The application of forensic geomorphology in rhinoceros poaching investigations in Africa

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Abstract

South Africa experienced since 2008 high escalations in 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 paper aimed to investigate the use of forensic geomorphology in the context of a poached rhino to assist in the prosecution of suspected poachers in the absence of any DNA linkages. Two experimental study sites mimicked the aspects of the landscape in which rhinoceros normally occur. Trace evidence was removed from the suspects that moved through the landscape in order to verify if any significant similarities could be identified against control samples collected at poaching sites and at locations based on the terrain utilized by the poachers during the simulated poaching incident. The paper concluded that a linkage could be recognized between the selected landscape and the collected trace evidence. The results indicate that the first experimental study site illustrated a definite linkage between the suspects and the poaching site, whereas the second experimental study site suggested that there was a possibility that a linkage could be made. This study only used inorganic material such as sand grains to link suspects to scenes.

Keywords: Poaching; forensics; geomorphology; investigations; rhinoceros

Introduction

Southern Africa's free-walking wildlife in large nature conservation areas and privately owned wildlife farms is one of its proud heritages. 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). 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. If poaching were to continue to increase by between +34% and +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 in South Africa, poaching of this iconic species mainly for its horn is still on the increase, forcing the remaining rhinoceros closer towards extinction. The horn is used for medicinal and wealth display purposes (TRAFFIC, 2012). Globalization and economic growth in especially the Asian countries have made it easy to establish illegal trading routes by international criminal syndicates (TRAFFIC, 2012). Addressing the rhinoceros poaching problem in South Africa is a complex task with an organized mesh of activities that involves uneducated poor poachers from rural villages, professional individuals such as veterinarians, pilots, and park officials including corrupt public officials (Eloff, 2012). 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 (Department of Environmental Affairs), 2014). All five remaining rhinoceros species are listed on the IUCN Red list of threatened species, with three out of five species classified as critically endangered (EWT, 2014).

The landscape in which the rhinoceros habitats exist makes it in most instances difficult for investigators to conduct forensic analysis. Geomorphology can play a role in forensic analysis, namely that shape of the land influences or controls human activity. This influence can be applied to forensic geoscience in order to convict suspects (Ruffel & Mckinley, 2013). Forensic geoscience is a field of analysis that utilizes 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 potentially valuable information is locked up in even small amounts of soil. This information 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, 1998). 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 the 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. The rest of the paper is as follows: The next section discusses forensic geoscience in more detail to lay the foundation for the methodology section. The methodology section is followed by a discussion of the results. The paper ends with a conclusion and possible future research.

Forensic geosciences

As mentioned in the introduction, 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 utilizes 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, Wiltshire, Parker, Bull 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 plasterboard, or micro-fossils (Morgan & Bull, 2007). The variability of the characteristics in 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 & Hillier, 2010).

Soils are complex materials that vary in properties in different areas and have characteristics owing to the natural effects and transfers made by human and other living organisms over time (Morgan et al., 2010). A 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 ions from synthetic fertilizers such as nitrate and phosphate and from different environments as environmental artefacts (such as lead or objects as glass, paint chips, asphalt, brick fragments, and cinders) whose presence may impart soil with characteristics that will make it unique to a particular location in varying proportions (Dawson & Hillier, 2010). These components may be naturally occurring or introduced by human activities thus soils contain a wealth of information of potential forensic use (Morgan et al., 2010). Also, 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 sample, may be used to indicate its provenance or to compare it with other samples of known provenance. The latter samples are known as control samples. 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).

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 1. 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 1. 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 (Source: Donnelly (2010))

The transfer of the aforementioned evidence is based on Locard's Exchange Principle (1930) where there is an exchange of material when two objects come into contact with each other (as referred to in Morgan & Bull, 2007). 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. An example is the 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. Once a trace material has been transferred, any subsequent actions of that material, for example, from the shoe to the carpet in a vehicle's foot well, are referred to as secondary transfers (Dawson & Hillier, 2010). 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 et al., 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).

Although it is possible to accurately link a suspect, clothing or object to a particular scene using geological trace evidence it is rendered useless if the investigator cannot determine which samples to collect for analysis from a vast landscape. Geomorphology is the scientific study of landforms and the processes that shape those (Schoeneberger et al., 2012). This discipline can also be used in forensics to determine suspect movement and to collect control samples. The application of forensic geomorphology is 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). Geomorphology reflects a fundamental principle in Gross' (1893) work, namely 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.

Ruffel and McKinley (2004) used various examples such as the 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 (Ruffel & McKinley, 2004). These cases reinforce the early work of Gross (1893, as cited in Ruffel & McKinley, 2004), and in the sociological context of Rossmo (2000), where both show how people operate within a landscape. Covert locations, lines of sight, ease of access and digging all play a strong role in criminal behaviour. Killam (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. In summary, 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 on the ground search as dictated by a broad range of forensic circumstances. The same applies to rhinoceros poaching where the lay of the land played a role in the crime as illustrated in Figure 2.

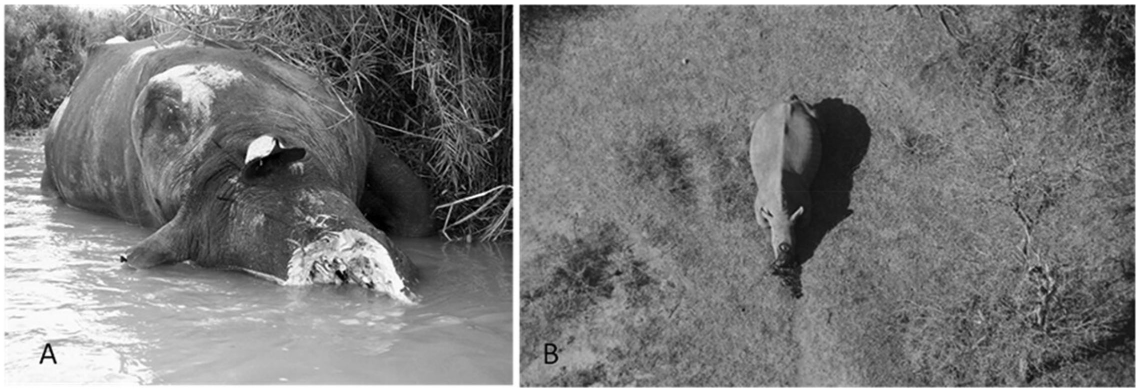


Figure 2. Different landscapes where rhinoceroses were poached (Source: http://www.savetherhino.org/rhino_info/threats_to_rhino/poaching_for_rhino_horn)

Location A was a waterhole with dense vegetation and location B is a typical Savannah. Both locations provided ample cover for poachers to move around and get close to their target. These two locations were mimicked in the study to illustrate the advantage of using forensic geoscience to link criminals to a crime site. The methodology with regards to sampling and analysis of the questioned and control sample will be discussed in the next section.

Methodology

The methodology applied in this paper was based on the exclusion principle and not the matching principle in forensic science. The questioned sample, in some instances referred to as the comparator sample, is excluded from control samples (exemplar samples) utilizing their physical, chemical, or biological characteristics, since the goal of matching the questioned sample to its origin is fundamentally flawed (Morgan & Bull, 2007). The exclusion principle in forensics was first mooted by Walls (1968) in his seminal work on forensic science. 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, 1991:240), 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. Owing to the amount of material obtained from the samples it was not possible to do a statistical analysis on the sample data to exclude the questioned sample from the control sampled. The methodology applied here is based on the descriptive characteristics of the samples to exclude the questioned sample form the control sample. The latter is mentioned as an acceptable method by Morgan and Bull (2007).

