Applications of forensic sedimentology

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Sedimentology and Stratigraphy

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Abstract

Forensic sedimentology is a relatively recently realized field, although the idea of it has been passed around in fiction and unrecognized practice for over a hundred years. The sedimentological methods used to solve cases have evolved as the field has developed, beginning with simple identification of minerals and progressing to the examination of individual grains using highly advanced scanning electron microscopes. More simple methods, such as color analysis, are still used today, but in addition, forensic sedimentologists look at surface textures and grain size distribution. Sedimentologists work on cases ranging anywhere from violation of environmental or ecological law to murder, theft, or kidnapping. More famous cases even involve the prevention of casualties during war. Cases like these demonstrate that each case a forensic sedimentologist works directly affects the lives of those involved.

Introduction

Forensics, or the application of science to the investigation of a crime (Ruffell and McKinley, 2005), has long been at the forefront of both legal investigation and the advancement of scientific techniques and methods. Since every new case presents a new challenge, a new puzzle, each requires a new perspective on the evidence presented. Many times, people do not think to include geology in the realm of forensics, as a commonly held idea is that geology deals strictly with rocks. Geology is the study of all Earth materials, however, including rocks, water, sediment, and many aspects of life; as Dr. Mark Wilson once said, “Life is a geological process” (pers. comm., 2017). As such, geology plays a pivotal role in any forensic investigation that involves the environment and even a few that do not. Sedimentology in particular can form connections between people, objects, and places, and consequently establish facts and likelihoods about those connections.

History: Sedimentary, My Dear Watson

Geoforensics has a long and well-established history of solving otherwise unsolvable cases in many times a rather unconventional way. From being written about in Sir Arthur Conan Doyle's Sherlock Holmes novels to being practiced on a regular basis by crime-fighting organizations worldwide, sedimentology has grown as geoforensics has matured. Moreover, as the field has progressed and gained recognition, it has become a leader in scientific criminology.

The earliest known idea of forensic geology likely came from the mind of Sir Arthur Conan Doyle. In his first novel, 'A Study in Scarlet' (1887), he says that Holmes is able to tell what part of London a person has been walking through based on the color and consistency of sediment on their clothes. Conan Doyle expanded upon this idea in other novels and short stories, such as in 'The Adventure of the Three Students' (1904) and 'The Adventure of the Devil's Foot' (1910). Hans Gross also helped to pioneer the field in his 'Handbuch fur Untersuchungsrichter' ('Handbook for Examining Magistrates', 1893). This somewhat more practical writing included theoretical ways that geology could be used to solve crimes as well as other forensic techniques such as ballistics (Ruffell and McKinley, 2005). The first documented use of geology for the cracking of a real case was in 1904 (Ruffell and McKinley, 2005). Georg Popp, a German laboratory owner, was asked to assist in solving the murder of Eva Disch, a woman who was strangled with her scarf. Popp matched materials, most notably the mineral amphibole, from a handkerchief found on the scene to materials under the suspect's fingernails, and soil from the suspect's trousers to soil at the scene of the crime (Ruffell and McKinley, 2005; Morgan and Bull, 2007a). Word of this new way to solve crime spread and soon, instead of being used solely by individuals, geoforensics became a popular method amongst established institutions.

Early in the 20th century, governments and educational establishments realized the potential of forensic study and started to take advantage of it. They set up specialized forensic laboratories and trained scientists to use their specialties to fight crime (Ruffell and McKinley, 2005). Universities developed programs for the study of forensic science and national organizations such as the FBI began to regularly use forensics to solve cases. The world soon realized the importance of using sediment as evidence, and even today, they are used to establish connections between people, places, and objects.

Methods

Sedimentologists are trained to be able to look at a rock or sediment sample and tell very quickly the likely environment it was deposited in, a very useful skill when it comes to determining sediment origin with a limited sample size and a time limit. They can use a variety of different methods to examine a sediment sample based upon what information they hope to gain from it. For example, in one case, a forensic sedimentologist may want to determine the origin of a sediment sample, while in another they may want to compare two samples to determine if they did or did not derive from the same source.

