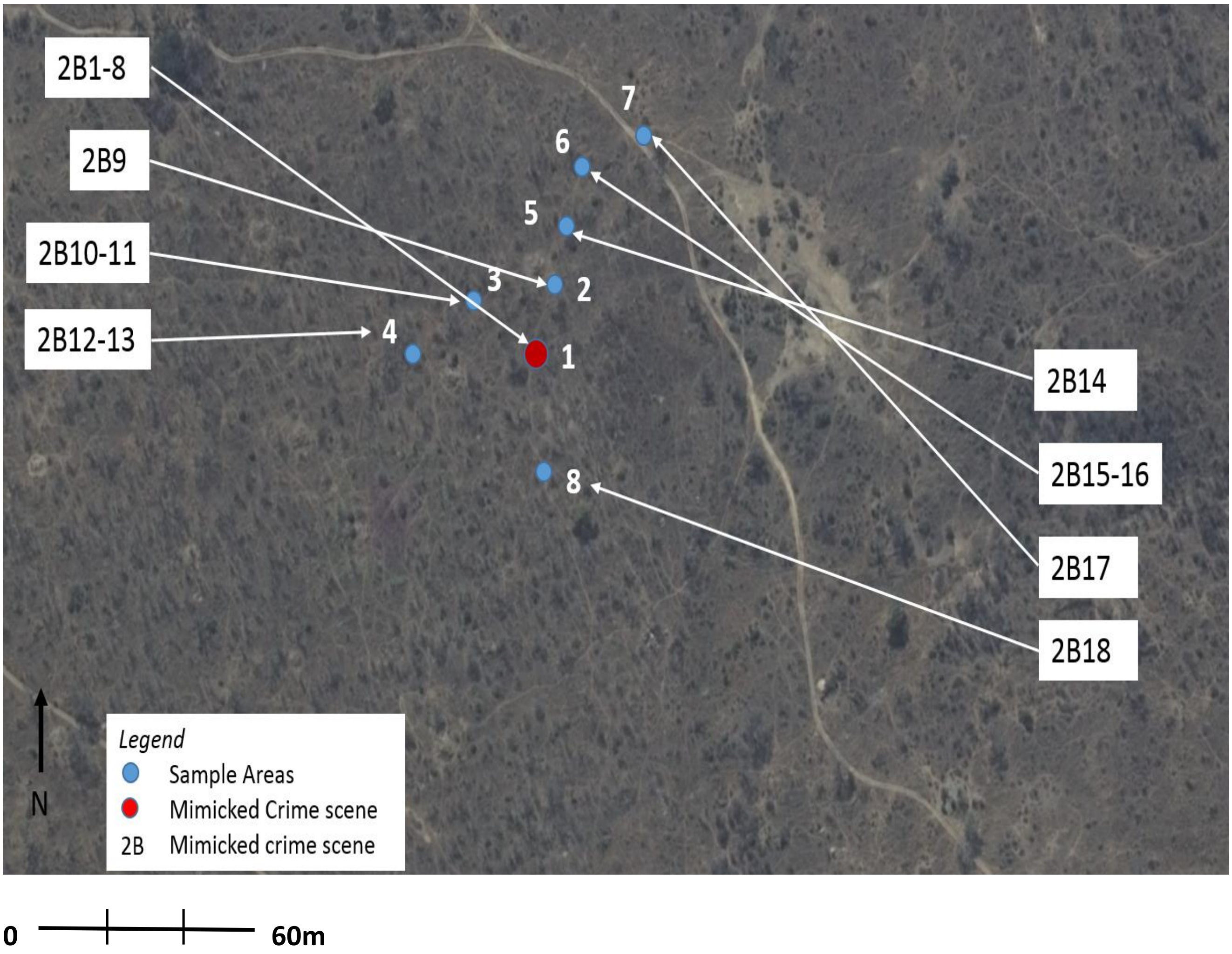


FIGURE 5.13: Points represent the eight areas that were selected for sample collection as well as the sample numbers collected at each of the eight areas at study site 2.

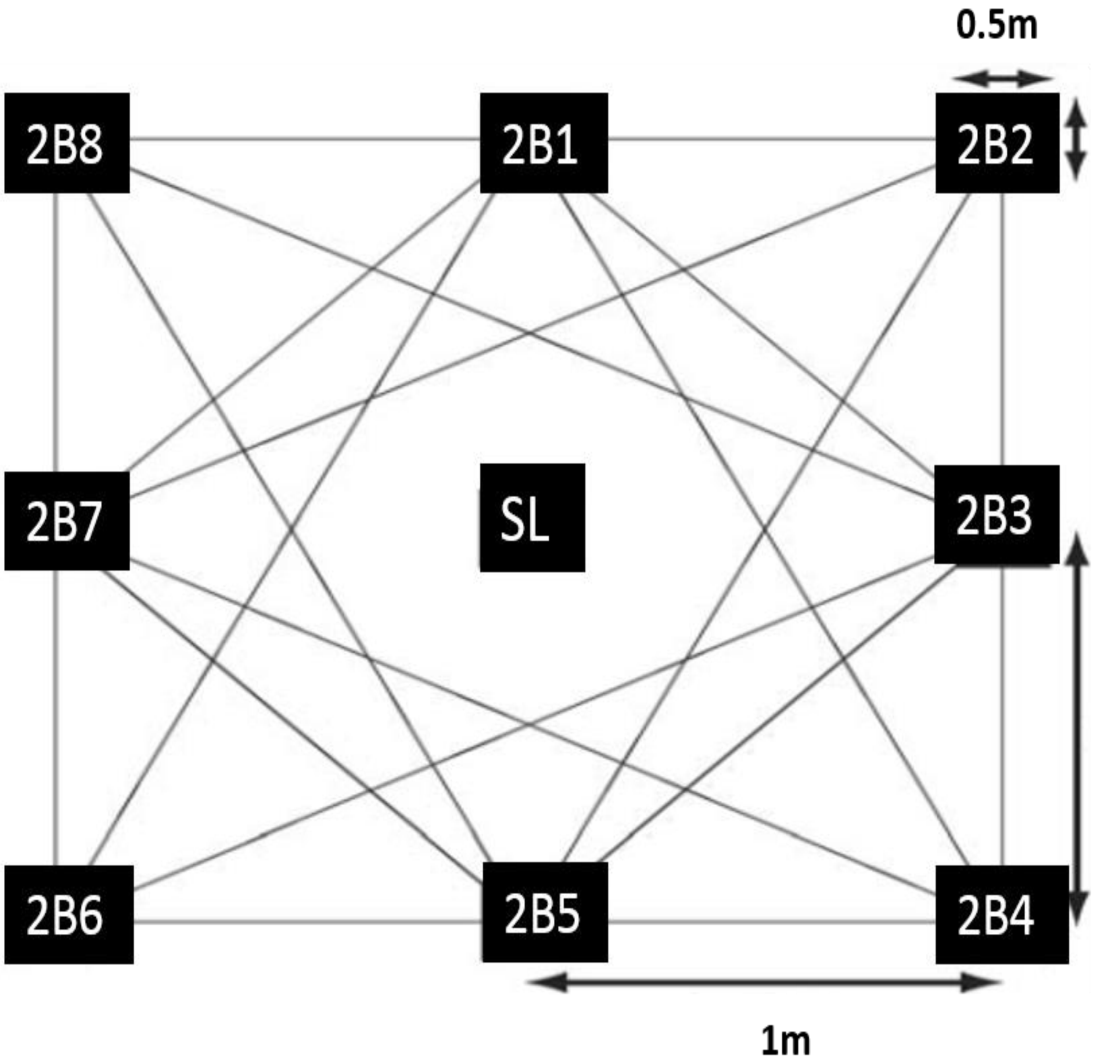


FIGURE 5.14: Sample grid around selected location represented by 'SL', numbers 2B1-2B8 represent samples taken. Note that the grid is larger than experimental study one as there was more movement of the suspects around the selected location.

At the location that served as the main crime scene, a sample grid was set up to effectively identify and collect the needed samples as illustrated in Figure 5.14. Footpaths are evidently visible in the area, and footprints could be identified at certain parts of the path (Figure 5.15 A and B) which makes it an ideal spot to collect samples.

A

B

FIGURE 5.15: Footprints could be identified along certain locations as illustrated in Figure 5.15A and B

TABLE 5.6: Known sample set gathered from experimental study site 2

Area	Location	Samples	Weight
1	Selected location, crime scene	2B1	50mg
		2B2	50mg
		2B3	50mg
		2B4	50mg
		2B5	50mg
		2B6	50mg
		2B7	50mg
		2B8	50mg
2	Footpath	2B9	50mg
3	Footprint	2B10	50mg
		2B11	50mg
4	Footprint	2B12	50mg
		2B13	50mg
5	Footpath	2B14	50mg
6	Footpath	2B15	50mg
		2B16	50mg
7	Dirt road	2B17	30mg
8	Grasslands	2B18	50mg

5.2.1.2 Comparator/questionable sample set

This sample set refers to the any trace evidence that could be gathered form the suspects' clothing or belongings that might have derived from the crime scene. Both primary and secondary trace evidence will be collected from the suspects. The suspects' clothing and items were analysed. Limited samples could be gathered in comparison with the first study site; even so the suspects' socks provided small traces of soil that could be collected. Small amount of soil could also be identified in the vehicle that was used. Two samples could be gathered from the suspects and their belongings.