Although no standard forensic soil examination method exists (Dawson & Hillier, 2010; 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, Wiltshire, Parker, Bull et al., 2006). Figure 3 illustrates the process flow of the methodology followed.

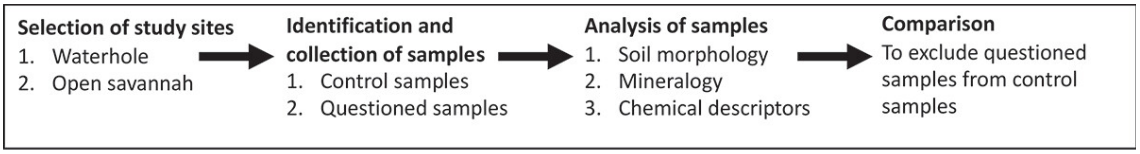


Figure 3. Methodology flow diagram to exclude questioned from control samples

Study site selection

As indicated in Figure 3, there are two simulated poaching sites, namely a waterhole in Sabie Park Private Game Reserve and open savannah in Sabie Sands Game Reserve as indicated in Figure 4. Both locations are similar to the landscapes found in the Kruger National Park. The experimental sites are located between 24° 57' and 25°S, and 31° 27' and 31° 30' E at an altitude of approximately 320 m 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 local geomorphology of the sites is sandy granite soils forming part of plains or lowlands (Munyati & Ratshibvumo, 2010).

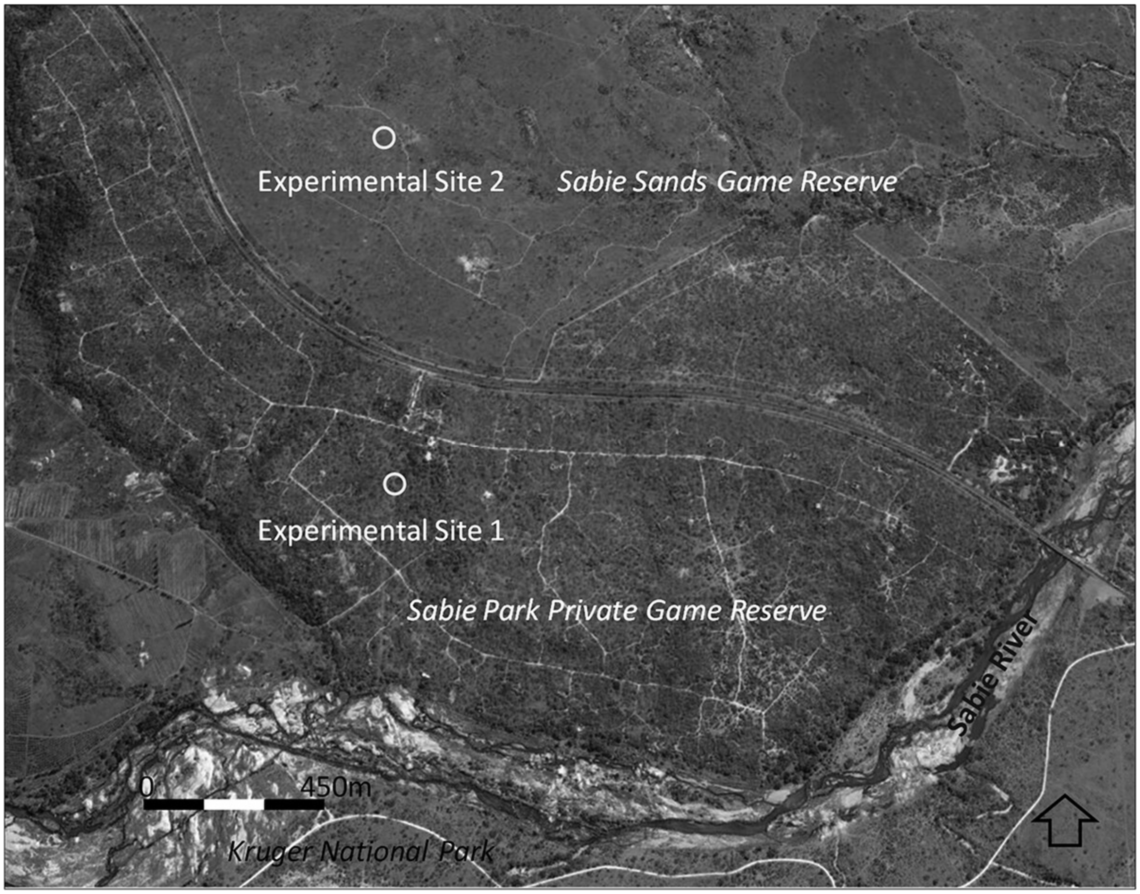


Figure 4. Locations of the simulated poaching sites for this study

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 (Munyati & Ratshibvumo, 2010; Heritage & Moon, 2000). The inselbergs are the result of locally higher resistance against weathering caused by dome-like structures in the granitoid rocks (Munyati & Ratshibvumo, 2010). The overall flora of the area is a mixed grass and woodland.

Sample selections at each experimental site and suspects

Several 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) have also stated and shown how criminals operate with regard to a landscape. Once an inventory of landforms, processes, and landform systems in the study area has been carried out, the experimental study sites were analysed, assessing for each 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 have been gathered; the first sample set is the control samples and is gathered from the simulated crime scene and surrounding area. The second set of samples is gathered from the suspect and his/her belongings which are the questioned samples. Dr Leonie Ras from the South African Police Services' Forensic Science Laboratory guided how to collect the samples to ensure that they comply with forensic rigour (Ras, 2014). Each sample that was collected was sealed in a sealable plastic bag including the plastic spoon that was used to collect the sample. This was done to avoid cross-contamination of samples.

In general, for geological analysis large amounts of samples will be gathered, however, owing to the nature of forensics this is not possible (Lindemann, 2001). Samples from anthropogenic sources such as a suspect, only trace amounts of soil and sediment are available which will mostly be gained from the persons' belongings (questioned samples) and the simulated crime scene (control samples). However, a successful analysis cannot be based on single locations, therefore samples will also be gathered from the geographical route the 'suspects' travelled to reach the crime scene as shown in Figure 5. Referring to Petraco et al.'s (2008) paper on case studies in forensic soil examinations, around eight to sixteen control samples will be gathered in field, depending on the landscape. These samples will not exceed more than 50 mg each as the samples gathered from the suspects and their belongings will prove to be fairly little in comparison according to Morgan and Bull (2007). Soil collected for comparative purposes must be relevant to the soil that was removed from the suspect(s). In most cases, this means the surface topsoil since this is the part of the soil layer that is in contact with persons. Consequently, care needs to be taken in avoiding contamination of the soil surface with deeper soil horizons. With regards to soil adhering to materials or objects including people Saferstein (2004) notes that the whole item should then be collected and bagged and examined in situ with an appropriate technique for the amount of soil available. Figure 5 gives the characteristics of the landscape that were used to select control samples for each experimental site. Figure 6 shows an example of the sites where control samples were collected. Each sample was approximately 50 mg.