Most often, the goal of a forensic sedimentologist is exclusionary, or to rule out a possibility by determining that two or more samples could not have derived from the same source. This is arguably a forensic sedimentologist's main role, as it is likely not possible to verify absolutely that two samples match because many factors can affect how well the samples match, leading to a higher probability for a false-positive result (Bull and Morgan, 2006; Morgan and Bull, 2007a; Morgan and Bull, 2007b). Only in rare cases is it feasible to tell with a significant degree of certainty that two samples match. These cases include samples that physically match, like two halves if a broken rock or a characteristic shoe impression, or mineralogical matches, for instance, several very rare particles found commonly in two samples (Pye and Croft, 2004). The possibility for a false-negative is always there as well, but the likelihood of it is significantly reduced. If a sample cannot be excluded from matching another, the next step is to determine the degree of similarity between the samples and the significance of that similarity to the case (Pye and Croft, 2004).

Mineralogy and Surface Textures

Oftentimes, forensic sedimentologists look for exotic minerals to characterize a sediment sample, but the problem with this lies in the often limited amount of sample sediment and the innate tendency of those minerals to be rare (Bull and Morgan, 2006). For instance, if a boot is found at the scene of the crime with a bit of soil stuck to the bottom, the bit of soil found is all the sedimentologist has to work with. Sometimes this small amount is enough to contain a defining, rare mineral, but more often the sample is too small to capture the full scope of origin minerals or the source itself simply doesn't contain any. The collection of minerals in a sample alone, however, can also identify or exclude a certain origin or pathway of transport. For instance, the presence of feldspar in a sample indicates that it was not subjected to water transport, as feldspar is particularly susceptible to hydrolysis. Color analysis is often used in concert with mineralogy, however many times, sediments of different origin rocks can have the same assemblage of minerals and color scheme, so other qualities must be considered in addition to these.

Bull and Morgan (2006) suggest that the careful examination of the more ubiquitous mineral quartz may help to further differentiate and characterize a sediment. These grains can be examined using advanced microscopes and categorized based on their surface textures. Quartz is used because of its notable resistance to both physical and chemical weathering and its prevalence around the world. Surface textures on such a stable mineral can tell the story of a grain’s journey over the course of the past few days, or they can show the history of the grain from millions of years ago. The many paths of erosion a grain can take leave telltale traces on the surface of the grain, allowing the story of the grain to be told.

Mechanical Features	Chemical Features	Morphological Features
Complete grain breakage	Oriented etch pits	Rounded
Upturned plates	Anastomosis	Subrounded
Hertzian fractures	Dulled surface	Subangular
Blocky edge abrasion	Solution pits	Angular
Platey edge abrasion	Solution crevasses	Low relief
Breakage blocks	Surface scaling	Medium relief
Conchoidal fractures	Carapace	High relief
Stepping	Amorphous precipitation	Elongate grains
Grinding features	Euhedral overgrowths	Irregular shape grains
Adhering particles	Diagenetic smoothing	Polycrystalline form
Fracture plates	Chattermarks	Microcrystalline form
Meandering ridges	Edge rounding	
Mechanical scratches	Silica gel globules	
V pits (indentors)	Biological etching	
Star fractures		
Dish-shaped concavities		

Table 1. Surface textures used to classify a quartz grain. Classifications are made based on transport mechanisms and specific surface features. Bull and Morgan (2006) recognize 23 different grain types based on surface texture (Bull and Morgan, 2006, table 1).

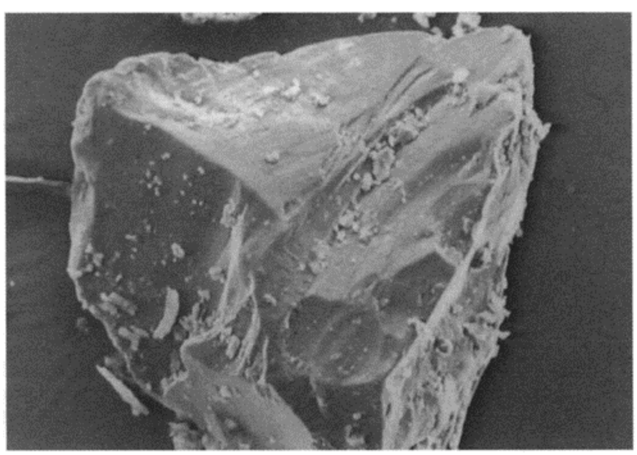

Figure 1. An image of a quartz grain showing blocky breakage taken using an SEM (Bull and Morgan, 2006, fig. 3).

