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McKinley, J., & Ruffell, A. (2021). Geographical Information Science (GIS), Spatial Sampling and Soil variability examined using a case of Manslaughter Forensic Soil Science and Geology. In R. Fitzpatrick, & L. Donnelly (Eds.), *Geological Society of London Special Publication: GSL Special Publication "Forensic Soil Science and Geology"* (Vol. 492, pp. 55-63). (Forensic Soil Science and Geology; Vol. 492). Geological Society of London. <https://doi.org/10.1144/SP492-2018-16>

Published in:

Geological Society of London Special Publication: GSL Special Publication "Forensic Soil Science and Geology"

Document Version:

Peer reviewed version

Queen's University Belfast - Research Portal:

[Link to publication record in Queen's University Belfast Research Portal](#)

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Geographical Information Science (GIS), Spatial Sampling and Sediment variability examined using a case of Manslaughter

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Abstract: The body of a missing person was found adjacent to a 3km-long sand-covered forest track in an upland area of Northern Ireland (UK). Geological trace evidence in the form of sand was found in the passenger foot well and on the foot pedals of a vehicle belonging to the last known associates of the deceased. A Geographical Information Science (GIS) methodology was used to integrate regional geological and soil databases to confirm the provenance of the sand and to find geographic locations for control (or alibi) samples. To compliment the forensic examination in the case, seventy-seven samples were taken at the scene in order to test whether such a collection assists knowledge of the scene, or whether fewer, targeted samples at access points to the body would have sufficed. The results demonstrate the potential applications of a GIS approach and show the usefulness of employing a spatial sample scheme to understand the degree of local variability between samples. The findings from this study demonstrated that fewer samples would have been sufficient to associate the questioned items with the scene, yet would not have demonstrated how other areas of the track could be progressively excluded from comparison.

A GIS Desktop study approach

The use of GIS has become an essential part of the traditional 'desktop' study. The integration of information as geo-referenced spatial layers offers the potential to query and extract information between layers to inform police, search and forensic investigators (McKinley 2017). Digital databases of solid geology, drift deposits and soil types are important resources as part of this GIS desk-based study. The use of GIS enables a forensic investigation to be refined from a regional scale to a site-specific scene of crime location. There are several published examples of a GIS digital database approach used for trace evidence soil provenance (Ruffell & Dawson, 2009); determining locations for collecting control

samples (McKinley & Ruffell 2007) and historic and more recent search operations (Harrison & Donnelly 2008; McKinley et al., 2009; Donnelly 2013; McKinley 2017; Bunch et al., 2016). A GIS framework enables the creation of an integrated database and data management system that can be used to produce digital and paper maps of low, moderate and high priority search areas such as RAG (Red-Amber-Green) maps (Donnelly & Harrison, 2017). This study uses a desk-based study to investigate geological trace evidence provenance starting from a regional scale through the use of digital soil and geology databases to the scale of a site-specific scene of crime location. The GIS framework enables samples taken at the crime scene and control samples to be geo-located and linked to the soil and geological databases. Even at the scale of crime scene, a spatial sampling scheme can be mapped and set within the context of a larger regional study. This is useful not only for soil provenance but also explore the spatial variability between samples at the scale of scene of crime.

Spatial Sampling in Forensic Geology

A review of publications on forensic geology (Murray (2011); Ruffell & McKinley (2008); Ritz et al. (2009); Bergslien (2012); Pye (2007) illustrates how relatively rarely description and analysis includes the spatial distribution of sampling with relation to crime scenes. Only Pye (2007) goes into any detail with this regard, the other works show one or two mapped examples in each. Some published articles contain maps with the locations of sample points included, sometimes on crime scene maps themselves (McKinley & Ruffell (2007); Fitzpatrick & Raven (2013)) with (however) little discussion of intra-scene variation. In consequence, the question of how many samples of soil, and from where, is critical, yet still rarely discussed in forensic geology (see above references). Sampling soil for agricultural or environmental analysis is far better described in the literature (Carter & Gregorich, 2008; Kariuki et al. 2009) begging the question as to why this has not been tackled in the forensic arena. Recommended good practice (Murray, 2004; 2011) in forensic geology suggests the examiner compares the questioned sample (or descriptions thereof) with the scene and alibi locations. In other words, the forensic geologist can visit the scene to look for soil or sediment that may bear comparison to that from a suspect, excluding those that do not. This decreases the

number of samples collected at the scene and alibi locations, but cannot be done effectively when (a) the questioned sample is dry and the scene is wet (or *visa versa*), or (b) the scene is otherwise incomparable (e.g. one or more location has been compromised, such as in building works, or intense rainfall/flooding).