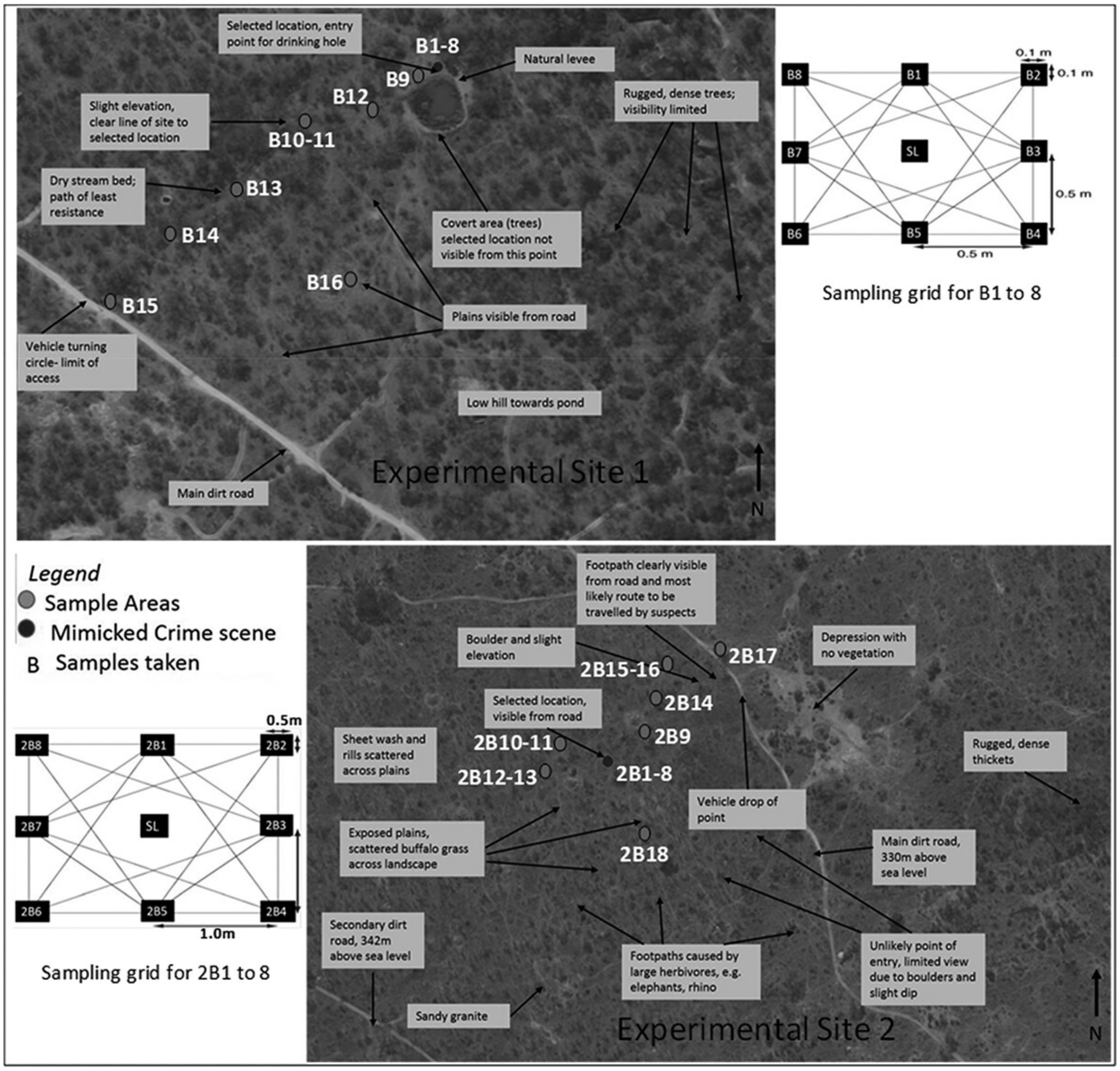


Figure 5. Landscape description and control sample sites

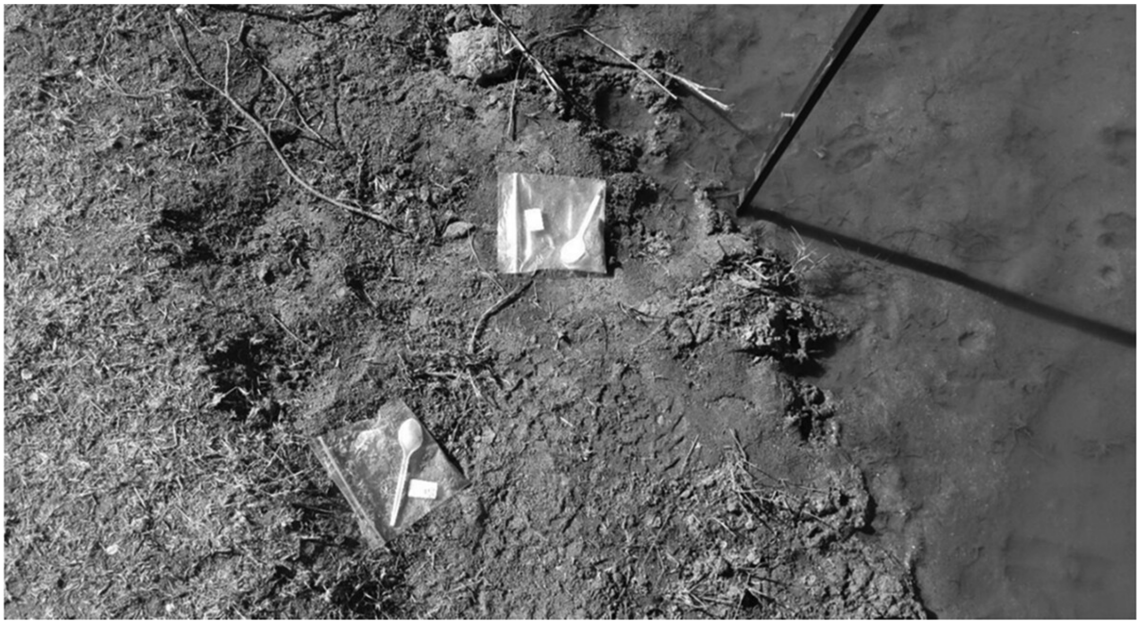


Figure 6. Control samples collection around the simulated crime scene

Samples from suspects, their belongings and equipment

The questioned samples were selected from the suspects, their belongings, and equipment used 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, 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 as shown in Figure 7. Another portion of soil was present within the sole of another shoe worn by the suspects. Perhaps the most valuable traces of soil were retrieved from the axe carried by the suspects as shown in Figure 8. For the experiment the axe was doused in water to simulate blood and allow the material to cling onto the axe.

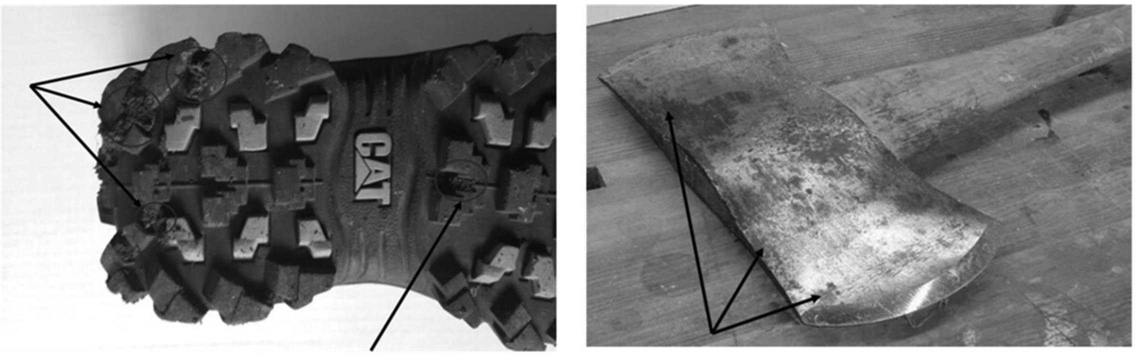
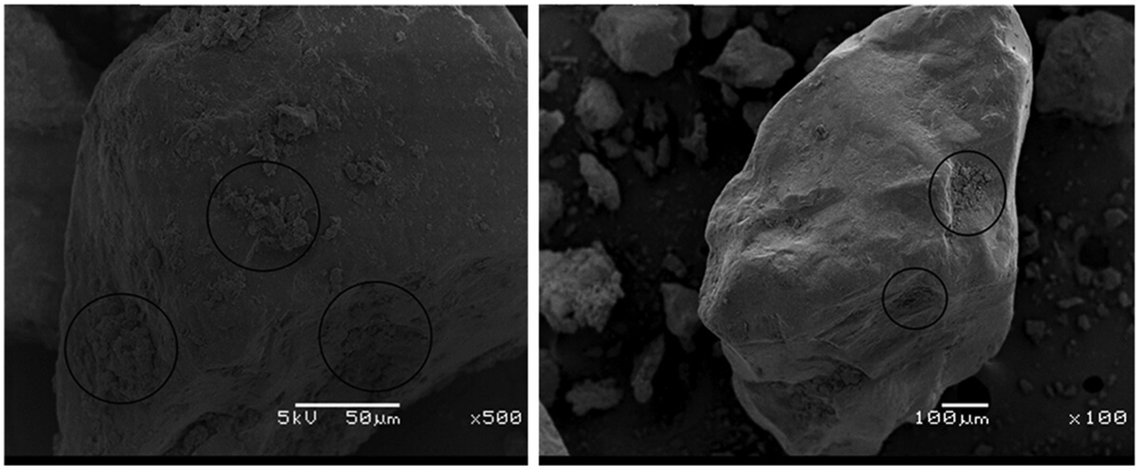