FIGURE 5.16: Traces of soil found within socks worn by suspects. As recommended by Saferstein (2004) samples that cannot be easily removed from clothing should be sealed to be further analysed in the laboratory.

TABLE 5.7: Comparator sample set gathered from suspects that wandered through experimental study site 2

Comparator/questionable sample set	Location gathered	Weight
2A1	Socks	5mg
2A2	Right shoe	5mg

5.2.2 Analysis

As with experimental study site 1, all soils and sediments gathered from the known (5.2.1a) and the comparator sample set (5.2.1b) were analysed to determine how accurately these geomorphic aspects, namely trace evidence, can be linked to one another. Munsell colour analysis indicated that 9 of the 18 samples were designated between 5YR 4/2 and 7.5YR 4/2, which approximates a greyish, brown colour and is one of the categories of the 80 or more recognised by the Munsell system of classification.

Stage 1: Soil morphology

Descriptors such as texture, consistency, structure, colour, and abundance of vegetation are the most useful properties to aid the identification of soil materials and to assess practical soil conditions. Table 5.8 displays soil morphological characteristics of both sample sets.

TABLE 5.8: Soil morphology of each sample in the known and comparator sample set of experimental study site 2

	Specimen	Texture	Size +/- (mm)	Consistency	Vegetation	Roundness	Sphericity
Comparator/ questionable Sample set	2A1	Very fine sand	0.05-0.1	Loose	No	Angular	Sub-prismoidal
	2A2	Very fine sand	0.05-0.1	Loose	No	Very angular	Sub-prismoidal
Known sample set	2B1	Very fine sand	0.05-0.1	Loose	No	Angular	Sub-prismoidal
	2B2	Very fine sand	0.05-0.1	Loose	Yes	Angular	Sub-prismoidal
	2B3	Silt	0.002-0.5	Loose	No	Very angular	Prismoidal
	2B4	Silt	0.002-0.5	Loose	Yes	Very angular	Sub-discoidal
	2B5	Silt	0.002-0.5	Soft	No	Sub-angular	Spherical
	2B9	Fine sand	0.1-0.25	Loose	No	Angular	Prismoidal
	2B10	Very fine sand	0.05-0.1	Loose	Yes	Angular	Sub-discoidal
	2B11	Fine sand	0.1-0.25	Soft	No	Very angular	Sub-discoidal
	2B15	Fine sand	0.1-0.25	Soft	No	Angular	Spherical

As with experimental study site 1, particle size of each sample set presented too little to be analysed by the Malvern Mastersizer 2000 laser granulometer and was determined by sieving once more to serve as a descriptive technique. The dominating size between the sample sets presented a very fine texture and loose consistency, which corresponds to the dusty landscape.

Although samples have shown similar characteristics regarding particle shape as can be seen in Figures 5.17 and 5.18, particle textures were more irregular than that of the samples gathered at experimental study site 1. However, matches could be found as to the consistency of particles. The consistency of the sample can be described as a very dry moisture content. The degree of cohesion and adhesion appears to be low as the soil samples can be deformed with relative ease and particles are presented in a solid state (Appendix 7). During scanning electron microscopy, small traces of hair could be detected in a sample from the known sample set (Figure 5.19). Hair is one of the most important resources in forensic science and is often responsible for providing valuable clues as to the identity of an assailant or attacker (Schoeneberger, 2012). The discovery of hair in one of the samples can be used to extrapolate DNA for comparison, enabling the investigator to determine whether or not the suspect was present at the crime scene.

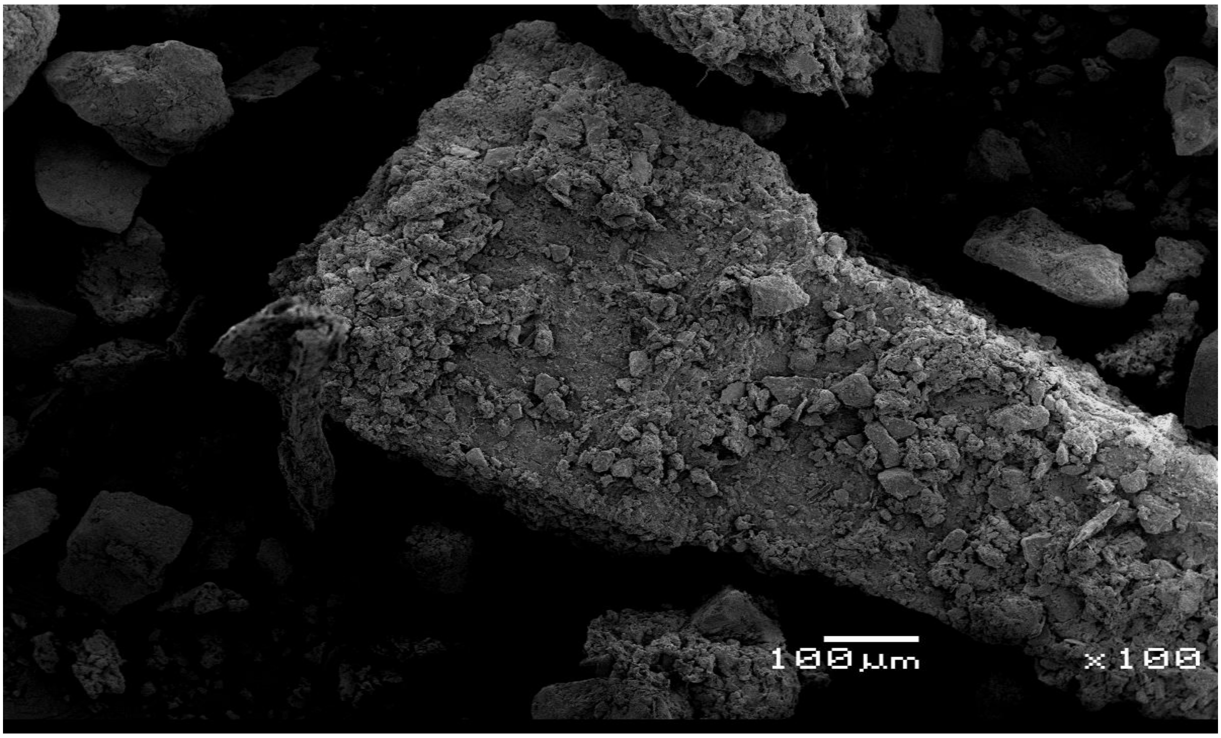


FIGURE 5.17: SEM image of sample 2A1 displaying an angular, sub-prismoidal shape

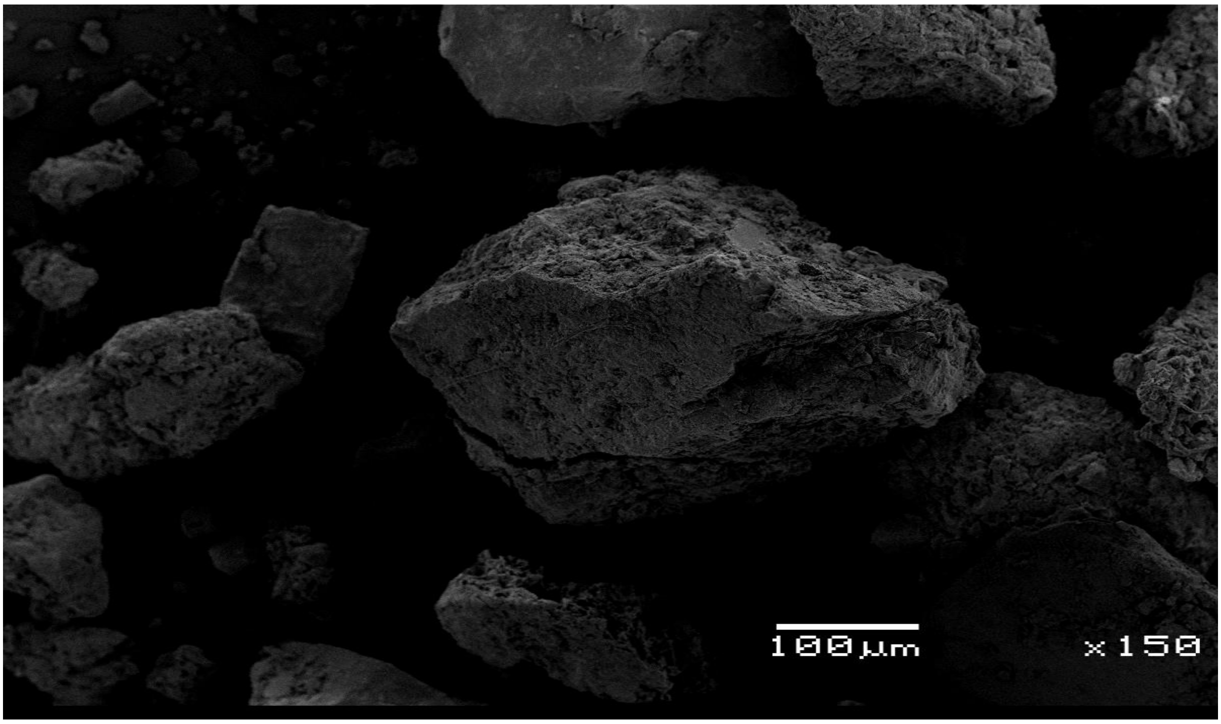


FIGURE 5.18: SEM image of sample 2B10 displaying an angular, sub-discoidal shape as well as impact features caused by wind transportation