When sedimentological evidence like this is presented to a jury, however, the raw data must be interpreted and summarized simply and succinctly. Too much detail tends to overwhelm the jury and bury the main point that needs to be made. Table 2 shows an example summary of the evidence highlighting the overall aim without providing unneeded detail, and is based on a real case (Bull and Morgan, 2006). The presence or absence of a particular grain type at each location is shown so comparisons can easily be made. Samples were taken from various sites in the vicinity of the body, from the material the body was wrapped in, and from inside the suspect's car (Bull and Morgan, 2006). Since the grain types from the body wrappings are so different from the grain types found in the vicinity of the body, it can be reasonably concluded that the material found in the wrappings could not have originated from the same source as the sediment collected from the area in which the body was found (Bull and Morgan, 2006). This method of exclusion is typically a more reliable indicator, but the similarity between the grain types found in the wrappings and inside the suspect's car can be noted, so long as it is kept in mind that this cannot conclusively establish that the two materials derived from the same source (Bull and Morgan, 2006).

Sample description	Quartz Grain Types I	II	III	IV	V	VI	VII	VIII	IX
Body Site A						X	X		
Body Site B								X	X
Body Site C				X					
Body Site D				X					
Body Site E	X			X					
Inside body wrapping A	X	X	X						
Inside body wrapping B	X	X	X						
Inside body wrapping C	X	X	X						
Inside body wrapping D	X	X	X						
Inside suspect s car A	X	X	X	X					
Inside suspect s car B	X	X	X	X					
Inside suspect s car C	X	X	X	X	X				
Inside suspect s car D	X	X	X	X	X				

Table 2. An example table showing quartz grain types found in varying locations for use in court. Body Site samples were taken from various locations around the body, with Site E being closest (Bull and Morgan, 2006, table 2).

Grain Size

Arguably the most routine test a sedimentologist performs is a grain size analysis. The distribution of grain sizes in a sediment sample can provide clues as to the origin of the sediment and transport mechanisms the sediment has undergone. Forensic sedimentologists use grain size analysis to compare or characterize sediments more often than, for instance, predicting depositional paleoenvironments, as more traditional sedimentologists may do. The technique used to measure the grain sizes depends primarily on what type of sediment is being analyzed. Sieving is most useful for sand- to gravel- sized grains, while sedimentation (pipette analysis) is effective for silt and clay (Pye and Blott, 2004). Dudley (1976) suggests using a Coulter Counter for silt and clay sizes, especially with a small sample size, which is often the case in forensics. Some laser granulometry instruments, however, are suitable for sand through clay sizes, making them the most versatile method (Pye and Blott, 2004). Results from each of these techniques are not directly comparable, however, as they measure the size of each grain based on different characteristics, for example sieve size or equivalent spherical diameter (Pye and Blott, 2004). Comparisons made between samples, however, should always be done in concert with other techniques, since grain size is heavily effected by sample size and selective transfer (Pye and Blott, 2004; Morgan and Bull, 2007b). Dudley (1976) suggests an additional assessment of color and pH of the sample, and similarly, Pye and Blott (2004) recommend using chemical and mineralogical analysis as well as knowledge of underlying geology in conjunction with grain size analysis to obtain reliable conclusions.

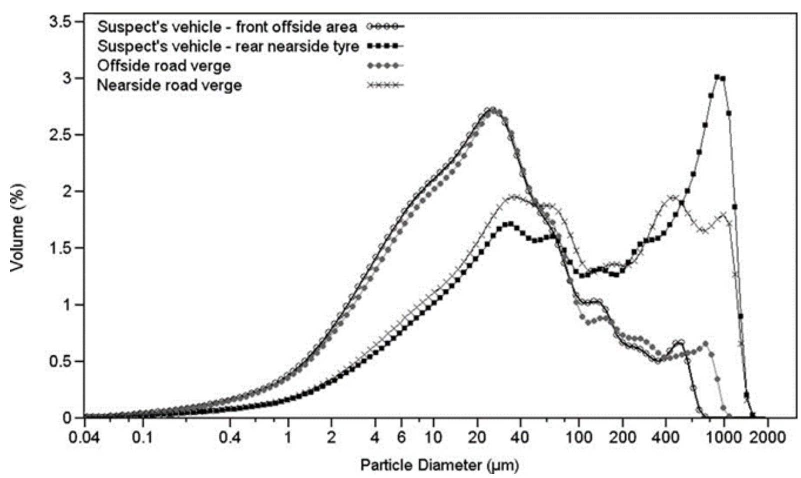

Figure 2. Example of a close match between grain size distribution plots. Samples were taken from a hit-and-run suspect's vehicle and the verge where the victims were hit (Pye and Blott, 2004, fig. 4).