Figure 7. Questioned samples collected from the shoe and axe



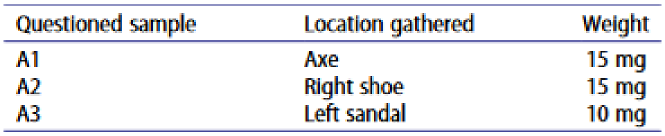
Waxy surface with clay films of B4 (Exemplar sample)

Waxy surface with clay films of A1 (Comparator sample)

Figure 8. Quartz grain similarities between questioned and control samples

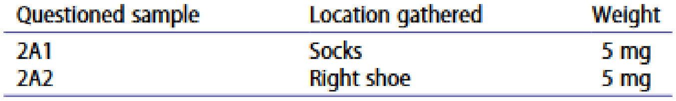
Table 1 gives the questioned sample and weight collected from the suspects at Experimental Site1, as shown in Figure 7, and Table 2 the questioned samples from Experimental Site 2. Each control and questioned samples were collected using forensic sample collection methods.

Table 1. Questioned samples at experimental site 1



Questioned sample	Location gathered	Weight
A1	Axe	15 mg
A2	Right shoe	15 mg
A3	Left sandal	10 mg

Table 2. Questioned samples ate experimental site 2



Questioned sample	Location gathered	Weight
2A1	Socks	5 mg
2A2	Right shoe	5 mg

Analysis methodology

The first step in the analysis is to group questioned samples with control samples based on colour. Using the Munsell colour classification system, samples from the suspect and crime scene were designated colour codes, and these must all be found to be within a similar range. As soon as all the samples have been selected and gathered, two methods were used namely, to include and to exclude, as was done in the methodology described in Ruffel and Mckinley (2013) and Morgan and Bull (2007).

Once all the samples that show strong similar characteristics have been nominated, a range of independent techniques were conducted to establish a set of meaningful results. These meaningful results are used to either exclude or include the questioned sample with the control samples. 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 independent analysis methods for characterizing soils for forensic comparison involve subdividing methods are conducted as follows:

- Descriptive analysis using colour, consistency, texture, and structure (Fitzpatrick, 2009) using the USDA Field Book v.3, which included the Powers chart of comparison on page 2–49 to determine the roundness of the grains.
- Binocular and a JEOL 5800 with EDAX scanning electron microscope with 5kV accelerating voltage and high vacuum were used to analyse sample assemblages and individual quartz grains, respectively.
- Mineralogy summary of each sample using X-ray diffraction (XRD). The samples were analysed using a PANalytical X'Pert Pro powder diffractometer in θ–θ configuration with an X'Celerator detector and variable divergence- and fixed receiving slits with Fe filtered Co-Kα radiation ($\lambda = 1.789$ Å). The phases were identified using X'Pert Highscore plus software. The relative phase amounts (weight%) were estimated using the Rietveld method (Autoquan Program).
- Detailed chemical characterization of soil particles using X-ray fluorescence (XRF) namely the Thermo Fisher ARL Perform'X Sequential XRF with OXSAS software spectrometer. The OXSAS software is used to set up the calibration for major elements, SiO2, TiO2, Al2O3, Fe2O3, MnO, MgO, CaO, Na2O, K2O, P2O5, Cr2O3, NiO, V2O5, ZrO2, CuO, and the LOI. A set of certified calibration standards of about 50 samples of varying composition are used to calibrate for the elements in concentrations higher than 0.1%. The wavelength dispersive instrument uses a Rhodium tube. The analytical crystal range includes LiF200 (Z, Ti, V, Ni, Mn, K, Fe, Cr), LiF220 (Cu, Ca), PET (Si, Al) AXO6 (Na, Mg), and Ge111 (P). Both FPC (Ti, V, Si, an, P, NI, Mn, Mg, K, Fe, Cr, Ca, Al) and SC (Zr, Cu) detectors are used. The collimator range is between 0.15 (Zr, Ti, V, Si, NI, Mn, K, Fe, Cr, Cu, Ca, Al) and 1.00 (Na, P, Mg). Counting times range from 20s (Na, Mg), 12s (Ti, V, Si, P, Ni, Mn, K, Fe, Cr, Cu, Ca, Al) and 8s (Zr). The X-ray tube power settings vary between 30kV/80 mA (Si, NA, P, Mg, K, Ca, Al) and 50kV/50 mA (Zr, Ti, V, Ni, Mn, Fe, Cr, Cu)

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, Wiltshire, Parker, Bull et al., 2006). Provided that there is enough 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 from whence they came, it should be possible to afford meaningful analysis, comparison, and interpretation of results (Pye & Croft, 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, 2) 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. The results are discussed in the next section.

Results

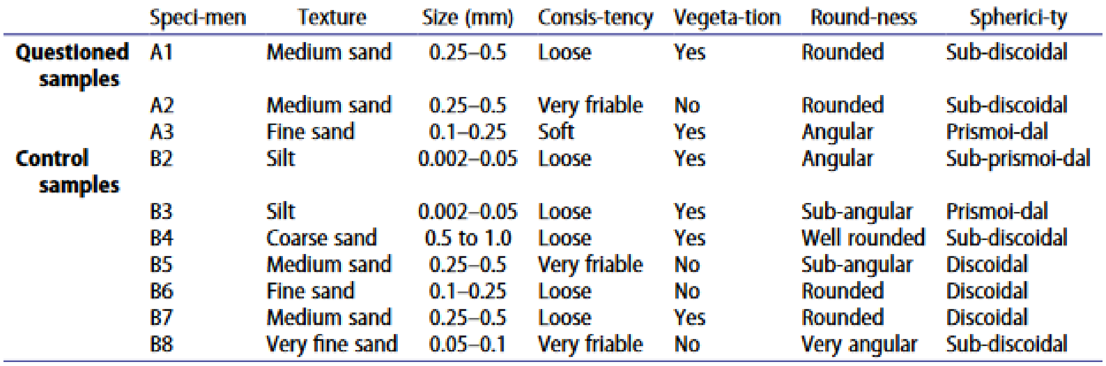
The results of the analysis are first discussed for Experimental Site 1 followed by Experimental Site 2 and ending with a discussion whether the questioned samples are excluded when comparing them against the control samples.