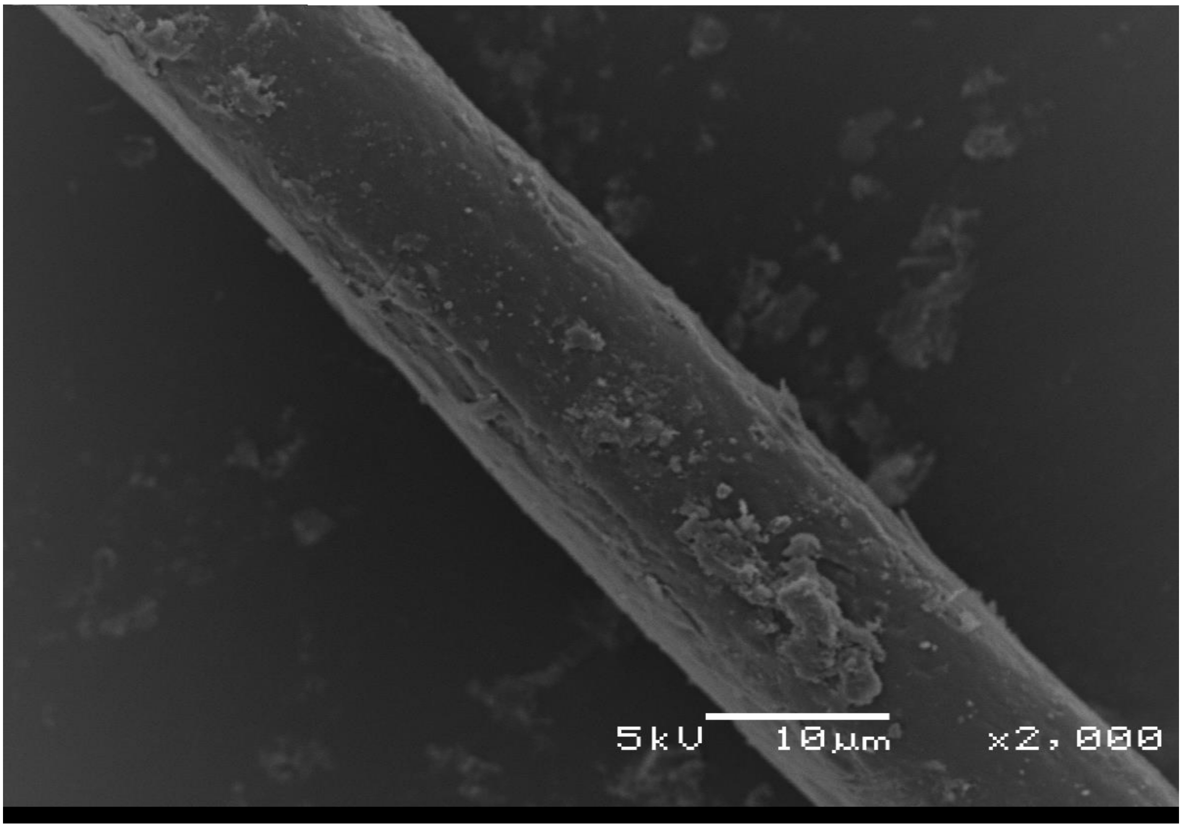


FIGURE 5.19: SEM image of hair that was detected in sample2 B2

The sample sets display some similarities regarding soil morphology, but definitely to a lesser extent than that which was found in experimental study site 1. 2B1, 2B2, 2B9, 2B10 & 2B11 present the most similar soil morphology characteristics to the comparator samples set. Although the soils display very common morphological features found widely across South Africa's grasslands (Cairncross, 2004), the similarities that were found could not allow the samples to be disregarded from the study.

From the aerial photograph in Figure 5.13, the landscape has very little vegetation cover and presents a very 'dusty' appearance. Grus is crumbled granite that forms by physical and chemical weathering and presents the same makeup and consistency of the finely crushed granite you would spread on a path (Anderson, 2008). Moderate winds and animal grazing accelerates this weathering process and might be the reason for the very loose, soft consistency presented by the samples (Figure 5.20).

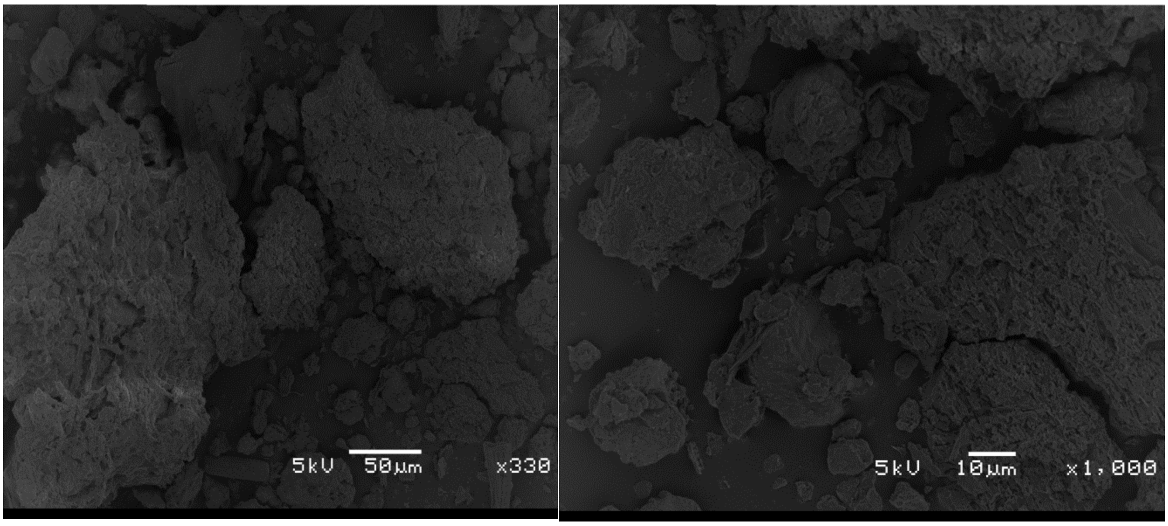


FIGURE 5.20: Sample 2A2 and sample 2B1 both display the same loose consistency as well as impact features

Samples that displayed the same morphological structure cannot be used as evidently as study site 1 due to the nature of the landscape. This is due to the topsoil in study site 2 which display the same morphological structure over a large area, whereas the topsoil in study site 1 differed over short distances. The *in situ* weathering of rock materials on the landscape are vulnerable to wind transportation, meaning that the dust recovered from the suspects' clothing could share similar characteristics to soil particles various distances further from the selected location. The abrasion and broken edges on the soil particles illustrates the presence of wind weathering in the area (Morgan & Bull, 2006).

Stage 2: Mineralogy

The comparator sample set along with samples 2B1, 2B2, 2B9, 2B10 & 2B11 of the known sample set were analysed with quantitative/detailed XRD in order summarise the mineralogical structure and percentage of each sample. As with experimental study site one, the more groupings of mineral structure the samples show, the more similarities can be drawn.

TABLE 5.9: Detailed/quantitative XRD results displaying mineralogy of samples that have not been excluded

Specimen	Location	Colour	Mineral	%	3 σ error	Vegetation debris
KS2	Site just below surface	5YR 3/3	Quartz	66.05	0.9	Medium
	2B1		Microcline	4.17	0.54	
			Plagioclase	29.78	0.93	
			Muscovite	Trace		
			Hornblende	Trace		
	Site at surface	5YR 4/2	Quartz	53.6	1.41	Trace
	2B2		Microcline	7.78	0.9	
			Plagioclase	31.13	1.62	
			Muscovite	7.49	0.99	
			Hornblende	Trace		
	Footpath 2B9	5YR 4/2	Quartz	53.06	1.05	Trace
			Microcline	8.69	0.84	
			Plagioclase	38.26	1.11	
			Muscovite	Trace		
			Hornblende	Trace		
	Footprint 2B10	5YR 4/2	Quartz	58.21	0.99	Medium
			Microcline	7.76	0.72	
			Plagioclase	34.03	1.05	
			Muscovite	Trace		
			Hornblende	Trace		
	Footprint 2B11	7.5YR 4/2	Quartz	47.46	0.99	Medium
			Microcline	7.81	0.78	
			Plagioclase	44.73	1.02	
			Muscovite	Trace		
			Hornblende	Trace		
KS2	Suspect's right shoe	5YR 4/2	Quartz	53.04	1.02	Trace
	2A1		Microcline	9.69	0.78	
			Plagioclase	37.27	1.05	
			Muscovite	Trace		
			Hornblende	Trace		
	Suspect's socks	7.5YR 4/2	Quartz	50.58	1.08	Trace
	2A2		Microcline	8.86	0.84	
			Plagioclase	40.56	1.08	
			Muscovite	Trace		
			Hornblende	Trace		

*Trace refers to less than 1%

*KS2- Known Sample set 2 *QS2- Comparator/questionable sample set 2

As the geology of the area is known to be granite, it is not surprising to find quartz to be the dominating mineral in both sample sets. Both the known- and comparator sample sets contain five crystalline mineral components, confirming that a degree of similarity could be considered. Quartz, microcline, plagioclase, muscovite and hornblende are common minerals in southern Africa and are widely spread across the landscape (Cairncross, 2004). Thus it would not be uncommon to find these minerals in a sample. However, the percentage of minerals that occur in each sample illustrated that there is some resemblance between the known- and comparator sample set and further chemical analysis was followed. As in stage 1, the mineralogical composition of both sample sets displays similar characteristics, but not to such an extent to confirm that the comparator samples have definitely derived from the selected location. The samples cannot just yet be excluded from the study. If the samples that show similar mineralogical and morphological characteristics display the same pattern during chemical analysis, a possible linkage can be made and final conclusion decided. 2B1 was the only sample that could be excluded from the investigation as it displayed an uneven mineralogical composition when compared to the other samples (Table 5.9).

