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Advanced Scientific Methods and Procedures in the Forensic Investigation of Clandestine Graves

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Abstract

Our goal is to discuss the new technologies and procedures that we have developed for the discovery and recovery of buried victims. We argue that forensic investigations of clandestine graves must be grounded in the most advanced scientific methods and evidence-collection techniques available. A structured program that includes an interdisciplinary team of forensic scientists and law enforcement experts is proposed to facilitate all aspects of the investigative and legal process. Such issues are of great relevance because most legal jurisdictions have a number of cases each year and present operating procedures are not standardized. There is a clear need for national dialog to improve our investigative efforts and insure best practices in forensic science across legal jurisdictions and law enforcement agencies.

Keywords

forensic archaeology, clandestine graves, human remains

In this article, we summarize our research efforts related to detection of clandestine graves and we propose protocols for future forensic investigative endeavors. Our discussion is based on practical experience and case studies of both new and cold case homicide investigations. The numbers are alarming. In the United States, more than 15,000 homicides occur annually (Federal Bureau of Investigation, 2010) and more

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than 100,000 active missing persons cases are pending (National Crime Information Center, 2009). As many as 25% of homicide cases are discontinued and designated cold cases because there are no leads or relevant evidence to pursue them further (Walton, 2006). The number of reported missing persons who have vanished because of a homicide is indeterminate. We know all too well that prosecutorial efforts are severely restricted when the victim's body cannot be found. Indeed, there is reason to believe that the investigations of homicides are becoming more like an arms race whereby the murderers are becoming increasingly sophisticated in their ability to hide their crimes as they become more aware of forensic techniques through exposure to popular media like CSI television programs (Geberth, 2006).

The methods of forensic archaeology, as practiced in the United States, are highly variable; some incorporate detailed scientific studies, others are cursory efforts of limited legal value. Importantly, the evidentiary record collected for any case is a product of the questions investigators pose, the evidence presumed to be present, the field methods and strategies criminalists elect to employ. It is the observational reference frame that dictates how investigators collect evidence and ultimately draw conclusions. Awareness and knowledge about the most recent advancements in forensic science are critical to insuring that justice is served.

Our goal here is to contribute to a dialog as to how we might best implement advanced methods and investigative techniques that may allow us to find clandestine graves and missing persons more efficiently and effectively. We also argue that once human remains are found, care must be given to their recovery, collecting as much evidence as possible using improved scientific methods, which are not commonly employed at present. Broadly speaking, contemporary science is becoming increasingly interdisciplinary, uniting investigators from related fields with common objectives to resolve complex problems (see Harvard University's Interdisciplinary Science Programs). Similarly, forensic teams incorporating homicide investigators, DNA experts, biologists, chemists, geophysicists, physical anthropologists, archaeologists, trace evidence professionals, crime scene experts, among others, are pooling their knowledge, expertise, and practical experience in revolutionary ways that will certainly change law enforcement and prosecutorial proceedings in the future. It is hoped that the alternative strategies proposed here will improve forensic sciences consistent with the recommendations published by the National Research Council of the National Academy of Sciences (2009) and those suggested by other national and international scientific organizations (Bohan, 2010; Brauman, 2010; Holden, 2009; Hughes, 2010).

Current Operating Procedures

Many local, state, and federal agencies have created specialized units for missing persons, cold cases, and clandestine grave investigations. By one count, there are more than 400 units of dedicated officers painstakingly attempting to uncover new clues that may solve homicide cases (Walton, 2006). Much can be learned from the collective history of law enforcement and forensic science and this accumulated knowledge can provide a valuable foundation to set standards, protocols, and decision-making factors relevant to cold case priorities, detection of clandestine graves, and recovery of human remains and related evidence.

We have noted that there is a tendency to reinvent investigative strategies for each new case involving the search for a clandestine grave. At present, most searches for clandestine graves are conducted by law enforcement personnel with the aid of a local university physical anthropologist or archaeologist employing observational methods that are often limited to only surface investigations. It is becoming increasingly clear that no one scientist possesses all of the professional skills necessary to conduct a systematic and complete clandestine grave search and excavation. A more responsive approach might be the establishment of special programs that incorporate a more robust strategy, using multiple forensic investigative methods guided by an interdisciplinary team of experts (see Connor, 2007; Dupras, Schultz, Wheeler, & Williams, 2006; Hunter & Cox, 2005).