Experimental site 1

Munsell colour analysis indicated that each sample of the questioned sample set is a 7.5 YR 4/2 category, which approximates a reddish, grey-brown colour and is one of the categories of the 80 or more recognized by the Munsell system of classification. Eight samples of the control sample set displayed the same colour as the questionable sample set which indicates that the samples in

cannot be excluded from the investigation. 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 (Morgan, Wiltshire, Parker, Bull et al., 2006). These soil morphological descriptors are listed in Table 3.

Table 3. Soil morphological descriptions for each sample



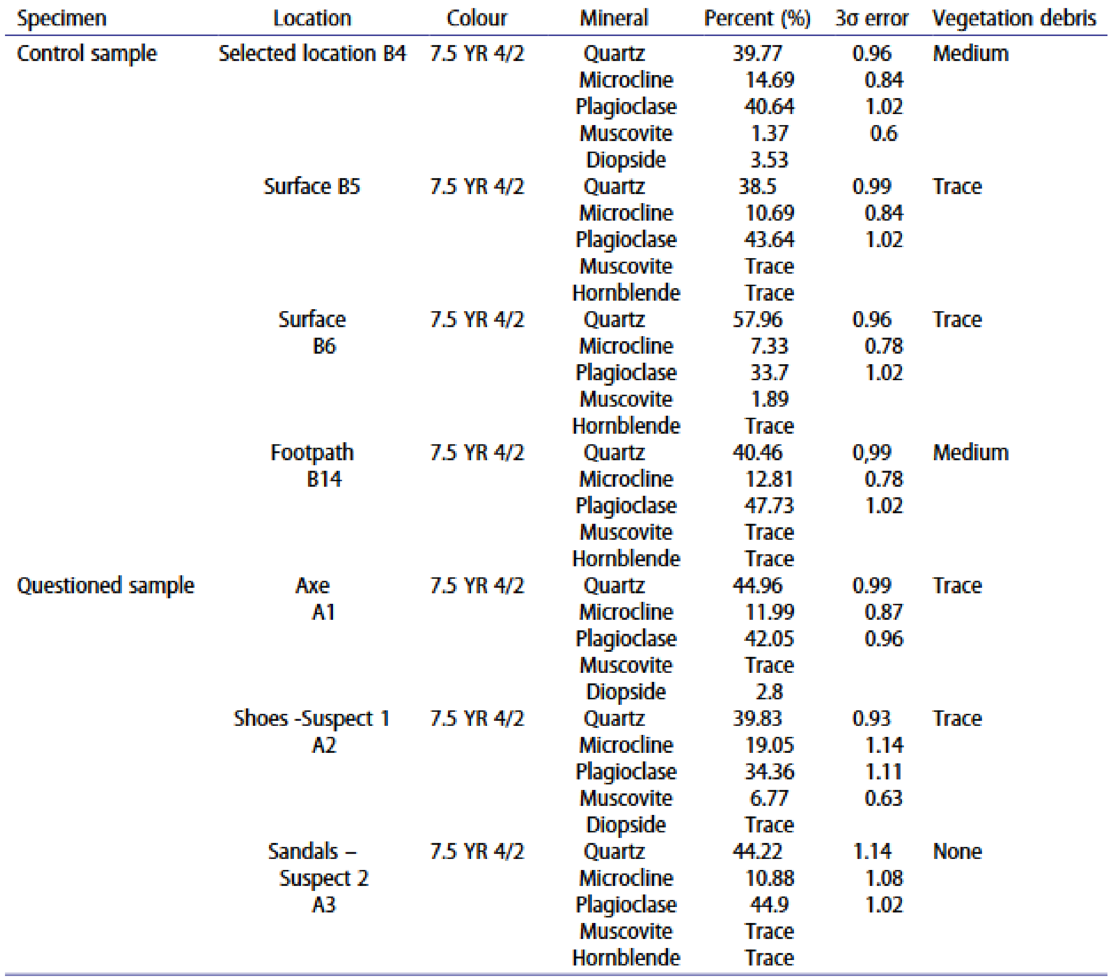
	Speci-men	Texture	Size (mm)	Consis-tency	Vegeta-tion	Round-ness	Spherici-ty
Questioned samples	A1	Medium sand	0.25–0.5	Loose	Yes	Rounded	Sub-discoidal
	A2	Medium sand	0.25–0.5	Very friable	No	Rounded	Sub-discoidal
	A3	Fine sand	0.1–0.25	Soft	Yes	Angular	Prismoi-dal
Control samples	B2	Silt	0.002–0.05	Loose	Yes	Angular	Sub-prismoi-dal
	B3	Silt	0.002–0.05	Loose	Yes	Sub-angular	Prismoi-dal
	B4	Coarse sand	0.5 to 1.0	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

Figure 8 gives an example of electron microscope sample for comparative purposes. Both the quartz grains from sample A1, questioned sample, and sample B4, control sample both have waxy surfaces with clay films as shown in

It is not uncommon to detect plant debris in samples taken in a natural environment and samples will 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 if not enough information is gathered through physical and chemical analysis. Most samples displayed the presence of root fragments and pollen. 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 such as identified in sample B6 could be used to establish a link between two samples through a proper palynological analysis, if the current analysis provides insufficient results.

Using soil morphological descriptors when comparing the questioned samples against the control samples, only four of the control samples cannot be excluded, namely, B4, B5, B6, and B14. These four and the questioned samples were further compared using the mineralogy of the samples. The mineralogy for each sample is listed in Table 4. 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, i.e. silicon dioxide, which is very common in soils, the significance of the comparability and its evidential value in terms of comparison criteria will be low. However, as Dawson and Hillier (2010) argue, if the two soils contain four or five crystalline mineral components, some of them unusual, then the degree of comparability will be considered as high.

Table 4. Mineral components for each sample



Specimen	Location	Colour	Mineral	Percent (%)	3σ error	Vegetation debris
Control sample	Selected location B4	7.5 YR 4/2	Quartz	39.77	0.96	Medium
			Microcline	14.69	0.84	
			Plagioclase	40.64	1.02	
			Muscovite	1.37	0.6	
			Diopside	3.53		
	Surface B5	7.5 YR 4/2	Quartz	38.5	0.99	Trace
			Microcline	10.69	0.84	
			Plagioclase	43.64	1.02	
			Muscovite	Trace		
			Hornblende	Trace		
	Surface B6	7.5 YR 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	7.5 YR 4/2	Quartz	40.46	0,99	Medium
			Microcline	12.81	0.78	
			Plagioclase	47.73	1.02	
			Muscovite	Trace		
			Hornblende	Trace		
Questioned sample	Axe A1	7.5 YR 4/2	Quartz	44.96	0.99	Trace
			Microcline	11.99	0.87	
			Plagioclase	42.05	0.96	
			Muscovite	Trace		
			Diopside	2.8		
	Shoes -Suspect 1 A2	7.5 YR 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		
	Sandals – Suspect 2 A3	7.5 YR 4/2	Quartz	44.22	1.14	None
			Microcline	10.88	1.08	
			Plagioclase	44.9	1.02	
			Muscovite	Trace		
			Hornblende	Trace		

Sample B4 contains a small percentage of diopside, which is also present in every sample in the questionable 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 advocates that it could have derived from the selected location at Experimental Site 1 and can therefore not be excluded from the crime scene.

The final analysis to determine which control sample can be excluded based on comparisons with the questioned sample is the chemical analysis using X-ray fluorescence spectroscopy. Table 5 gives the chemical composition for each sample.