Stage 3: Chemical analysis

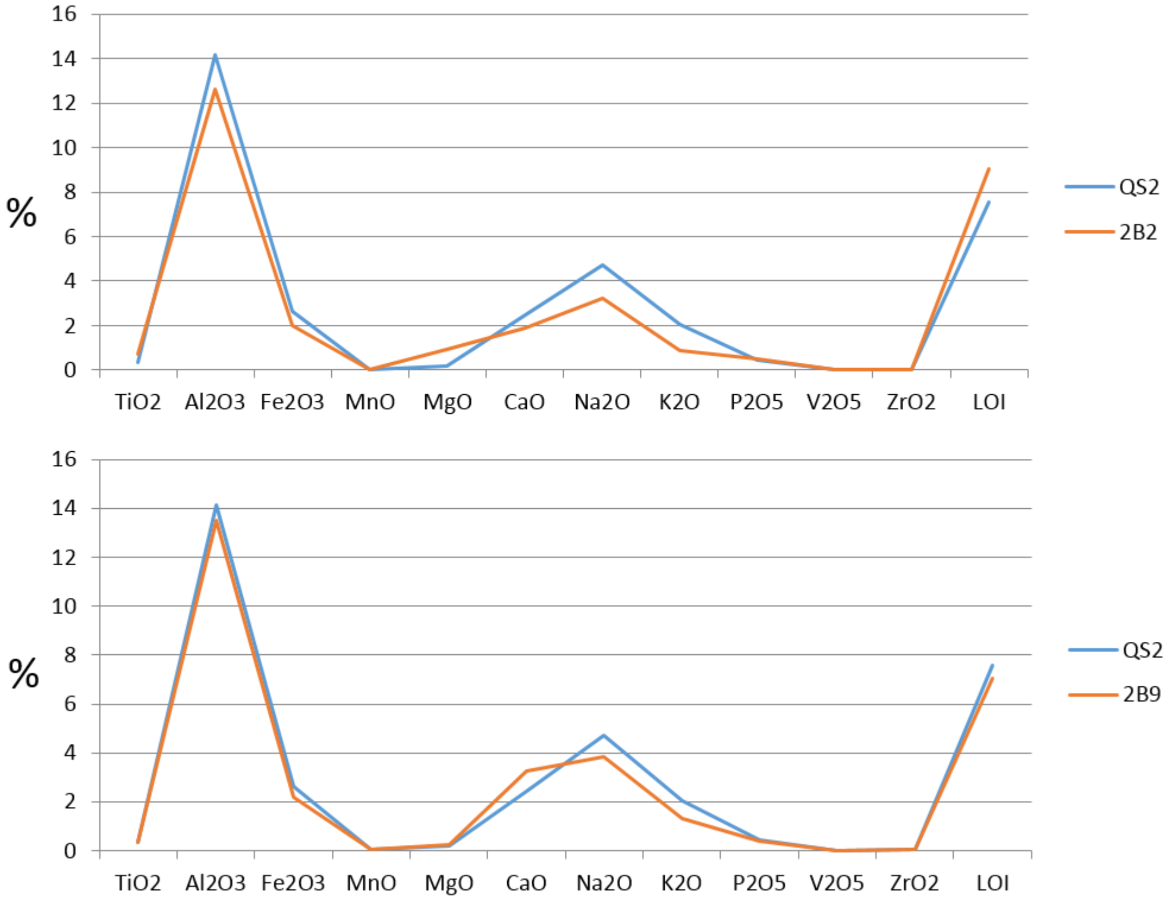
The comparator and known sample sets were analysed using X-ray fluorescence spectroscopy (Table 5.10) in order to gain a final soil sample comparison of major and trace elements.

TABLE 5.10: Percentage and range of elemental concentrations in comparator- (2A1, 2A2) and known sample set (2B2, 2B9, 2B10, B11)

%	Certified	Analysed	2A1	2A2	2B2	2B9	2B10	2B11
SiO_2	99.6	99.7	65.29	64.19	67.94	67.26	75.56	73.75
TiO_2	0.01	0	0.34	0.37	0.69	0.35	0.18	0.25
Al_2O_3	0.05	0.01	14.06	14.26	12.63	13.49	9.48	11.22
Fe_2O_3	0.05	0.01	3.08	2.13	1.99	2.18	3.58	2.63
MnO	0.01	0	0.03	0.03	0.04	0.04	0.01	0.02
MgO	0.05	0.01	0.06	0.32	0.91	0.23	0.06	0.11
CaO	0.01	0.01	2.36	2.53	1.9	3.27	1.56	1.83
Na_2O	0.05	0.02	4.73	4.71	3.21	3.82	3.08	3.43
K_2O	0.01	0.01	1.27	2.79	0.86	1.32	0.87	1.18
P_2O_5	0	0.03	0.64	0.25	0.49	0.39	0.06	0.06
Cr_2O_3	0	0	0	0	0	0	0	0
NiO	0	0.01	0	0	0	0	0	0
V_2O_5	0	0	0.01	0.01	0.01	0.01	0.01	0.01
ZrO_2	0	0.01	0.03	0.04	0.03	0.04	0.01	0.02
CuO	0	0	0	0	0	0	0	0
LOI	0	0.1	7.44	7.7	9.03	7.03	4.78	5.31
TOTAL	100	99.92	**99.34**	**99.32**	**99.73**	**99.44**	**99.25**	**99.83**

XRF data can be used preliminary discrimination of soil samples, the amount of elements should allow for a final comparison of the samples.

The SiO_2 percentage is significantly different than the percentage obtained in study site 1. The data in Table 5.10 illustrates how sample 2A1 displays a similar chemical composition than that of sample 2B2 and 2B9. Yet the chemical composition of these soils cannot be classified as rare findings, thus both samples sets need to display very similar percentages as the presence of the same chemical components is not enough. As with experimental study site 1, the mean of the comparator sample set is plotted to each of the remaining samples from the known sample set (Figure 5.21) in order to determine if a comparison can be made between the sample sets.



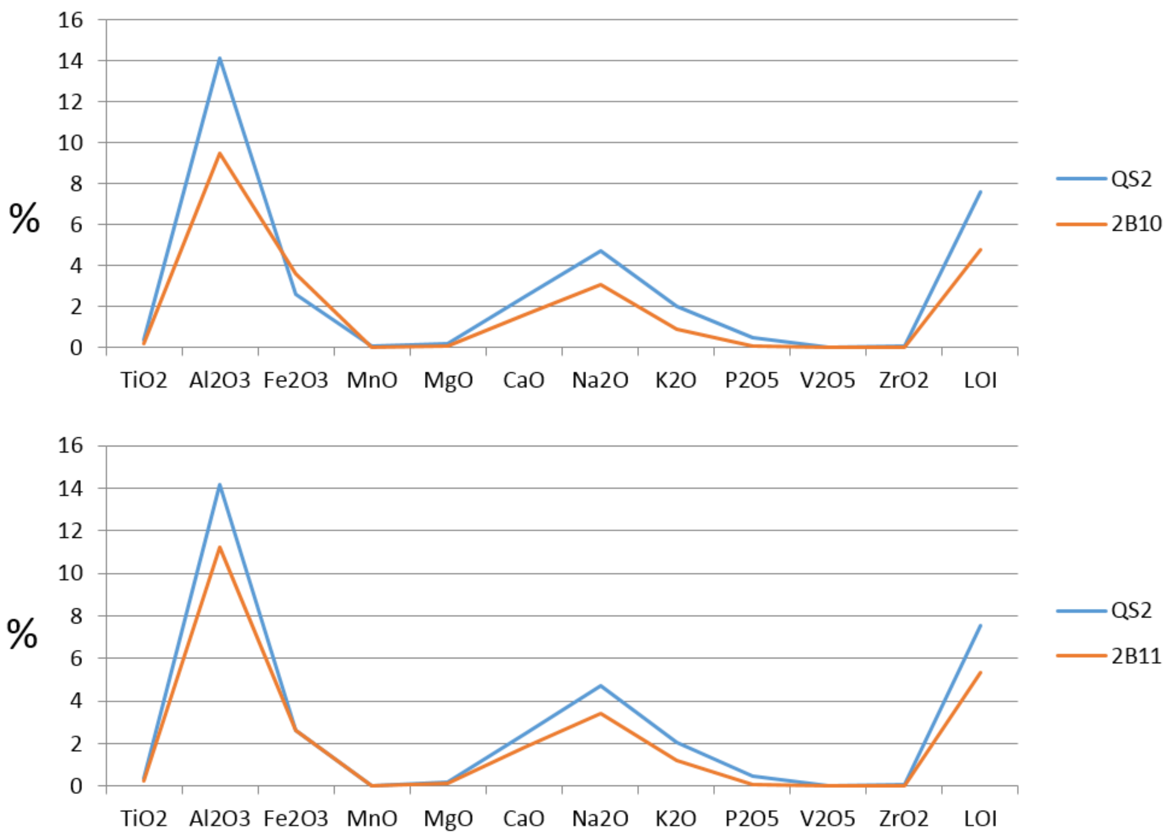


FIGURE 5.21: Graphs displaying the average percentage of the comparator sample set compared to each of the samples from the known sample set. SiO_2 has been excluded from the graphs to allow the rest of the chemical components to be viewed under a larger scale.