Only Pye (2007), Murray (2011), McKinley & Ruffell (2007) and Fitzpatrick & Raven (2013) have discussed directly the spatial location of soil or sediment samples with regard to forensic geology and crimes such as murder (homicide), rape or terrorism, as opposed to soil studies (environmental, agricultural applications). The question is one of balance: if both questioned and scene/control samples are equally dry/wet, then a practically infinite number of visual comparisons can be made, because, as Murray (2011) describes, the examiner may take a description (and photographs) or the actual questioned sample (suitably wrapped/protected) to the scene and alibi locations and visually exclude possible comparators and sample those that maybe considered for further analysis. This simple, but effective method deploys the exclusionary principle highlighted in Morgan & Bull (2007) in the first two of their four 'basic precepts of forensic geoscience' (the other two being the need for independent forensic techniques and the use of exotic [*cf.* 'Unique' particles in the sense of Sugita & Marumo (2004) vs. ubiquitous particles]). If the scene is identified before any questioned items are seized, or alibi locations identified, or (as above) the questioned and scene/alibi samples are incomparable (e.g. because of different moisture content), then the question remains, how many samples to take? Murray (2011) and Pye (2007) take a pragmatic view of likely entrance and exit points to a scene or alibi location, and recommend sampling selectively. McKinley & Ruffell (2007) consider whether taking more than just one or a few samples (they took over 100) actually improves our understanding of whether exclusion or comparison of a questioned sample and a potential scene is really justified. Their work relied on obtaining numbers of unique particles, but did not cover what happens when the soil/sediment at the scene appears homogenous (*viz* Morgan & Bull's fourth precept [above], the absence of the unusual or the ubiquitous). Is it necessary to take a large number of samples (McKinley & Ruffell, 2007) or to selectively sample at what appears to be logical places (entry/exit points, places someone may alight from a vehicle [Pye, 2007])? This work aims to test these

questions. It is hoped the results will be of interest or even significance to crime scene management as taking a few as opposed to over one hundred will have repercussions for understanding both intra-scene variability and also how the scene samples compare to other controls.

Case description

In early February 2008, a report was made to police officers of an altercation between four acquaintances that had led to a person exiting from a vehicle on a forest track off a main road in a forested upland location on the border between N.Ireland (UK) and the Republic of Ireland. Police inspected the area (hereon, the body deposition site, or BDS) and found a cadaver (the Injured Party, or IP). The three acquaintances were arrested and gave similar accounts of what had happened, admitting that they had told the IP they were sorry for the argument and would give him a lift home in their vehicle. They stated that instead they took him to (what would become) the BDS, where the suspect who said he sat in the front passenger seat of the vehicle admitted getting out, with the IP, hitting him on the face and getting back in the car. The second suspect claimed to have been driving the car (he was the legal owner) and denied leaving the vehicle. The third suspect was a minor (under 18 in UK law), who stated he stayed sat in the rear of the car. We now present a description of the evidence from the scene, the suspects and their alibi locations.