Table 5. Chemical composition of each sample

Mineral (%)	Certi-fied	Ana-lysed	A1	A2	A3	B4	B5	B6	B14
SiO_2	99.6	99.7	72.75	74.02	71.23	69.50	71.65	71.5	73.65
TiO_2	0.01	0	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	1.47	1.64
MnO	0.01	0	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	0.3	0.35	0.2	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	4.7	2.25	5.46	1.58
K_20	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	0	0	0	0	0	0	0
NiO	0	0.01	0	0	0	0	0	0	0
V_2O_5	0	0	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	0	0	0	0	0	0	0
LOI	0	0.1	3.33	2.68	4.07	5.7	5.44	3.88	5.54
Total	100	99.92	99.26	101.8	100.5	99.8	100.56	99.37	99.0

Chemical analysis of the seven samples was undertaken to determine the comparability of the chemical composition as given in Table 5. The percentage of silicon dioxide (SiO2) appears to be average among the seven samples, which could be expected in the Bushveld area where granite and gabbro are the dominant geology types and have a high Silica composition. The analysis results for Experimental Site 2 will be discussed in next sub-section.

Experimental site 2

The Munsell colour analysis indicated that nine of the 18 control samples were designated between 5 YR 4/2 and 7.5 YR 4/2, which approximates the same greyish, brown colour of the questioned samples and is one of the categories recognized by the Munsell system of classification. The nine control and two questioned samples soil descriptions were analysed to determine which control sample can be excluded. The result of this analysis is given in Table 6.

Table 6. Soil morphological descriptions for each sample

	Speci-men	Texture	Size (mm)	Consis-tency	Vegeta-tion	Round-ness	Sphericity
Questioned samples	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
Control samples	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	0.002–0.05	Loose	No	Very angular	Prismoidal
	2B4	Silt	0.002–0.05	Loose	Yes	Very angular	Sub-discoidal
	2B5	Silt	0.002–0.05	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

During scanning electron microscopy, small traces of hair could be detected in 2B2, a sample from the control sample set, as shown in Figure 9. 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 et al., 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.

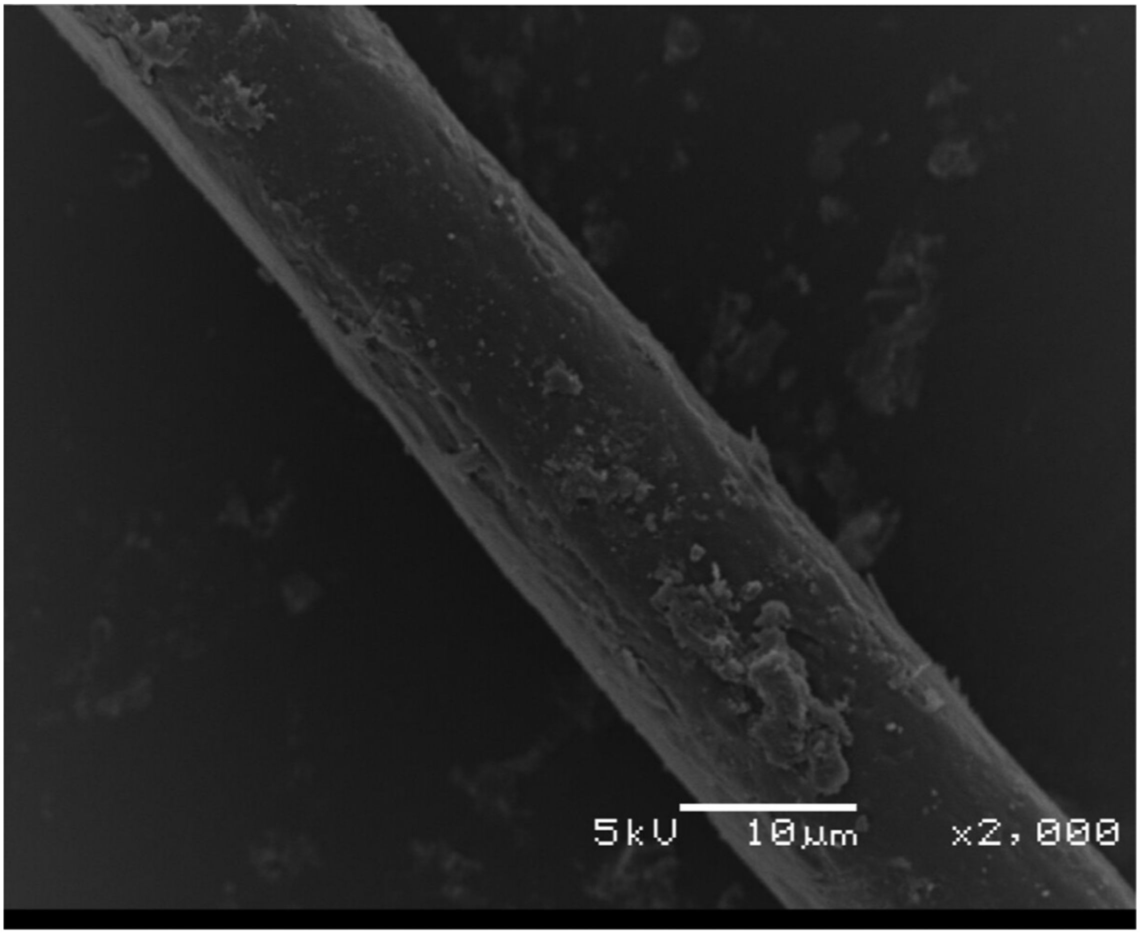


Figure 9. Hair found in control sample 2B2

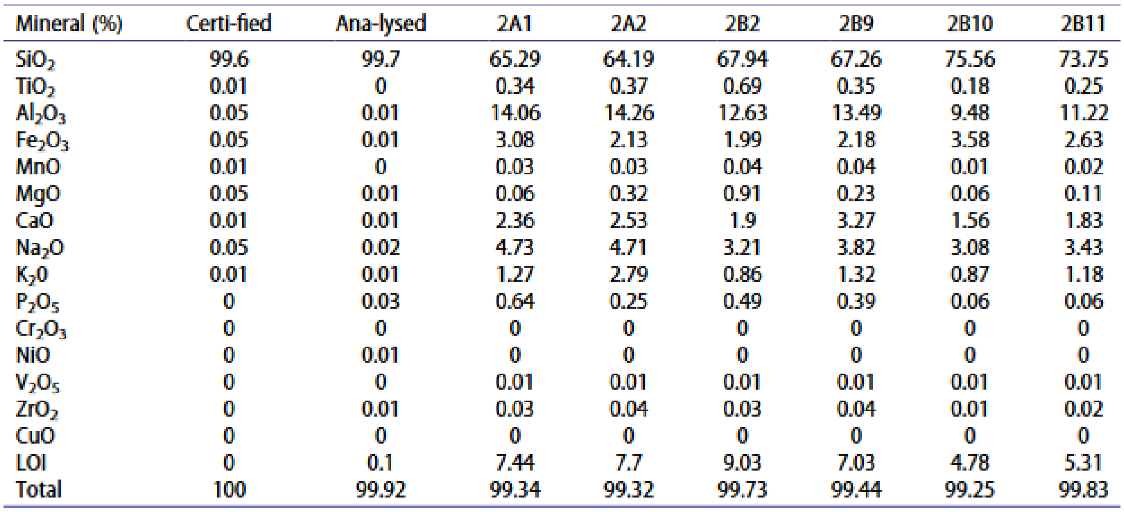
The sample sets display some similarities regarding soil morphology, but definitely to a lesser extent than that which was found at experimental site 1. Control samples 2B1, 2B2, 2B9, 2B10, and 2B11 present the most similar soil morphology characteristics to the questioned samples. The mineralogy for the control and questioned samples was done to exclude control samples from the questioned samples. The mineralogy for each sample is listed in Table 7.