Forensics science concerns the collection of multiple sources of evidence and is, therefore, intrinsically interdisciplinary. To generate discussion, we propose several protocols for the management of clandestine grave search activities and outline the responsibilities of each investigative team member, such as the lead detective, crime scene investigators, DNA experts, cadaver dog handlers, and various forensic scientists. We also discuss geophysical survey equipment, new advances in soil chemistry analysis, and the use of in-field trace element detection equipment as well as alternative excavation methods and evidence-collection techniques. Experience demonstrates that a well-prosecuted homicide case is built on excellent detective work, structured chain of command, well-conceived operational plans, use of forensic experts, adherence to detailed methods of evidence collection, and custody processing.

History and Common Homicide Patterns

An examination of case histories from decades of clandestine grave investigations around the United States reveals several common characteristics. First, assailants will typically bury the victim less than four feet below the ground surface and often attempt to camouflage their activities by placing trash or brush over the grave. Second, stressed assailants will take the path of least resistance by burying the body in close proximity (less than 50 feet) to their vehicle (Harrison & Donnelly, 2009). Sometimes the murderer will use existing burrow areas, drainage pipes, construction areas, or various kinds of pits under trees or near water to dispose the victim's remains (Connor, 2007; Dupras et al., 2006; Hunter & Cox, 2005). Third, weapons and evidence of ligatures, blindfolds, clothing, and other personal items are often buried with the victim (Connor, 2007; Dupras et al., 2006; Hinkes, 2006; Hunter & Cox, 2005). Fourth, murderers who employ stealth measures will sometimes use dead animals to cover their victims whereas others will use toxic chemicals.

Assailants typically dispose of victims' bodies at night in unlighted areas: parks, agricultural fields, forested areas, and deserts are common locations (Geberth, 2006).

If the victim's death is drug related, the locality of methamphetamine production or drug transaction areas can be a potential disposal area. Investigators must employ a number of methods to narrow down the potential areas for further consideration.

Typical Clandestine Grave Investigation

It is very difficult to find a clandestine grave without reliable information, either from an eye witness or from the perpetrator as part of a plea bargain (Geberth, 2006; Walton, 2006). Without this information, investigators rely on extant evidence and their sense of the perpetrator's identity. Often, there is evidence of motive, opportunity, and strong suspicion that is based on guarded information not forthcoming from a suspect. Investigators may be able to reconstruct a timeline of interactions between the suspect and the missing person and, in many cases, the suspect was the last person seen with the victim (see Geberth, 2006; Walton, 2006). Telephone records and triangulation of telephone connections consistent with the timeline may lead to potential locations. In some cases, there are witnesses who recall suspicious activities within the parameters of specific localities. In other cases, the suspect may have had access to a remote property or may have frequently gone camping or hiking in a specific rural area. These are triggers, which often prompt fieldwork in the form of pedestrian surveys, cadaver dog searches, geophysical surveys, and subsequent excavation of specified localities. The total number of investigations conducted annually by local and state law enforcement agencies is difficult to estimate, but is likely in the hundreds, if not thousands. At present, our failure rate far exceeds our success rate.

Issues and Problems

Investigations for clandestine graves often encounter problems, such as inaccurate or compromised evidence of the suspect's movement, detective misinterpretations, misguided witness testimony, and outright lies by the suspect during the plea bargaining process (Connor, 2007; Geberth, 2006; Walton, 2006). In the field, there can be false alerts by cadaver dogs, misidentification of dog alerts relative to the victim's actual burial location, geophysical anomalies due to natural factors rather than clandestine activities, misreading of soil profiles and potential burial areas by the forensic team, and the inability to accurately understand the results of the technology. Misapplication of archaeological excavation methods often lead to a confused evidential record with items found in the soil from a grave being associated with several grid numbers instead of labeling the grave soil and body (a context number). Associated items in the grave with the victim are sometimes missed and related field drawings are inadequate or uninformative. The worst-case scenario is when a clandestine grave is shoveled out haphazardly, thereby destroying the complete evidentiary context of the burial crime scene (Connor, 2007; Dupras et al., 2006; Hunter & Cox, 2005).