Complications

Although sedimentologists have a wide variety of tools at their disposal, forensic sedimentology in particular can be tricky as no one method of analysis can universalized, in addition to the many anthropological factors that can affect a sediment's makeup and analysis.

At the root of the problem is the basic method of sample collection, which is usually done by police officers and scenes of crime officers rather than forensic geoscientists (Pye and Croft, 2004). The officers are often unaware of proper geological sampling requirements, leading to poor or tainted samples. Samples collected must be representative of the source to get an accurate analysis of the source, and moreover, samples should only be compared with like samples (Morgan and Bull, 2007a; Morgan and Bull, 2007b). For example, if the scene of the crime involves a hole, such as a grave site, samples must be taken both of the top soil and the sediment below, as soil is often differentiated with depth. Because of this, top soil samples should only be compared with other top soil samples, as comparison between a top and bottom soil sample can lead to false-negative results and unfounded conclusions (Morgan and Bull, 2007b). Additionally, it is immensely helpful to forensic geoscientists to be able to see the scene and get a sense of the geology of the surrounding area (Pye and Croft, 2004).

Figure 3. A soil profile showing clear changes in composition and color as depth increases. Many sediments do not show such an obvious change, so samples must be taken with care to fully represent the evidence and avoid mixing of layer samples.

(http://munsell.com/color-blog/soil-formation-process-archaeology/)

One of the most common problems a forensic sedimentologist encounters is a small sample size. Evidence often only has a trace amount of sediment available for analysis, greatly limiting the number and types of tests that can be performed (Dudley, 1976; Morgan and Bull, 2007a; Morgan and Bull, 2007b). Moreover, Morgan and Bull (2007a) recommend leaving at least half of the sample in its original, untested state for other scientists to reanalyze results and perform new tests, further reducing the amount of material available to analyze. Forensic sedimentologists, then, must be sure to carefully arrange beforehand the order of tests to be performed on a sample to ensure all necessary tests can be done. This can limit the types of tests able to be done, as the sediment must be able to be recovered for further analyses.

Forensic sedimentologists must also consider the effects humans have on the samples. When a sample is taken from a human possession rather than directly from the ground, such as from clothing, shoes, or car floor mats, the possibility of mixing sediments from multiple sources is ever present (Bull and Morgan, 2006; Morgan and Bull, 2007a; Morgan and Bull, 2007b). This means that a sedimentologist can hardly ever be sure that sediment taken from evidence like this is exclusive to one or two localities. On top of this, forensic sedimentologists must take into account that sediments can be selectively transferred to some materials, which can skew the representation of a sample (Morgan and Bull, 2007b). For instance, if a boot is found as evidence and mud on it is analyzed for grain size distribution, it may be found to be unusually abundant in clays and silts, but this can be explained by the tendency of finer particles to cohere more than sands. Unfortunately, there is no way to confirm if this is truly the case or if the source sediment indeed has an abnormal excess of silt and clay. This is why forensic sedimentologists most often seek to exclude one sample as having originated from the same source as another rather than attempting to match samples (Pye and Croft, 2004; Bull and Morgan, 2006; Morgan and Bull, 2007a; Morgan and Bull, 2007b).

Applications

Sedimentology can be used in a wide variety of ways to solve many different types of cases, as the versatility of geological knowledge allows it to be useful in many situations. Sedimentologists are commonly recruited to assist in environmental cases, such as illegal wetland draining, and engineering failures, such as roadway collapse, possibly caused by defective construction or improper maintenance. The more infamous cases, however, unfortunately tend to involve the harm of people in some way, for instance locating a body or tracing the tracks of a kidnapper. In such cases, forensic sedimentologists are often called upon to determine if a suspect visited the scene of the crime (Pye and Croft, 2004). Grains of sediment found on or around the scene of a crime can give clues about where the perpetrator had been before visiting the crime scene or can be compared to grains found on a suspect or their belongings to determine if the suspect visited the scene of the crime. For example, specific surface textures of aeolian grains can give an indication of the specific energy regime and environmental conditions that produced the texture, limiting the possible areas the suspect may have visited (Marshall et al., 2012). Geologists use this same technique to predict the depositional settings of ancient rocks and sediments, so the concept is not necessarily a new idea, rather a new application of a basic concept. In addition to analyzing evidence presented, geologists oftentimes help find evidence. Irregularities on the ground's surface as well as information about ground drainage can significantly aid in the search for buried objects, like bodies, to avoid more invasive, expensive, and time-consuming methods like excavation (Ruffell and McKinley, 2005).