Table 7. Mineral components for each sample

Specimen	Location	Colour	Mineral	Percent (%)	3σ error	Vegetation debris
Control sample	Just below the surface 2B1	5 YR 3/3	Quartz	66.05	0.9	Medium
			Microcline	4.7	0.54	
			Plagioclase	29.78	0.93	
			Muscovite	Trace		
			Hornblende	Trace		
	Surface 2B2	5 YR 4/2	Quartz	53.6	1.41	Trace
			Microcline	7.78	0.9	
			Plagioclase	31.13	1.62	
			Muscovite	7.49	0.99	
			Hornblende	Trace		
	Footpath 2B9	5 YR 4/2	Quartz	53.06	1.05	Trace
			Microcline	8.69	0.84	
			Plagioclase	38.26	1.11	
			Muscovite	Trace		
			Hornblende	Trace		
	Footprint 2B10	5 YR 4/2	Quartz	58.21	0,99	Medium
			Microcline	7.76	0.72	
			Plagioclase	34.03	1.05	
			Muscovite	Trace		
			Hornblende	Trace		
	Footprint 2B11	7.5 YR 4/2	Quartz	47.46	0,99	Medium
			Microcline	7.81	0.78	
			Plagioclase	44.73	1.02	
			Muscovite	Trace		
			Hornblende	Trace		
Questioned sample	Suspect's right shoe 2A1	5 YR 4/2	Quartz	53.04	1.02	Trace
			Microcline	9.69	0.78	
			Plagioclase	37.27	1.05	
			Muscovite	Trace		
			Diopside	Trace		
	Socks -Suspect 2A2	7.5 YR 4/2	Quartz	50.58	1.08	Trace
			Microcline	8.86	0.84	
			Plagioclase	40.56	1.08	
			Muscovite	Trace		
			Diopside	Trace		

The predominant geology of the area is granite which causes quartz to be the dominating mineral in both sample sets. Both the control and questioned sample sets contain five crystalline mineral components, confirming that a degree of comparability 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 illustrates that there is some resemblance between the control and questioned sample sets. Control sample 2B1 owing to its much higher Quartz content was the only sample that could be excluded from the investigation as it displayed an uneven mineralogical composition when compared to the other samples. Chemical composition analysis on the remaining samples was conducted to determine which control sample could be further excluded when compared against the questioned sample. Table 8 gives the chemical composition of each sample.

Table 8. Chemical composition of each sample



Mineral (%)	Certi-fied	Ana-lysed	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_20	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

When comparing questioned sample 2A1 against the control samples, only 2B2 and 2B9 displays a similar chemical composition than those of control samples to sample 2A1. The same applies to questioned 2A2. The control samples 2B10 and 2B11 based on the general chemical composition can be excluded from the questioned samples. Overall the analysis of samples at Experimental Site 2 is more inclined for exclusion than for inclusion as shown in the aforementioned figures and tables when compared against the samples from Experimental Site 1.

Overall results

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. The highest concentration of soils was found on and around the footwear. Particulates such as pollen tended to be preserved around technical details of clothing such as stitching or relief design features on shirts and pants. 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 dust particles adhering to shoes and socks providing the investigator with a substantial number of particles for investigation. However, if the suspects belongings were only apprehended several days later, the redistribution of any particulate trace evidence elicits an alteration in the spatial distribution of the evidence in question. There 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 as a failure to do so may have consequences for the correct interpretation of such evidence. Source heterogeneity and susceptibility to post-transfer fractionation or mixing with pre- and post-transfer sources (Broeders, 2006, as referenced in Dawson & Hillier, 2010) cannot be always easily be estimated or accommodated using conventional methods. It is therefore essential to be able to interpret the trace evidence must be obtained correctly through methods such as colour and moisture in order to specify the timeframes in which the trace evidence was 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 clear to identify the possible routes from which to collect samples. However, more areas were identified for sample collection at Experimental Site 2 as the possible route to the selected location was not as restricting as with Experimental Site 1, this was largely due to lack of vegetation and uniform topography. The necessity for collecting samples at the right locations were established by both experimental sites, as samples that were randomly selected on the landscape, namely B16 and 2B18. These two samples 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 homogenizes the sample and produces, unknowingly the possibility of false-positive or even false-negative results (Bull et al., 2006).

The final process whether the exclude or include is shown in Figure 10. Using this decision tree process, control samples B4 and B14 from Experimental Site 1 cannot be excluded from the same source when compared against questioned sample A1. This finding would have an impact on the investigation.

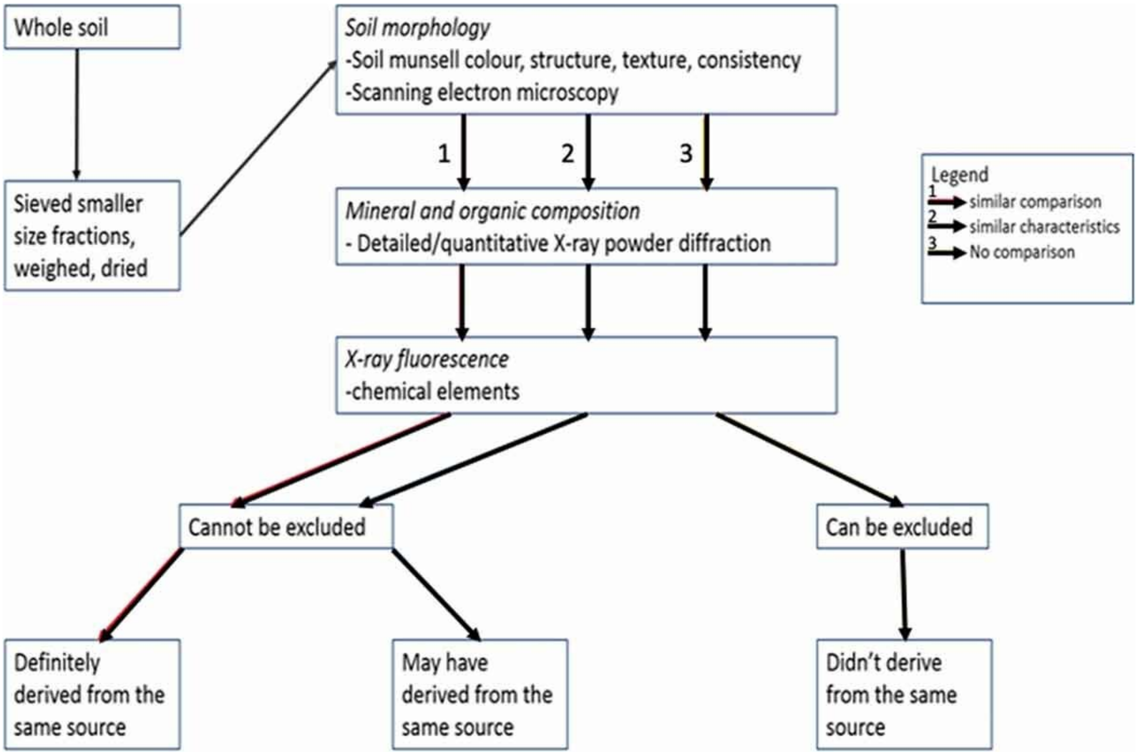


Figure 10. Exclusion decision tree followed to exclude samples

With regards to Experimental Site 2, owing to it being a bit more uncertain compared to Experimental Site 1, the control samples, 2B2 and 2B9, may have been derived from the same source as the questioned sample 2A1 and 2A2. Based on the aforementioned, the indication is that the suspect may have been active at the simulated crime scene. This finding most likely would not have an impact on direction of the investigation.