Anyone involved in the investigation of missing persons or cold cases has likely experienced some or all of these problems. There are times when there has been excellent detective work to determine the right location, but the fieldwork effort to locate the grave fails. Other times, resources are used to search and dig areas that are based on inadequate or poor investigative work, often due to limited time and funding.

Another potential problem well-known to the seasoned veteran is investigator bias, recently identified as a major factor and point of criticism by a panel of forensic scientists and attorneys in the National Research Council Report (2009). The problem, simply put, is that investigators and forensic scientists are vulnerable to psychological propensities to unknowingly interpret their results in a subjective manner because they want to be correct in their judgment. This happens for a variety of reasons, including desire to convict those that they believe are guilty, to support the position of coworkers, their belief that their methods are infallible, the desire to connect multiple lines of evidence, and other factors. Clear and convincing evidence can point an investigator in a specific direction with a sense of certainty. The detective is only human and wants to put a stop to other potential atrocities, especially in cases that involve children or helpless women. The dog handlers, geophysicists, forensic archaeologists, and botanists feel no less a desire to stop the murders, do the right thing, stop crime in general, and uphold justice. This sense of responsibility can sometimes lead to false results in the detection of clandestine graves. Cadaver dogs can react to the handlers desire to locate a grave and geophysicists, forensic archaeologists, geologists, and botanists may identify false anomalies. All of this is understandable.

With so many complicating factors playing a role in our investigations of clandestine grave cases, it is important that as we move forward to improve protocols and decision-making criteria to do all we can to insure accuracy, fidelity, and the highest standards of scientific conduct. The protocols below and the new methods advocated here are presented to help foster a dialog of how we can go about our investigations in a manner that improves our fact finding and fulfils our objective of seeking the unbiased truth.

Previous Research

Over the last two decades, several books have provided excellent background information for the conduct of clandestine grave searches and postdiscovery excavation methods (Connor, 2007; Dupras et al., 2006; Harrison & Donnelly, 2009; Hunter & Cox, 2005; Killam, 1990; among others). To varying degrees, the field investigation methods discussed are cadaver dogs, geophysical surveys, soil analyses, excavation methods, and entomological and botanical evidence collection. Some focus on the identification of human bone and pathological studies conducted by physical or biological anthropologists. Importantly, all of these contributions make a concerted effort to stress scientific principles and careful evidence collection.

Perusal of extant scientific literature also reveals that investigative methods are becoming increasingly specialized in forensic geology, botany, chemistry, and entomology, to name a few (Connor, 2007; Dupras et al., 2006; Harrison & Donnelly, 2009; Hunter & Cox, 2005). Recent advances in DNA research involving specialized recovery and laboratory analyses of touch DNA have produced exceptional results and it is imperative that law enforcement personnel and forensic scientists stay alert to these improvements (see, for example, DNA Initiative, n.d.).

Beyond the advanced methods, investigative personnel should also be aware of innovations in equipment, such as remote sensing tools (thermal cameras, photographic enhancements of soil profiles, high-resolution field microscopes), mapping instruments, near surface geophysical devices, portable soil chemistry equipment, and other instrumentation (Harrison & Donnelly, 2009). Fortunately, these instruments are becoming more affordable for law enforcement and there are even examples of state and federal organizations sharing tool inventories.

When called on, university anthropologists and archaeologists are often very willing to contribute their knowledge and skills to assist law enforcement. The administration of most educational institutions considers it a valued community service. Educators are typically aware of the forensic literature and have practical experience, but often do not understand the multiple levels of complexity associated with a homicide investigation. Important insights may be gained by reading Richard H. Walton's *Cold Case Homicides: Practical Investigative Techniques* (2006) and Vernon J. Geberth's *Practical Homicide Investigation: Tactics, Procedures, and Forensic Techniques* (2006). These books emphasize professional conduct, legal process, contemporary investigative methods, patterns of criminal behavior, crime scene reconstructions, and the need for impeccable evidence collection. In addition the authors communicate exceptionally well the profound duty and responsibility that professionals and those who assist them have in homicide investigations. They stress that inevitably those who are involved in homicide investigations, in whatever manner, will be affected by the tragedy of murder, but the paramount goal is to assist the families of the victims and assure that justice prevails.