Example Cases

The impact of forensic sedimentology is best seen through specific cases, which demonstrate the ability of sedimentology to aid in forensic investigation. The fire balloon case discussed below had international implications and aided American efforts in the Second World War. The focus of sedimentologists in this case was to trace the origin of the sediment. The second case discussed is a more routine case for forensic sedimentologists, focusing on the inevitable transfer of materials from crime scene to evidence or suspect.

Japanese Fire Balloons

During World War II, Japan developed what was, at the time, the longest ranged weapon that had ever been used, called fire balloons. They were hydrogen balloons that carried firebombs and were ballasted by sand bags, designed to travel in the winter Jet Stream from Japan across the Pacific Ocean to the United States (Sacchi and Nicosia, 2013). Hundreds of them hit their target, landing all the way from the Aleutian Islands to Wyoming, some bringing the sand bags with them. Most sand bags were lost to the Pacific to keep the balloons in the Jet Stream, but many were recovered near unexploded balloons (Sacchi and Nicosia, 2013). The same dark sand filled each bag, which, upon closer examination, revealed to contain diatoms, foraminifers, and mollusks believed to originate from the launch area (Sacchi and Nicosia, 2013). Geologists from the Military Geology Unit of the U.S. Geological Survey were tasked with analysis of the sand and location of the launch area. Based on the mineralogical and paleontological content of the sand, the geologists were able to pinpoint the origin of the sand and the fire balloons, using geological maps and articles written on Japanese microfauna (Sacchi and Nicosia, 2013).

Figure 4. A Japanese fire balloon. Many fell into the Pacific on their journey or failed to explode upon landing, but the intention was to start fires across the United States' western seaboard, forcing them to withdraw from the war (Sacchi and Nicosia, 2013).

(https://en.wikipedia.org/wiki/Fire_balloon)

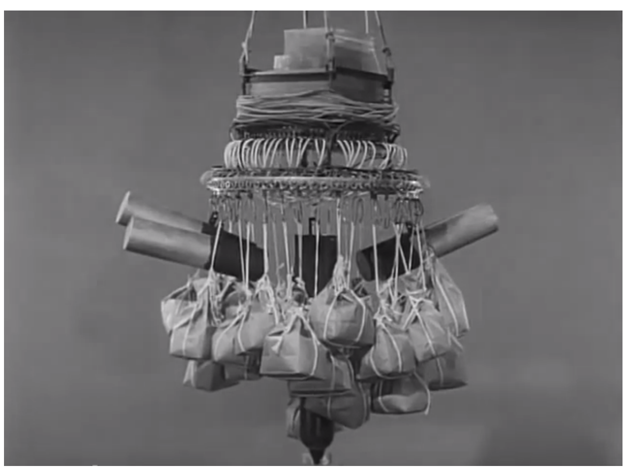

Figure 5. A close-up of the sand bags used to ballast the balloons. Sand bags would drop if the balloon was too low in the Jet Stream, and hydrogen would release if it was too high (Sacchi and Nicosia, 2013).

(http://hackaday.com/2015/04/14/retrotechtacular-using-the-jet-stream-for-aerial-warfare/)

Illegal Badger Baiting

Badger baiting is a popular illegal blood sport in the United Kingdom in which badgers are pitted against dogs, usually resulting in the death of the badger and serious injury to the dog or dogs. In some instances, a badger sett is dug up to find a badger to abuse. In a badger baiting case described by Morgan and Bull (2007b), an unearthed badger sett, which was highly disturbed, was found and investigated by officials. A bulk soil sample was collected from the sett, but likely because of the disturbance contained mixing of surface soil and soil of deeper horizons (Morgan and Bull, 2007b). Officers soon arrested a suspect on a nearby road and seized two muddy spades from the suspect's vehicle. At the lab, forensic scientists took ten sub-samples from the bulk sett sample in an attempt to compensate for the mixing of soil and took twenty samples from each spade (Morgan and Bull, 2007b). Grain size distribution analysis was performed on all samples using laser granulometry, revealing two distinct curves representing the relative depths the samples originated from, shown in figure 6 (Morgan and Bull, 2007b). Chemical and mineralogical analyses performed could not exclude the samples from having originated from the same source. A quartz grain surface texture analysis was also done; the same three main groups of surface textures were identified in all samples, including one relatively rare marker grain type (Morgan et al., 2006). The independence of these techniques provides reasonable support for the conclusion that the two spades cannot be excluded from having derived from the sett, and the similarities observed in all samples can be noted as significant (Morgan et al., 2006).