Conclusions and recommendations

The research 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 various landscapes 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 Site 1 provided more accurate comparison between the sample sets. This is owed to soils with higher soil moisture content at or nearby the watering providing more soil to adhere to the suspects. Early morning dew can also cause more soil to cling to suspect owing to wet shoes and clothes. A rhinoceros poached next to a river may also present its own difficulties for investigators as sedimentation constantly changes along a riverbank. Nevertheless, this study demonstrated 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 questioned 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 reduce any bias and allow for efficient identification and analysis of the samples.

The future direction in 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 and Hillier (2010) mention 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 varies vary spatially, both contribute to added discriminatory potential and this delivers the added value of a combined approach. For example, Brown et al. (2002) refer to a case where petrology was combined with palynology in a search in a murder investigation, on 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, elements obtained within some samples could have been analysed to improve the evidential worth of the soil formation. At Experimental 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 identified at Experimental 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 et al, 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.

The samples contained traces of minerals such as Diopside and Hornblende which requires further research into how much does these traces impact on the inclusion or exclusion of samples. The alternative is to determine to exclude these traces and depend on the non-trace minerals to include and exclude samples related to the crime scene.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Broeders, A.P.A., (2006) Of earprints, fingerprints, scent dogs, cot deaths and cognitive contamination—a brief look at the present state of play in the forensic arena. Forensic Science International 159(2–3), pp 148–157.

Brown, A. G., Smith, A., & Elmhurst, O. (2002). The combined use of pollen and soil analyses in a search and subsequent murder investigation. *Forensic Science*, *47*(3), 614–618. https://doi.org/10.1520/JFS15302J.

Bull, P. A., Parker, A. & Morgan, R.M., (2006) The forensic analysis of soils and sediments taken from the cast of a footprint. Forensic Science International 162(1–3), pp 6–12.

Cairncross, B. (2004). *Field guide to rocks and minerals of Southern Africa*. Struik Nature.

Dawson, L. A., & Hillier, S. (2010). Measurement of soil characteristics for forensic applications. *Surface and Interface Analysis*, *42*(5), 363–377. https://doi.org/10.1002/sia.3315

DEA (Department of Environmental Affairs). (2014). *National strategy for the safety and security for rhinoceros populations in South Africa*.

Donnelly, L. J. (2010, January). *The role of geoforensics in policing and law enforcement*. Emergency Global Barclay media Limited.

Eloff, C. (2012, March) *Rhino poaching in South Africa: A spatial analysis*. http://www.pmg.org.za/report/20120126-public-hearings-solutions-rhino-poching-culling- old-bull-elephants-k

EWT (2014) *Current rhino statistics*. Endangered Wildlife Trust. https://www.ewt.org.za/.

Fitzpatrick, R. W., Raven, M. D., & Forrester, S. T. (2009) A systematic approach to soil forensics: Criminal case studies involving transference from crime scene to forensic evidence, In Ritz K., Dawson L., Miller D. (Eds.), *Criminal and environmental soil forensics* Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-9204-6_8

Fitzpatrick, R. W. (2009). Soil: Forensic analysis. In A. Jamieson and A. Moenssens (Eds.), *Wiley encyclopedia of forensic science*. John Wiley & Sons, Ltd. doi:https://doi.org/10.1002/9780470061589.fsa096.pub2

Gallop, A., & Stockdale, R. (1998). Trace and contact evidence. In P. White (Ed.), *Crime scene to court: The Essentials of forensic science* (pp. 64–65). The Royal Society of Chemistry.

Gross, H., (1893). Handbuch fur Untersuchungrichter al System der Kriminalistik. J. Scheitzer Verlag, Munich, p493.

Heritage, G. L., & Moon, B. P. (2000). The contemporary geomorphology of the Sabie River in the Kruger National Park. *Koedoe*, 43(1), 39–55. https://www.cabdirect.org/cabdirect/abstract/20001915473

Killam, E. W. (2004). *The detection of human remains*. Charles C Thomas.

Kirk, P. L. (1974). *Crime investigation* (2nd ed.). Wiley.

Lindemann, J. W. (2001). Forensic geology. *Environment and Engineering Geology*, 3, 1–9.

Locard, E. (1930). Analyses of dust traces parts I, II and III, Am. J. Police Science, p276–298, 401–418, 496–514

Montesh, M. (2012). *Rhino poaching: A new form of organised crime, report to college of law research and innovation committee of the university of South Africa*. University of South Africa

Morgan, R. M., & Bull, P. A. (2007). Forensic geoscience and crime detection; Identification, interpretation and presentation in forensic geoscience. *Minerva Medicolegale*, 127(2), 73–89. https://www.geog.ox.ac.uk/staff/pbull_pub01.pdf

Morgan, R. M., French, J., O'Donnell, L., & Bull, P. A. (2010). The reincorporation and redistribution of trace geoforensic particulates on clothing: An introductory study. *Science and Justice*, 50(4), 195–199. https://doi.org/10.1016/j.scijus.2010.04.002

Morgan, R. M., Wiltshire, P., Parker, A., & Bull, P. A. (2006). The role of forensic geoscience in wildlife crime detection. Forensic Science International, 162(1–3), 152–162. https://doi.org/10.1016/j.forsciint.2006.06.045

Munyati, C., & Ratshibvumo, T. (2010). Differentiating geological fertility derived vegetation zones in the Kruger National Park, South Africa, using Landsat and MODIS imagery. *Journal for Nature Conservation*, *18*(3), 169–179. https://doi.org/10.1016/j.jnc.2009.08.001

Murray, R., & Tedrow, J. C. F. (1991). Forensic geology: Earth sciences and criminal investigation (republished 1986). Rutgers University Press

Petraco, N., Kubic, T. A., & Petraco, N. D. K. (2008). Case studies in forensic soil examinations. *Forensic Science International*, 178(2–3), 23–27. https://doi.org/10.1016/j.forsciint.2008.03.008

Pye, K., & Croft, D. J. (2004). Forensic Geoscience: Introduction and overview. Geological Society Special Publication, 232, 1–5.. https://doi.org/10.1144/GSL.SP.2004.232.01.01

Ras, L. (2014). *Personal communication. South African police services' forensic science laboratory*.

Rossmo, D. K. (2000). *Geographic Profiling*. CRC Press.

Ruffel, A., & Mckinley, J. (2013). Forensic geomorphology. *Geomorphology*, *206*(1),14–22. https://doi.org/10.1016/j.geomorph.2013.12.020

Ruffel, A., & McKinley, J. (2004). Forensic geoscience: Applications of geology, geomorphology and geophysics to criminal investigations. *Earth-Science Reviews*, 69(3–4), 235–247. https://doi.org/10.1016/j.earscirev.2004.08.002

Saferstein, R. (2004). *Criminalistics: An introduction to forensic science* (8th ed.). New Jersey.

Schoeneberger, P. J., Wysocki, D. A., & Benham, E. C., Soil Survey Staff. (2012). *Field book for describing and sampling soils, Version 3.0*. Natural Resources Conservation Service, National Soil Survey Center. Lincoln, NE.

Schumm, S. A. (2005) Forensic geomorphology. GSA Today, 42–43 (December).

TRAFFIC. (2012). *Annual report*. TRAFFIC International, Cambridge, United Kingdom.

Walls, H. J. (1968). *Forensic Science*. Sweet and Maxwell.

Ward, J., Peakall, R., Gilmore, S.R. & Robertson, J., (2005) A molecular identification system for grasses: a novel technology for forensic botany. Forensic Science International 152, 121–131.

Woods, B., Lennard, C., Kirkbride, K. P., & Robertson, J. (2014). Soil examination for a forensic trace evidence laboratory—Part 1: Spectroscopic techniques. *Forensic Science International*, 1–8.