Leadership, Chain of Command, and Quality Control

In this section, we propose an administrative structure that is designed to manage and direct law enforcement personnel and forensic experts more effectively. Decisions regarding chain of command, jurisdictional issues, legal requirements, and professional responsibilities must be integral to all planning and implementation tasks associated with a clandestine grave search and excavation. Organizational structure is a critical aspect for any homicide investigation and its importance here cannot be underestimated.

Lead Detective

We believe that it takes a *team* of law enforcement officers, legal experts, and forensic scientists to come together to set goals and objectives for a well run investigation. This is best accomplished under the leadership of the lead detective, who is typically the most informed team member, knowledgeable about the suspect's behavior, the circumstances of the victim's disappearance, and other factors associated with the case. In Table 1, we offer a checklist of actions or tasks to be conducted under a

Table 1. Checklist of Actions

Call comes in
Lead detective in consultation lead scientist determine need for field investigation
Lead detective organizes resources and time table and *management program*
Lead scientists and lead detective develop *search plan*
Lead detective and lead scientists organize *field investigative team*
Lead scientists, lead detective, and consulting experts develop *recovery plan*
Forensic archaeologists in consultation with others scientists conduct *recovery*
Remains and soil matrix transported to forensic laboratory for *evidence processing*
Lead detective coordinates *report* preparation and case *prosecution documents*

typical case scenario similar to the checklist produced by homicide investigators Geberth (2006) and Walton (2006). Importantly, an investigation is a matter of formal structure with well-established guidelines and dependable response efforts by all the professionals involved. The lead detective works directly with the prosecutor's office, keeps all records, manages evidence collection, keeps team members informed of events and changes in strategies with morning and afternoon meetings, interacts with the public information officer (PIO), prepares reports, and insures the safety of the investigative team. Working with the victim's family and the media are critically important activities for the PIO.

Once a victim's remains are encountered, the locality becomes a crime scene with adherence to all necessary legal requirements for that particular state. In many jurisdictions, the medical examiner or coroner is responsible for all human remains and the determination of cause of death among other concerns. Although the office of the medical examiner or coroner should be consulted in these cases and, where required, included as part of the management and investigative team, it is incumbent on law enforcement detectives, consulting with appropriate forensic specialists, to lead the homicide investigation. Table 2 lists the potential experts needed for clandestine grave searches and excavations as well as their responsibilities and task activities.

Dependent on the circumstances of the case, jurisdiction may be transferred to a federal investigative unit, such as the Federal Bureau of Investigation (FBI). The Evidence Response Teams (ERT) of the FBI have developed strategies that enable a direct line of communication within the team, integral to a successful criminal investigation and employment of excellent science. The ERT is a model program for local law enforcement.

Lead Scientist

The lead scientist works directly with the lead detective to maintain quality control, set the scientific requirements for the case, coordinate with various scientific experts, and work directly with legal experts and evidence-collection coordinators. Most scientists

Table 2. Personnel

Lead detective
Lead scientist
Forensic archaeologist
Forensic biological anthropologists
Trace evidence expert
Crime scene investigator
Dog handlers
DNA expert
Forensic geophysicists
Lead chemical soils scientist
Forensic entomologist
Forensic geologists/hydrologist

are accustomed to teamwork and easily adhere to standards and guidelines. The lead scientist must solicit input from each expert, develop realistic timelines, and coordinate each task for each scientist. The challenge is to make collective decisions that are resource cognizant and time efficient. With all the available information, the team can calculate the probabilities matrix for the likelihood of discovery of victim's remains and associated evidence for particular locations. Each case requires that flexibility be built into the formal investigative structure. Thinking outside the box often produces important results, especially when the lead detective and scientist view accumulated results and consider multiple levels of input from team members.

The lead detective and lead scientist, in collaboration with the rest of the team, will make the final decision to conduct excavations at the particular location dependent on the results generated by the forensic team. This leadership will also determine when to terminate excavations and other field activities. The lead scientist will be called to testify in legal proceedings and it behooves any agency to set protocols and guidelines that can be referenced in courtroom testimony.