A linear pattern between the two sample sets could not as accurately be recognized as was done with experimental study site 1, nor are there any chemical elements that would not be uncommon to find within soils and sediments. Although the comparator sample set (2A1 & 2A2) share a similar pattern with sample 2B9 and to a lesser extent 2B2, the percentages of the chemical compositions is not that aligned to make a definite conclusion.

CHAPTER 6: Discussion

The experimental studies demonstrated that reincorporation of trace particles occurs from upper to lower parts of the suspects' clothing under conditions that mimicked forensic reality. Although the highest concentration of soil was found in and around the footwear (lower part), particulates such as pollen tended to be preserved in stitching or relief design features on shirts and pants. Thus, the removal or decay of these particulates and soils after the suspect has left the crime scene does not necessarily involve the loss of those particulates and soils. These findings have implications for the interpretation of trace evidence when seeking to establish the source of initial contacts or the chronology of pertinent events; the second experimental study demonstrated soil particles adhering to shoes and socks providing the investigator with a substantial amount of particles for investigation. However, if the suspect's belongings were only apprehended days later, the redistribution of any trace particulate evidence, may render the investigation meaningless. With future studies it is therefore a necessity to take the context of trace evidence into account and also to follow protocols that are sensitive to these aspects of trace evidence behaviour. Source heterogeneity and susceptibility to post-transfer fractionation or mixing with pre- and post-transfer sources (Broeders, 2006, as referenced in Dawson & Hiller, 2010) cannot always be easily evaluated or accommodated using conventional methods. It is, therefore essential to interpret the trace evidence obtained correctly, through methods such as colour and moisture in order to specify the timeframes in which the trace evidence were added onto the belongings.

Areas identified for sample collection, based on Killam's (2004) principle that suspects use paths of least resistance, presented satisfying results. Through landscape interpretation, it became possible to identify the routes from which to collect samples. However, more areas were identified for sample collection at experimental study site 2 as the possible route to the selected location was not as restricted as in study site 1. This was largely due to lack of vegetation and uniform topography. The necessity for collecting samples at the appropriate locations were established by both experimental study sites, as samples that were randomly selected on the landscape (B16 & 2B18) illustrated a complete different morphological structure than the samples that were gathered from the estimated route. This confirms Morgan *et al*.'s (2010) statement that soils vary over small distances. Analysis of the wrong type of samples in a landscape in effect homogenises the sample and produces, unknowingly the possibility of false-positive or even false-negative results (Bull *et al*., 2006).

As mentioned in Chapter 3, the methodologies used to match samples vary depending on the case study researched. Bull & Morgan (2006) showed in their articles that significant results can be obtained by simply using quartz and grain surface textures as an exclusion mechanism, yet the mineralogy and chemical elements were still analysed during this research. One of the underlying conceptual themes running through this dissertation has been that a sample's morphology, mineralogy and chemical analysis are used to exclude a sample from deriving from the same or similar provenance as the comparator sample. The methodology used and the results obtained during the research is based on the illustration in Figure 6.1.

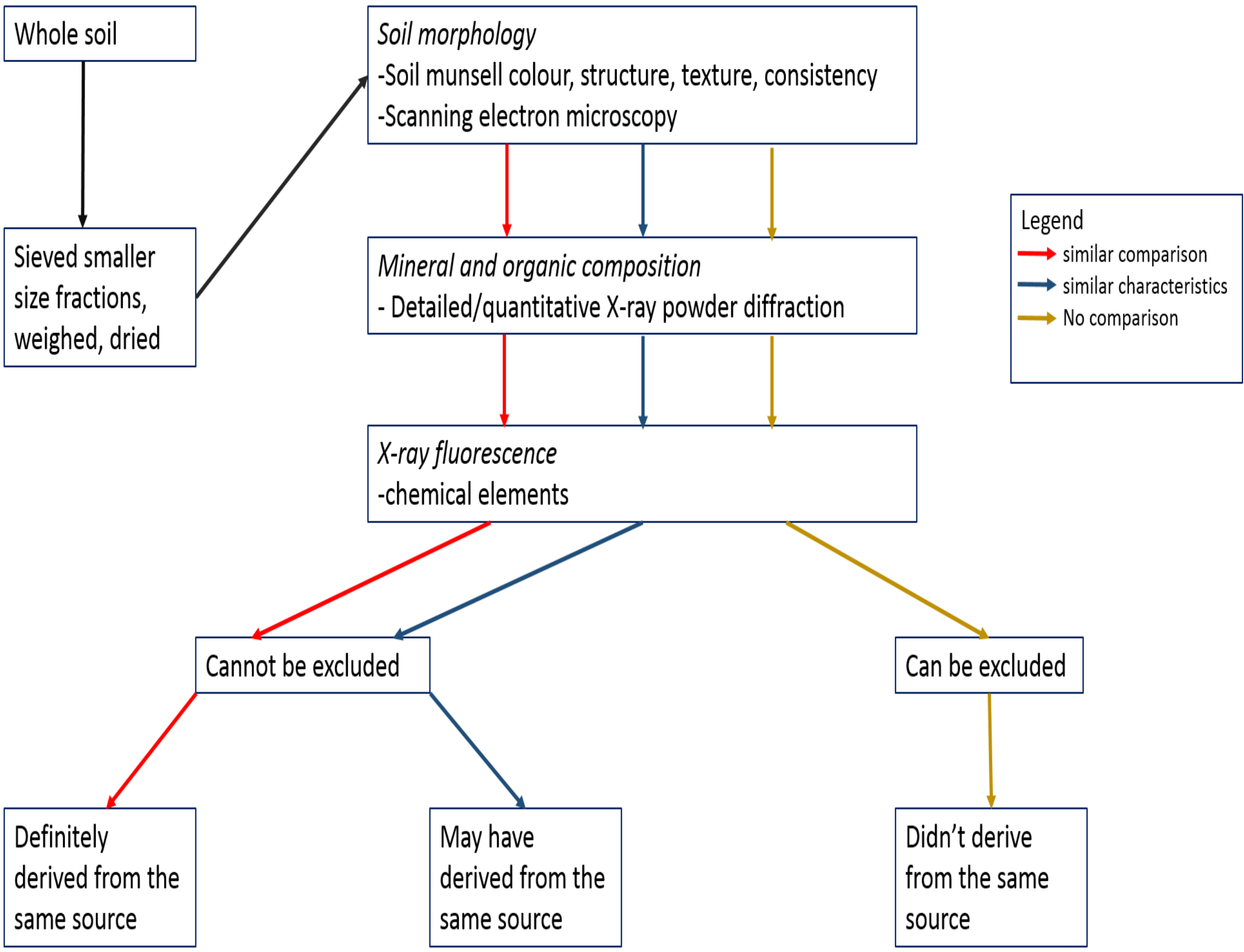


FIGURE 6.1: A systematic approach used for both experimental studies to discriminate soils from a selected location (Figure is author's own creation, however the idea was adopted from Fitzpatrick, 2009)

6.1 Experimental study site 1

From the sixteen samples that were collected at the specified locations, two samples show similar physical and chemical characteristics to the comparator sample set; samples from the selected location itself (B4) and the footpath (B14) towards the selected location. Generally, sample B4 from the known sample set shares a distinctive pattern with sample A1 (axe) from the comparator sample set; these two samples share an indistinguishable pattern with one another regarding soil morphology, mineralogy, and chemical composition. Stage 1, 2 and 3 illustrates that the samples were consistent with their makeup compared to the comparator sample set.

Given the general variability even within one soil type, the variances identified from comparison between the comparator sample set and the two known samples (B4, B14) suggest that the samples could not be excluded from having been derived from the same or similar source. The similarities are made even more significant as sample B16, which was selected approximately 30 meters away from the footpath (B14) bed and selected location (B4), display completely different soil morphology, confirming Fitzpatrick's (2009) point that soil characteristics vary over short distances as mentioned in chapter 2.

It must be recalled that soil is complex and that there will be a certain degree of spatial heterogeneity in chemical composition as well morphological structure (Morgan & Bull, 2007). There were, for example, traces of muscovite and hornblende compounds in some samples, as well as phosphorus pentoxide discovered on the axe (A1). The axe might have been used for other work so mixed assemblages, contamination, might be present. Overall, the soils obtained on the axe had closest resemblance to those taken from the upper soil taken at the selected location. If the results were still unclear at this stage, the vegetation and pollen identified in Figure 5.11 could then be used for further analysis.

In conclusion, if the known sample set were not the source of the soil found on the axe, then to achieve the morphological and chemical composition analysed there must be a place that offering identical conditions, which is highly unlikely. Morgan *et al.* (2006) points out that such a similar site, the existence of which is theoretically possible, has yet to be encountered by the authors of forensic geoscience (concluding that testimony concerning the sand specimens could be used at a trial to help a judge reconstruct the event). The conclusion can be made that the questioned sample almost certainly did come from the location of interest.