Sample Locations: Vehicle, Scene and Controls (alibi locations)

The exterior of the vehicle was free of any significant adhered or lodged soil or sediment (Fig. 1a). It appeared to have been cleaned thoroughly. The brake, clutch (shift) and accelerator pedals were all of the type with an indented grip on them, with an orange sand (dry) noticed embedded in many areas of the indents (Fig. 1a,b). The rest of the interior of the vehicle was full of waste materials, mainly comprising food wrappings and alcoholic drink containers, empty glue cans and prescription drug packets. In spite of the debris in the vehicle, a blue plastic bag was noticed in the front foot well of the passenger's seat. On removal, this bag had caught in its folds, damp orange sand (Fig. 1c,d). The footwear of the suspects and IP and other vehicles known to be used by the suspects were also sampled, and

form part of the overall criminal investigation, but are not further considered here. The BDS was in an area of vegetated peat (rushes, grass, no exposed soil) ground, 4m from the sand-covered track used by forestry vehicles. Areas of unconsolidated ground/likely contact points between footwear and vehicles at the suspect's homes and workplaces (potential alibi locations), as well as those of the IP were examined: no sand-rich ground could be observed but unconsolidated material of a variety of types (asphalt, assorted urban debris, soil) was sampled to see if any particles were observed from the vehicle that may not have originated at the scene.

Methods

GIS Analysis

Available digital polygon vector data to undertake a GIS desk-based analysis included geology and soil data and were provided by the Geological Survey Northern Ireland (GSNI). GIS analysis showed that there were two locations which fulfilled the criteria of the police investigation (prior to the sampling discussed here) namely tracks accessible from the only transport route over the upland area that included the BDS. Tracks comprising unconsolidated ground ('unmetalled' or with no asphalt/tarmac or concrete) were considered due to police intelligence from questioning the suspects. One of these locations was confirmed as the BDS (Location 2, Fig 2). The two locations are found to be on different bedrock geology (GSNI, 2006). Location 1 is on the Barony Glen Formation composed of sandstone conglomerates, while Location 2, the BDS, is on the Dart Formation composed of psammite and semipelite (Fig. 2a). Drift deposits also were different at each location. The BDS (Location 1) is on peat whereas Location 2 is on alluvium overlaying glacial sands and gravels (Fig. 2b). Location 2 was used to collect control (or alibi) samples. Local information from the forestry service who maintain the area, stated that sand was brought in from a quarry/sandpit. The GSNI database helped us establish the likely quarry source as some 20km from the area. Thus the sand used to create the track surface on the peat area of Location 1 should be different from the naturally derived alluvium and glacial sands and gravels in the area, specifically at Location 2.

Sample collection

In the suspect vehicle, new Ziploc bags were placed over each pedal and by inserting a pristine toothbrush; the sand was removed to the bag directly. The plastic bag was placed in a large Ziploc bag, photographed, the sand removed, split (cone splitter) and one half dried, the other stored for later examination, as were samples from the vehicle pedals. At the scene (Fig. 3a), the area of the BDS, access, and track were examined for loose material (geologically transferable material) in the sense that it could transfer from ground to a person or vehicle. The sand on the track way was considered the most promising material, not excluding particles invisible to the naked eye. How to sample such a scene becomes critical at this point in an investigation, as the scene and BDS were damp, yet the seized samples from the vehicle pedals were dry. In the introduction, we describe the approach of Pye (2007) who uses a common-sense approach and targets areas of transferable material (flowerbeds, loose ground) and areas of access (gateways, alleyways, gaps in hedges). We also referred to the grid-based approach (McKinley & Ruffell, 2007) where sampling of a crime scene was conducted for a full geostatistical analysis (not undertaken in this study). At the scene, we collected eight (8) sediment samples at the access point to where the body lay, from the sand track - as the BDS itself had no loose soil or sediment (geologically transferable material) available, being covered by thick grass, moss and rushes. Samples from the sand track were included in an elongated grid of seventy-seven (77) samples the limits of the area, defined as the end of the track and junction with the road in order to test the variability (as in McKinley & Ruffell 2007) of the sediment (Fig. 3b). Some visual variation was noted in the track, with areas of finer-grained orange fine sand and others with coarser grained orange sand. Nonetheless, the extent of the track where vehicles could move was included in the sampling scheme and measured: samples were taken at every metre along two sides of the track (to attempt to replicate areas where vehicle tyres may move or passengers alight). The area leading from the track to the BDS was also sampled at a 1-metre spacing, to remain consistent with the track, as limited visual lateral variation was also noted here. Unlike the area around the body, the vehicle track and entrance to the BDS comprised sand that was loose, allowing individual plastic spoons to be used for each sample, and a regular amount and depth (0.5cm) of sample to be collected