Forensic Archaeologists, Physical Anthropologists, Trace Evidence Specialist, and DNA Experts

It is important for the forensic archaeologist on the case to have experience in the detection of clandestine graves, aware of the natural geomorphology of the local terrain, and experience with the application of geophysics in crime scene investigations. Their role becomes especially critical in three areas. First, they organize the pedestrian surface survey, which includes law enforcement officers, other scientists, and volunteers to cover 100% of the surface area, usually by walking parallel transects not more than five feet apart, and marking the corners of each transect unit with field tape. Before fieldwork commences, forensic archaeologists clearly identify and show the team examples of the kinds of disturbance of the natural environment that will reflect clandestine activities. They inform the team to watch for changes in surface soils (subsidence and change in soil color or texture), alterations to vegetation patterns (in consultation with the forensic botanist), suspicious accumulations of debris and trash, and other camouflage such as dead animal carcasses covering a subsurface pit (Table 3). Second, the forensic archaeologist is responsible for directing all excavation activities and insuring that appropriate records are kept, precision maps are generated, photographic records are maintained, and that all evidence is collected in an impeccable scientific manner. Last, in consultation with the safety officer and lead scientist, they must insure the safety of the excavation crew, especially regarding biological threats and potential toxic hazards.

The physical anthropologist is responsible for instructing team members how to identify human remains, in the form of fragmented bone or disarticulated body parts, and makes field identification of whether bones that are found are human or animal. They are also responsible for assisting the forensic archaeologist during (or, if they have appropriate expertise, they may direct) the excavation for human remains and they perform subsequent skeletal identification and pathology studies.

The forensic team should also include a trace evidence specialist(s) to insure that all levels of physical evidence are considered in the investigation of clandestine burials and related crime scene environments. Their contribution is essential for the complete collection of microlevel materials including hair, saliva, blood, and other body fluids, trace DNA, plants and pollen, paint particles, textile fibers, soil chemistry and provenance evidence, chemical ballistics, glass fragments, and latent fingerprints among other kinds of patterns or trace evidence (see Blackledge, 2007). These scientists can bring valued experience and insights to the investigation of buried victims. Importantly, they are expert in processing evidence in ways that preclude potential for contamination and errant handling of evidence. Their responsibility for processing and evaluating chemical tests and other scientific data can be critical to homicide investigations and it is therefore prudent to have these experts involved at all levels of an investigation. In many jurisdictions, these professionals will serve as lead scientists and it is essential that they be current in the newest scientific techniques and related methods of collecting crime scene evidence.

As soon as human remains are discovered, all field activities are stopped and plans are made for recovery of the victim's remains and all associated evidence. It is the responsibility of the lead detective, lead scientist and forensic experts, in consultation with legal authorities (members of prosecutor's office) to design a well-structured *recovery plan*. It is important to recognize that the soil around the victim and items in the soil, including artifacts, residual DNA, weapons fragments, items used for ligatures, and chemical signatures must be handled with the greatest degree of scientific proficiency (see below). As in any homicide case, evidence provides the basis for determining the type of homicide that can be charged and argued for in court (Connor, 2007; Geberth 2006). Indeed, the removal of the victim and collection of all associated crime scene evidence is the most critical stage of the investigation and is often the

Table 3. Search Areas and Methods Work Aid

Identify a search area	Witness accounts, confessions, police intelligence, suspicions, evidence, and logic.
Method choice depends on the following	Terrain, environment, vegetation, size of search area, soil type, hydrology, subsurface, age of suspected occurrence, manmade activity in the area, amount of surface moisture—need help from geologist, botanist, anthropologist.
Canines	L
Line searches	L
Probing/soil coring	S
Magnetometer	S
Metal detector	L
Soil resistivity	S
Visual (mounding/subsidence/debris piles, and so forth)	L
GPR	S
Thermal	L
Fluorescence	S
Resonance	S
Vegetation changes	L
Odor analysis	S
Soil chemistry	S

Freshly buried corpse (<1285 accumulated degree days [ADDs])