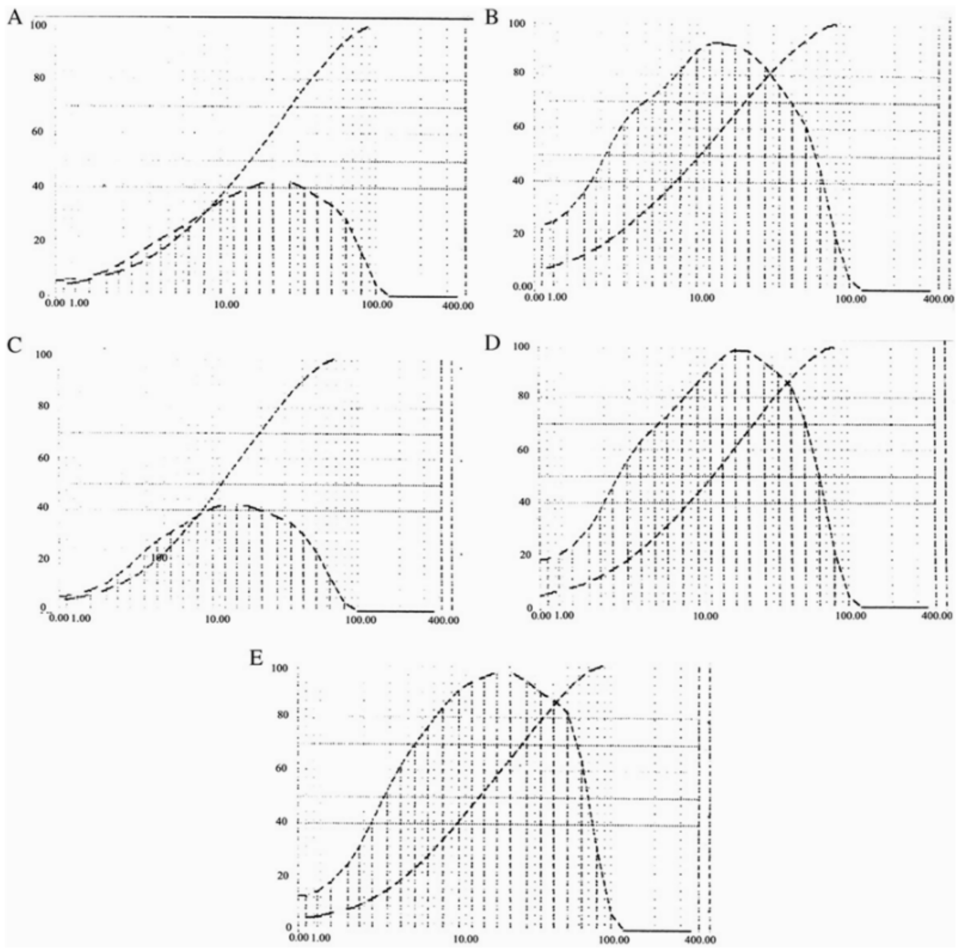

Figure 6. Grain size distribution curves of samples taken from A and B, the badger sett site; C and D, spade 2; and E, spade 1. Two distinct curves representing different soil depths can be seen (Morgan and Bull, 2007b, fig. 3).

Conclusions

Forensic sedimentology has grown slowly over time from a kernel of an idea in a novel to one of the foremost crime-fighting methods of investigation. It continues to use and revolutionize the basic ideas of sedimentology, driving innovation both within the lab and in the field. Since each case presents a new problem, creative solutions must be devised to ensure correct conclusions are reached in the case, but these solutions can be applied by sedimentologists in any field of work. One of the main differences between traditional and forensic sedimentology, however, lies in the interpretation and presentation of these conclusions. While traditional sedimentologists present their findings and theories to other informed scientists, forensic sedimentologists present their evidence to average citizens in a court of law, and so must leave no room for speculation (Morgan and Bull, 2007a). Every interpretation a forensic scientist makes must be unbiased and based in fact, as they directly affect the lives of those people involved in the case.

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