6.2 Experimental study site 2

A linear pattern between the two sample sets could not as accurately be recognised as was done with experimental study site 1. The possible reason for the difference is that the comparator sample set provides far less trace evidence, increasing the difficulty for comparison analysis. Although morphological attributes are important tools to use as an comparator technique (Fitzpatrick *et al*., 2009), normally more than 10mg of a sample is needed in order to establish a conventional morphological pattern such as texture and particle size (Dawson & Hiller, 2010). Even so, some of the sample from the two sample sets still displayed the same loose consistency and soil texture possibly caused by wind transportation. The quartz grains in both sample sets illustrated blocky edge abrasion that can be caused by wind abrasion. However, the morphological descriptors cannot be used as an accurate indicator to exclude a sample from the investigation due to the small amount that was available for analysis, and so doing a larger number of samples than study site 1 were selected for mineralogy and chemical analysis to serve as a more accurate exclusionary method.

Mineralogical analysis showed quartz to dominate in each sample and this is not an unusual given the granite geology. At this point the samples are analysed to concentrate on finding very low proportions of exotic minerals, which may provide effective comparison between samples. However, no such minerals could be identified among the sample sets. The only comparison worth noting was that of the mineral percentages that seemed to be aligned between the sample sets. This, however, could still not be used to exclude a sample nor can it establish a linkage. Chemical analysis showcased that only relatively small differences were obtained between one source sample and the transfer materials in elemental chemistry. Yet, the analysis cannot be used to establish a definite linkage between the sample sets.

All three stages in experimental study site 2 presented samples that recorded some forensic characteristics which could be used to compare the sample sets. However, no conclusive association could be derived. If comparative analyses were based on only one of the three stages; morphology, mineralogy, and chemical composition, the samples might have been excluded from the investigation. However, since all three stages displayed the same mild linkage between the sample sets, the transfer materials obtained cannot be excluded from deriving from the source of the selected location. Rather the analysis provides a descriptive attribute for the investigator.

6.3 Legal considerations

Various statistical approaches look at data in different ways, and if inconsistent differences cannot be explained and understood, then the evidence based on that analytical profiling is open to challenge in court (Dawson & Miller, 2010). Any analysis carried out for presentation in court must be of high standard and levels of uncertainty must be minimised (Small *et al*., 2004). If this study was to be applied to an actual wildlife crime scene, then analysis should be carried out preferably by an accredited laboratory. Nevertheless, the results obtained can still be used as an estimate to determine the strength of the results as actual evidence. The NHMRC (2000) handbook for evidence has been used to determine the overall relevance of the results obtained in each study site to be presented as evidence. A summary of the results obtained in each study site is displayed in Tables 6.1 and 6.2.

TABLE 6.1: Type of evidence dimension as adopted by the NHMRC (2000) for experimental study site 1

Strength of trace evidence:	The investigation was done following basic forensic procedures to a degree that bias has been eliminated by design.
Size of effect:	The effect of the investigation can be considered as highly important, as the results gained confirms that the suspects cannot be excluded from the crime scene as the trace evidence indicates that must have been in the environment of the selected location or a location that displays the exact same characteristics.
Relevance of trace evidence:	The relevance of the trace evidence may be considered as high. The similarities between the traces of soil found on the suspect and the selected location illustrates that the suspects are most probably the wanted poachers.

TABLE 6.2: Type of evidence dimension as adopted by the NHMRC (2000) for experimental study site 2

Strength of trace evidence:	The investigation was done following basic forensic procedures to a degree that bias has been eliminated by design.
Size of effect:	The effect of the investigation is to such a degree that the results may narrow down suspects and allow for a more precise investigation in certain areas. However the effect is not of that magnitude to make an important difference and decision regarding the investigation.
Relevance of trace evidence:	The samples can be used as an indicator that the suspects may have been involved in the crime scene and cannot be excluded from the investigation. However, it does not display the similarities to an extent that it may change the course of an investigation.

Any of the three methodological approaches used in this study, would have been sufficient to extraxt a conclusive association for the samples at study site 1. This was mainly due to the nature of the landscape that presented soils which were unique to their location. In contrast all three analysis were necessary for experimental study site 2 in order to obtain a form of comparative analysis results. Due to the nature of the landscape, soils could not easily be traced to the exact location from which it was removed. Saferstein (2004) is precise when he remarks that all soils have unique features and can therefore be traced back to specific locations, however the experimental studies illustrated how the nature of the landscape is essential to determine how accurately soils can be traced back to specific locations. The topsoil used for analysis in study site 2 presented far more complexities in obtaining comparative and exclusionary samples, whereas the deeper soils would probably be more appropriate to Saferstein's (2004) statement. The topsoil used for analysis in study site 1 on the other hand was more fixed to their position of removal due to the nature of the landscape.

Through the analysis undertaken it is clear that proper landscape interpretation and knowledge of the area is essential to gain an appropriate understanding of the nature of soils and sediment during forensic analysis. With the suitable knowledge and techniques, geomorphic aspects (namely trace evidence) can be accurately linked back to a certain location or suspect. In both experimental studies, a pattern could be established between a suspect and a selected location. The accuracy of the linkage between a suspect and their belongings is dependent on the landscape on which the actions have taken place. Dawson & Hiller (2010) mentioned that trace evidence located on a suspect's clothing, belongings, vehicle etcetera may be contaminated or lost over time as the suspect moves through different areas. Furthermore, the location from where this trace evidence originated from could just as easily experience variation and contamination. The landscape at study site 2 has large herbivores grazing and the soils are vulnerable to dry winds that are observed there, causing the topsoil to be distributed to different locations over time leading to the loss of valuable soil characteristics. Soils and sediments may be inert and not affected by time or sample storage (Dawson & Hiller, 2010), it is the time scale prior to sample collection which could affect forensic analysis. To some extent soils, and sediment collected for forensic analysis, display the same weakness than that of organic evidence, which in time depletes the accuracy to which a sample could be used as evidence prior to identification and collection. This weakness highlights the necessity to conduct an investigation as swiftly and effectively as possible. Certain landscapes are more resistant to change than others. Experimental study site 1 may be more persistent to time due to the type of vegetation and other geomorphic aspects of the landscape. The geomorphic description given for each experimental study is of high value in order to determine the rate of variability of the samples collected. Nevertheless, in the experimental studies conducted some form of linkage could be made between soils retrieved from a person and/or their belongings and the location it derived from through proper exclusionary methods.

CHAPTER 7: Conclusion

The research conducted and reported in this dissertation illustrates the potential that landscape interpretation and soil characteristics can provide to the forensic field in order to determine a possible linkage between a suspect and a poached rhinoceros. The results obtained from the experimental studies have provided results reminiscent of Locard's (1930) 'every contact leaves a trace'. Although in retrospect, it seems relatively obvious that a two-way transfer of materials will take place when a person is hacking the horn off a rhinoceros and moving through numerous natural land of bush and dust to avoid prosecution. The challenge an investigator faces is the collection and correct interpretation of the trace evidence. However, traces of soil may not always be detectable. Experimental study site 1 provided more accurate comparison between the sample sets. This is perhaps due to the watering hole that provided more soil to adhere to the suspects due to the moisture content, or the timeframe which allowed soils to adhere to clothing due to dew. A rhinoceros poached next to a river may also present its own difficulties for investigators as sedimentation constantly changes along a river bank. Nevertheless, this study demonstrates that it is feasible for trace evidence laboratories to make use of their existing technology to conduct preliminary screening of the discrimination of soil samples. It is evident that soils and sediments can routinely be analysed to produce very detailed characteristics from large numbers of samples and to be used effectively as a comparator method between crime scenes and a person or group of persons. Although the landscapes in which the actions occur play a major role in the accuracy of the samples, the skills and expertise of the investigator may also eliminate any bias and allow for efficient identification and analysis of the samples. Since 2008 the media has reported many cases where alleged rhinoceros horn poachers were apprehended with high calibre rifles and equipment typically used for rhinoceros poaching. Many of these cases have been closed due to lack of evidence to exclude or connect some of these suspects to a poached rhinoceros in the area. The research conducted illustrated how accurately some of these equipment apprehended could provide a connection between the suspects and the crime scene, effectively providing evidence to include or exclude a person or group of persons from a specific location. This highlights the necessity to which this field of forensic analysis should be practiced and established in order to obtain more successful results in prosecutions.

This thesis presents the results of the investigation of two experimental study sites using geoforensic analysis aided by the discipline of geomorphology. Several important points have arisen from these simple cases that need to be viewed within the theoretical framework outlined at the beginning of this dissertation.

1) The fundamental principles in the role geomorphology contributes to geoforensics

The criminals, rhinoceroses, game rangers and investigator all interact with a landscape and, thus, forensic work will be advanced by the input of a geomorphologist. Investigators face the challenge of correct collection and interpretation of trace evidence. Rhinoceroses thrive on an irregular and large landscape (Eloff, 2012), which is simply too big a scale and time consuming to set up a random sample grid. The proper landscape interpretation, as shown in experimental study site 1 and 2, allowed the investigator to accurately and effectively identify the route and actions taken by perpetrators, and by doing so contribute to the successful collection of samples. Both experimental study sites established the necessity for collecting samples at the right locations, as samples that were randomly selected on the landscape (B16 & 2B18) illustrated a completely different morphological structure than the samples that were gathered from the estimated route. This confirms Morgan *et al*.'s (2010) statement that soils vary over small distances. Analysis of the incorrect samples in a landscape, in effect, homogenises the sample and produces, unknowingly the possibility of false-positive or even false-negative results (Bull *et al*., 2006). As mentioned in chapter 2, the effective use of geomorphology at each experimental study site reinforces Schumm's (2005) thoughts on the importance of the discipline of geomorphology at forensic investigations.