at each location. All samples were dried and split by cone-splitting and one half dried for examination, with the split stored for later use if need be. The division or homogenization of samples can cause problems. Division of a sample could be perceived by a jury to be unrepresentative as it has been divided and thus each separate section may contain different results, or an important piece of information may be contained within one sample but the result missed because it has been sent for an inappropriate analysis technique which resulted in its loss or it not being detected. It is important to consider these issues when deciding which analysis technique to select. Splitting a sample allows an original to be left for further analysis and repeatability of results if questioned at a later date. A total of 40 control, or alibi samples were collected, also using separate plastic spoons for each location, where access points and loose ground were selectively sampled.

Analysis

The dried scene and BDS samples (placed back in Ziploc bags) were laid out both randomly and in the same order and relationship as they were collected in the field (Fig. 3c). The questioned samples (vehicle pedals, dried plastic bag sand, plus control samples [not reported on here]) were then visually compared to the scene samples, as recommended in Murray (2004, 2011). When examined for comparison, questioned samples (those of unknown origin, e.g. from a suspect) must have a similar moisture content to the scene and control samples, whose origin is known. This allows some confidence (ahead of further, possibly more sophisticated analysis than just visual examination) in excluding those samples with no comparison. A subjective level of confidence in terms of exclusivity/comparability was assigned, purely to simplify our test. The degree of exclusivity/comparability was based on colour (Munsell Soil Colour Chart) and visible grain size (texture). We applied an arbitrary weighting scale of 1 to 5, with 1 showing no or limited visual comparison and 5 showing high levels of visual comparison. A different weighting could be used: this is simply an experiment in variation. This weighting was marked on the field map of sample locations (Fig. 4). A spline interpolation technique (taking into account 12 neighbouring points and using thin plate spline interpolation) as described in McKinley & Ruffell (2007), was used to show the distribution of levels of

comparison in the form of an elementary contoured surface (Fig. 5). Full details of the spline technique are described in Hutchinson & Gessler (1994): in summary this allows mathematical predictions where there are no sample values, by using the spatial dependence of neighbouring values, as opposed to those further apart, as in all interpolation. The Thin Plate Spline interpolator in ARCGIS allows the analyst to select a tension value from geostatistical cross-validation which detects any unbiased directionality (the 'tension') in the data. The method is only operator-dependent in the choice of tension that is selected. The combination of producing a numerical scale and contoured surface would not normally be presented in court in such a manner, as this work is experimental.

Discussion

Our preliminary visual assignment of comparability/exclusivity between samples at the scene and those from the vehicle was used to create a simple map of comparability (Fig 5), effectively replicating in the laboratory what (in ideal circumstances) Murray (2004; 2011) would advocate in the field. This map shows weighted relative comparisons between the area of the track closest to the BDS and samples from the interior of the vehicle, including all samples from the foot pedals. This appears to be obvious, but without the other samples from along the track, this statement could not be made, nor tested by the observations/further tests of another examiner. If questioned items are available: if both scene of crime and alibi locations can be visited and most critically, if samples can be directly compared (i.e. they are all equally dry), then the methodology of Murray (2011) can be employed. This relies on the skill of the examiner to distinguish colour, grain size, texture and to observe unusual particles, plus the experience and training of the forensic geologist to visually exclude incomparable samples in the field, leaving only those that may compare for further exclusionary-based analysis. This successive method is the most powerful, as a virtually unlimited number of field comparisons may be made as the examiner works across a scene or alibi location, and leaves the fewest but representative samples for analysis. This methodology only works where both questioned items and scene have been identified, and all samples are comparable. In the authors' experience, this may

not happen – commonly a scene is identified (e.g. a BDS), but suspects have yet to be apprehended and thus no questioned items (or their descriptions) can be taken to the field for exclusionary comparison. Equally common is the scenario described in this case, where the critical samples (from the vehicle foot pedals) were dry, yet the BDS and surrounding scene wet/damp. This does not necessarily preclude comparison, as long as the examiner is aware of the limitations soil moisture contents impose (Bergslien, 2012). In cases where questioned items are not available, or cannot be compared to the scene and alibi locations (e.g. due to different soil moisture content), some informed judgement on sampling strategy must be employed. In our introduction, we outline the methods of Pye (2007, p.199), who uses common sense observations like the location of access points and loose (transferable) ground, to take a rough grid or line of samples, as opposed to McKinley & Ruffell (2007) who collected a grid of over 110 samples for geostatistical modelling.

This study shows that in the location studied, both the approaches of a) a selective sampling strategy based on some informed judgement and b) a grid or line sampling strategy to access intra-scene variation have useful outcomes. Samples from the most direct access point between the BDS and track did show the greatest subjective visual similarity (more similar than those further away) to samples from the vehicle foot pedals and from the plastic bag (front passenger foot well), vindicating the approach outlined by Pye (2007), as no alibi locations could be identified that had sand at the location. However, the above statement could not have been made without collecting the other samples from the scene (effectively controls to the road access point), and those from alibi locations. Where does this leave us regarding advice for the examiner? In the absence of being able to directly compare questioned items with the scene, we recommend a balanced approach, targeting the focus of the scene (i.e. around a body, around an accident or illegal items discovery) and moving out along likely access routes (as in Pye 2007). Thereafter, there is no limit to the number of samples that can be collected, and the greater the number, the better understanding of intra-scene variation is built up, any variation is better observed and if a geostatistical analysis (as in McKinley & Ruffell 2007 but not here) is to be applied, the greater the number of samples, the better. As this scene (and the control locations) comprised loose material with

no micro-stratigraphy, sample collection was straightforward, taking about one hour more than would have been taken with fewer samples.

Conclusions

Every case and scene are different, therefore with regards to collecting samples an examiner must assess each scene with regards to spatial variability. If the scene is very variable then the number of samples collected will have to reflect this nature. If the scene is homogenous, differentiation of where the suspect was, becomes more difficult. In the case reported on here, the number of samples that showed a diminishing comparability to the questioned items, as we moved away from the BDS, gave weight to the argument that it was at the BDS the driver contacted the ground (which he denied), as opposed to a few metres along the track. None of the control samples (suspect homes, workplaces etc.) showed any comparison to the scene or vehicle, excluding them from the examinations. Likewise none of the suspects footwear showed any comparison to the scene or vehicle, with some comparability to controls from their home locations. Both suspects were convicted of involuntary manslaughter.

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Figure captions

Fig. 1. The interior of the suspect's vehicle: a) Driver side front car tyre; b) brake pedal; c) front passenger foot well and d) the wet orange sand on blue bag found in the front passenger foot well as described in text.

Fig. 2. GIS desk-based study showing a) bedrock geology and b) drift geology. Data provided by Geological Survey Northern Ireland (GSNI). The locations

indicated by GIS analysis are shown: Location 1 (used for control (alibi) sample) and Location 2 body deposition site (BDS).

Fig. 3.. a) Aerial view of the scene and BDS; b) Close up of BDS with sample locations marked and (Insert) a field sheet of sample locations taken on the day; c) Dried samples (re-bagged) and laid out in the rough order and location they were collected, to facilitate visual comparison with questioned samples, as discussed in the text. It was from this visual analysis that our preliminary assignment of similar to dissimilar was made, purely for the purposes of this experiment (as opposed to the courts).

Fig. 4. The original sample locations, now coded (orange/red is similar, green/cream is dissimilar, 1-5 scale) by the laboratory (visual) analysis displayed in Fig. 3c. The weighting scale of 1 to 5 is discussed in the text, with 1 (coded green/cream) showing no or limited visual comparison and 5 (coded orange/red) showing high levels of visual comparison.

Fig. 5. Interpolated map produced using a spline technique (thin plate spline with tension) of the weighted classification shown in Figs. 3c and 4 with field sheet.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5