Due to the unique nature of any investigation, it is difficult to prescribe approaches in regard to relevant spatial scales of interest. However in general terms the discipline of geomorphology allows for an intelligence role at a broad scale. This discipline is likely to be helpful in defining the scale of interest, and therefore inform the intended focus, choice of method and design of research validation studies. However, the wider adoption of the so-called 'forensic geomorphology' as a conventional toolkit for sediment provenance investigations is hampered by the fact that there have been few attempts to develop general guidelines for dealing with a number of key methodological uncertainties.

2) The analytical techniques chosen for this study

Care was taken to choose analytical techniques, which were suitable for previous investigations and applied with extreme caution in forensic applications (as was suggested by Morgan *et al*., 2006). It is suggested that as many techniques should be employed as possible, but this is often determined by the quantity of a sample.

The following key issues are especially important in forensic soil examination because the diversity of soil strongly depends on topography and climate, together with anthropogenic contaminants. Forensic soil examination can be complex because of the strong diversity and heterogeneity of soil samples (Fitzpatrick, 2009). However, such diversity, heterogeneity, and complexity enable forensic examiners to distinguish between soil samples, which may appear similar to the untrained observer. A major problem in forensic soil examination is the limitation in the discrimination power of the standard and nonstandard procedures and methods. No standard forensic soil examination method exists (Dawson & Hiller, 2010). The main reason for this is that materials from different environments differ and thus every crime scene needs an approach best suited for its location.

The complexity and variability of soil properties is both an advantage and a hindrance (Dawson & Hiller, 2010). Complexity means that many different characterisations can be used to provide high-resolution signatures but, equally, the variability in this complexity creates a problem of ensuring that reference samples are representative and that sampling accounts for the expected variation (Dawson & Hiller, 2010). The suite of techniques reviewed here, which includes the chemical, mineralogical and molecular fingerprinting of soils, can both complement conventional forensic methods and provide new investigative or matching tools where previously none existed regarding rhinoceros poaching. There is no general consensus as to the best protocol or best methodologies for the forensic examination of soil samples. Indeed, the method of choice tends to vary dependent upon availability of instruments and national preferences (Dawson & Hiller, 2010). Each case has a different type of approach in locating and analysing samples. The methodology followed in this dissertation is a summary of some of the forensic geoscience experts such as Morgan & Bull (2007), Fitzpatrick (2009), and Ruffel & McKinley (2005).

The complexity of soil materials and the analysis of the different components deliver different types of information. Individual analytic techniques will have different degrees of importance depending on the nature of the crime scene and the terrain that shape them. Each method has its strengths for different situations and there is great need to give more guidance on how to deploy the suitable techniques for a given situation. As methods become quantitative, their use in combination will help to characterise the soil more generally and thus help to improve and narrow its probable origin as well as give increasingly robust sample matches with probabilities that can be quantified (Dawson & Hiller, 2010).

This dissertation has shared a methodology and rationale for forensic soil examinations and comparisons that have been used successfully in some forensic casework previously (Chapter 2). The method is quick and easy to use, allows for the rapid screening and comparison of complex soil specimens, limits the use and need of more time consuming procedures and provides the forensic science community with a quick, simple procedure for the accurate inclusion or elimination of questioned and known soil specimens. It must be noted that these were experimental studies and actual cases may prove to be more complex.

3) Future directions

The future direction for the forensic analysis of soils is likely to be an increase in the combined use of very different, but complementary, methods to enhance the evidential value of soil information. Dawson & Hiller (2010) mention that the significance of merging methods is essentially that of increased discrimination or association. Differences in the spatial scale at which some methods may discriminate samples, as well as variances in the manner a measured property vary spatially, both contribute to added discriminatory potential and this delivers the added value of a combined approach. For example, Brown *et al.* (2002) refers to a case where petrology was combined with palynology in a murder investigation using soil samples from a car believed to have been used by a suspect in a missing person's case. The soil inorganic characteristics were used to redefine the search area using geology and soils maps, while the organic characteristics, such as pollen and vegetative remains, were used to target woodlands with a specific species mix. As an end result, two bodies were discovered and the environmental evidence was used in the ensuing trial (Brown *et al*., 2002).

In both experimental studies in this research, elements obtained within some samples could have been analysed to improve the evidential worth of the soil formation. In experimental study site 1, pollen and other root fragments were identified and the use of Palynology could be an important tool to increase the value of the results obtained. Organic material such as hair was also identified in experimental study site 2. Hair is one of the most important properties in forensic science and is often responsible for providing valuable clues as to the identity of an assailant or attacker (Schoeneberger, 2012). The discovery of hair in a sample can be used to extrapolate DNA for comparison, enabling the investigator to determine whether or not the suspect was present at the crime scene.

4) The necessity for additional research and practical work

Forensic soil examination can be complex because of the variety and heterogeneity of soil samples. However, such variety and complexity allows forensic examiners to distinguish between soils, which may appear to be alike (Fitzpatrick, 2009). Nonetheless, the extent to which transfer and persistence issues influence the comparison between a 'questioned' soil sample and a set of reference samples are poorly understood. A greater understanding of the expected variability introduced when soil is transferred in different ways to various evidential types would help to guide how best to account for the associated uncertainty in the analytical observation (Dawson & Hiller, 2010). There is an overall lack of expertise in this relatively new area among soil scientists. For research and application in this area to grow appreciably, it will need to be considered and taught as a fundamental part of both soil science and soil science courses (Fitzpatrick, 2009). As a final point, an attempt should be made to develop and refine methodologies and approaches to develop a practical "soil forensics manual with soil kit for sampling, describing and interpreting soils" (Fitzpatrick *et al*., 2009 as referenced in Fitzpatrick, 2009; p10).

The future will hopefully see an increased use of soil as evidence. Newer automated methods of examination, increased resolution and miniaturisation of techniques, *in situ* sampling and analysis, improved training of those who collect samples and research on the diversity and variability of soils and on how, when and what parts of soils are transferred during various types of contact (Dawson & Hiller, 2010). In court, quantitative methodologies will increasingly be required as evidence, as will the reference to reliable databases, to set appropriate contextual information. In an analogy to the use of human DNA database material, when similar links are recognised for soil material, it will provide good and reliable estimations of probability. Consequently, the use of soil as physical evidence in sample comparison and as a search instrument should increase (Dawson & Hiller, 2010). This study added to the continuum of development in methods, which contributes to new opportunities rising in parallel with new scientific developments in research, ensuring scientists keep ahead of the criminal mind. It is essential that the research conducted in this thesis is to be studied and practiced further in order to establish the role geomorphology and geology have in forensic science and the results these disciplines can obtain.

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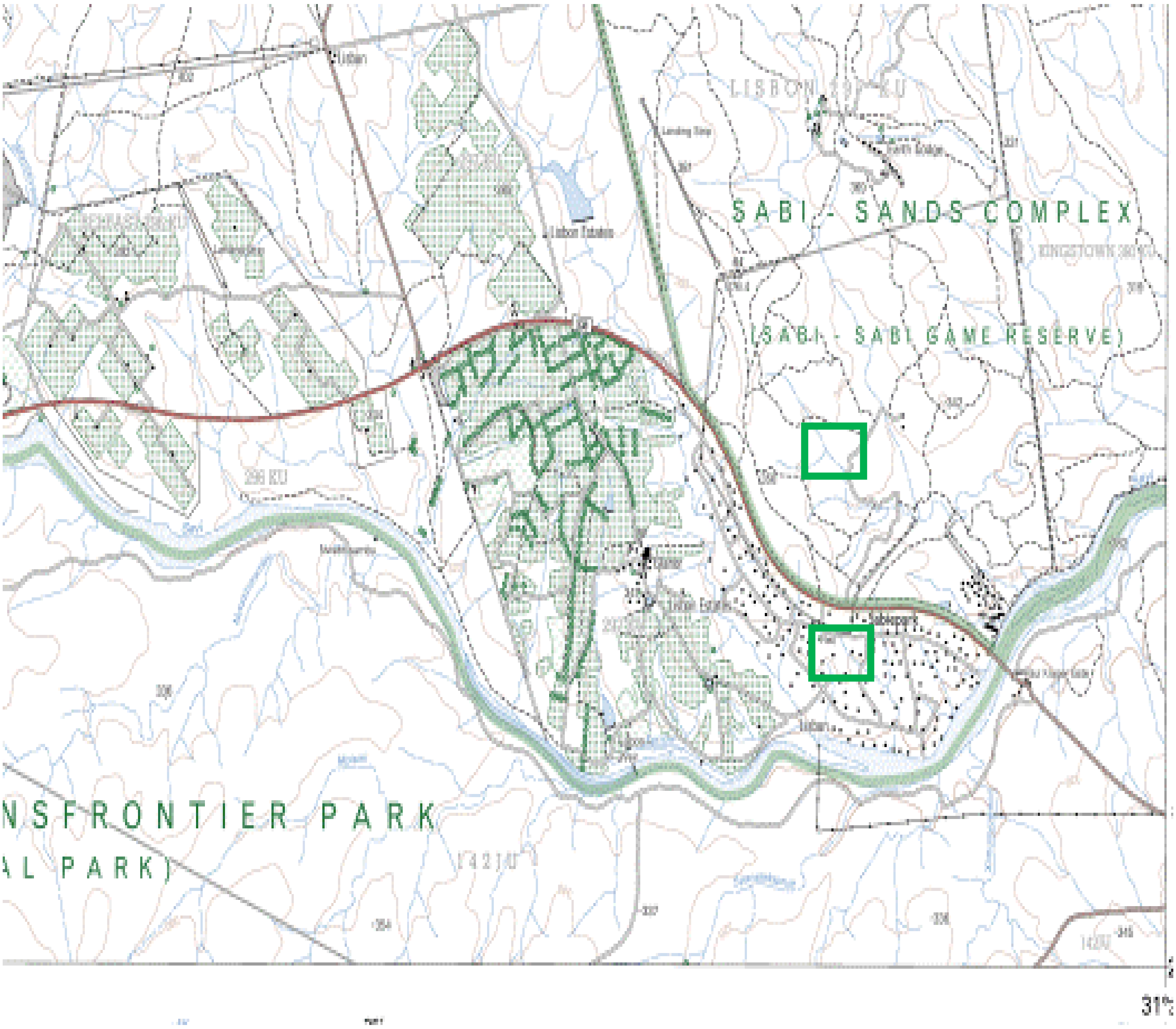
Appendices

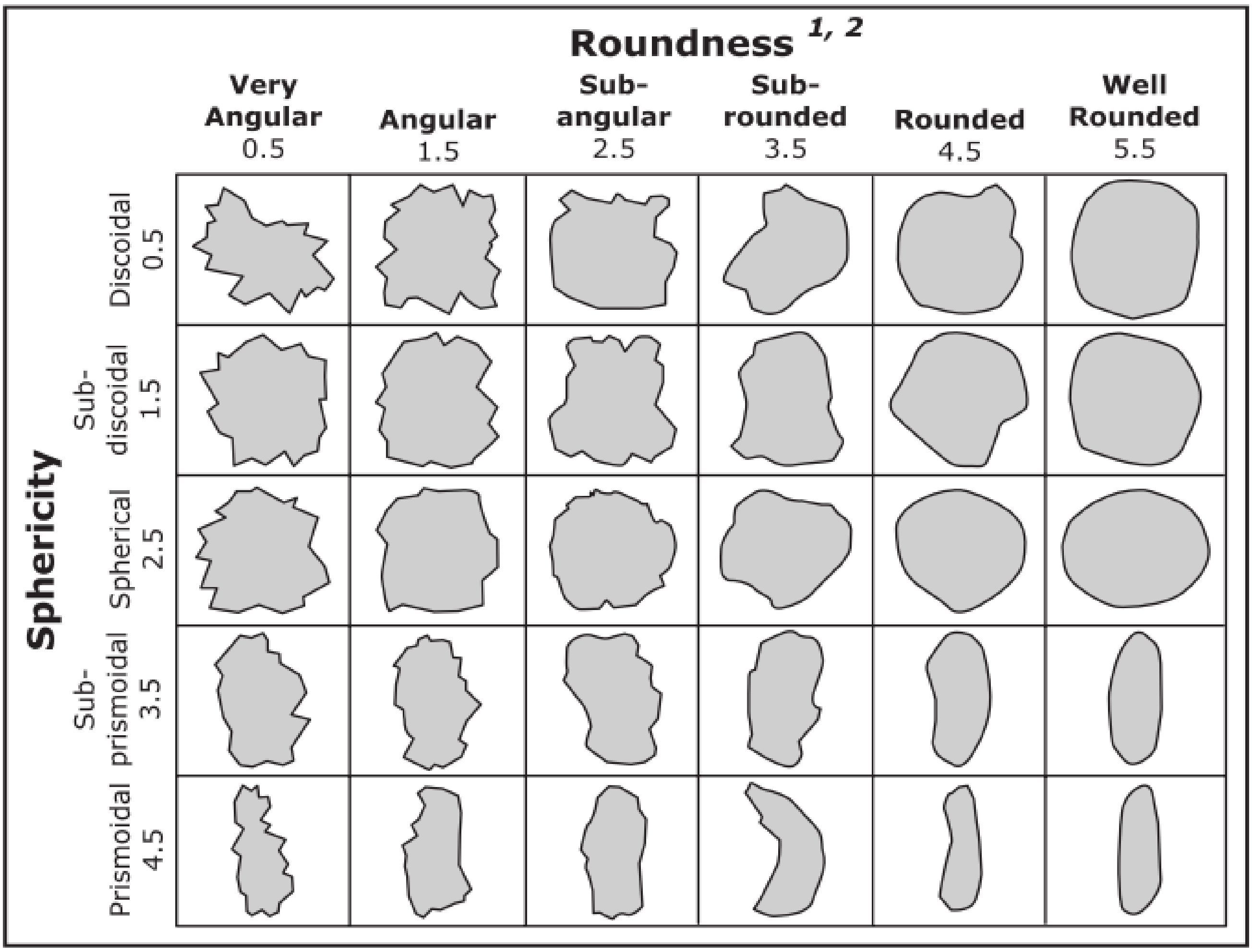
APPENDIX 1: Topographic map of Figure 4.1 illustrating study areas (NGI, 2013)



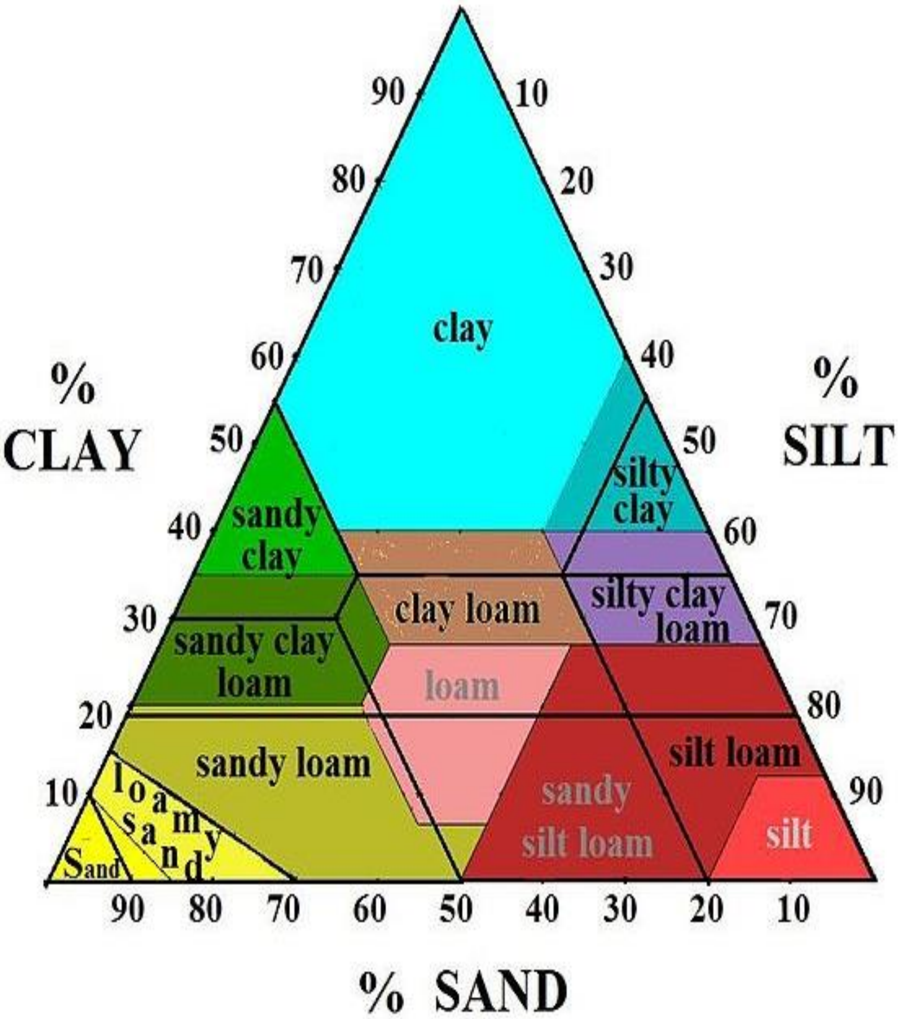
APPENDIX 2: Soil texture classification (Schoeneberge *et al*., 2012)

Name of soil separate	**Diameter limits (mm) (USDA classification)**
Clay	less than 0.002
Silt	0.002–0.05
Very fine sand	0.05–0.10
Fine sand	0.10–0.25
Medium sand	0.25–0.50
Coarse sand	0.50–1.00
Very coarse sand	1.00–2.00

APPENDIX 3: Soil shape determination graph (Schoeneberge *et al*., 2012)



APPENDIX 4: A soil textural triangle showing the ubtle differences between the USDA (colours) and the UK-ADAS (black lines) soil classes (Whiting *et al.*, 2011)



APPENDIX 5: Dry and moist consistency of soil particles (Schoeneberge *et al*., 2012)

Moist	Dry	Stress Specimen Fails
Loose	Loose	0
Very Friable	Soft	< 8 N
Friable	Slightly Hard	8 to < 20 N
Firm	Moderately Hard	20 to < 40 N
Very Firm	Hard	40 to < 80 N
Extremely Firm	Very Hard	80 to < 160 N

1 Newton (N) = 0.224 lb/ft