- Ground penetrating radar—success is dependant primarily on soil type and depth of burial. Roots, rocks and other subsurface anomalies can interfere with the reflected signal. Works best in dry, sandy soils.
- Visual examination of ground and probing—detection of mounding or subsidence (good method if familiar with what you are looking for). Not good if burial is covered with debris. Slow, not good for large areas.
- Odor analysis—use of real-time instrumentation to detect specific odors in the air associated with decomposition (looking for sulfur dioxide, carbon tetrachloride, dimethyl disulfide, toluene, benzene, dimethyl benzene (either 1,2; 1,3; or 1,4), and freons such as dichlorodifluoromethane—many others, but these are some of the key ones.
- Detection of low-energy electromagnetic fields—as bone is piezoelectric, it gives off a weak electric field (magnetic field) which can be detected. Does not work if bone is in water or wrapped in rubber.
- Thermal scans - Soils directly over freshly overturned soil can be up to 2 to 3 degrees higher than surrounding soils—also only works if the burial is shallow and only if relatively fresh.
- Metal detection—good if buried with metal objects.
- Vegetational changes—burials are acidic (surface finds are basic). This sudden pH shift can kill or alter vegetation if any is around.

(continued)

Table 3. (continued)

Older burials—Skeletonized (>1285 ADDs)

- Cadaver locating canines—very good detection, primarily ground/water searches only, can be slow going*
- Odor analysis—use of real-time instrumentation to detect specific odors in the air associated with decomposition (looking for freons, aldehydes like nonanal, decanal, and so forth)
- Detection of low energy electromagnetic fields—as bone is piezoelectric, it gives off a weak electric field (magnetic field) which can be detected. Does not work if bone is in water or wrapped in rubber.
- Metal detection—good if buried with metal objects.

Best environmental conditions for canine searches or when using real-time OC detection techniques

- Barometric pressure <30 Hg (<1016 hPa) and falling.
- Temperature >12C and rising—ideally with sunlight hitting the site and warming the soil.
- Soil type—clay is the worst, sand is very good, humic is somewhere in the middle.
- Soil moisture—quite moist, but not waterlogged, dry bone is difficult to detect.
- Air humidity—between 70% to 85%.
- Significant amounts of dew impede volatiles; it is best to search when the dew has evaporated.
- Rainfall during search makes sent detection difficult.
- Wind <15mph.

Note: L = large search area (<10 acres), S = small search area
*Regardless of environmental conditions, it is recommended that well-trained canines should always be used in the search for human remains. Special care should be given to insure the safety of the canines and their handlers, especially under the most difficult search conditions (i.e., heat, foxtails, cactus, quicksand, rattle snakes, and so forth).

point at which mistakes are made (Federal Bureau of Investigation, 2007; Geberth 2006; Walton 2006).

We recommend that DNA experts be actively engaged in all aspects of an investigation because their knowledge of evidence collection and sample processing may be vital to prosecutorial efforts. The degree of scientific reliability and legal weight of DNA evidence in the courtroom has proven to be a linchpin in many cases (Butler, 2009; National Institute of Justice, 2002). Recovery of forensic DNA has improved dramatically in recent years due to new processing techniques, collection methods, and equipment innovations. With today's technology, scientists are able to retrieve animal and plant DNA from soils that are older than 200,000 years (Willerslev, 2003) and from Neanderthal skeletons that are 70,000 years old (Green et al., 2010; For more information on improvements in scientific methods for DNA evidence and legal prosecution, see Butler, 2009; Michaelis, Flanders, & Wulff, 2008; National Research Council , 2009).

DNA evidence is considered by many legal authorities to be the *evidence of choice*, a notion that is well supported by hundreds of successful case histories (National

Research Council, 2009). The key here is *not to assume* that DNA is absent at a clandestine gravesite, but rather that it is present, and when it is found, it can be used to convict or exonerate suspects. The soils incorporating an evidentiary matrix around a victim can hold preserved DNA, not only of the victim but of the assailant as well, dependent on the age of the crime, presence of garments, soil chemistry, geohydrological environment, and other factors.

DNA retrieved from a buried victim's clothing or touch DNA retrieved from associated objects can be compared to DNA profiles of missing persons, potential suspects, and the databanks of known offenders. It is also important that the suspect's clothing be analyzed for evidence of the victim's DNA regardless of the date of the crime. Recovery of cold case or "old DNA" is the responsibility of the forensic DNA specialists working closely with other scientists and the lead detective.

Search Dogs and Handlers

It is well-known that cadaver dogs are exceptional assets in the search for human remains and clandestine burials. Dogs have scent capacity 1,000 times more sensitive than that of humans and this evolved anatomical and neurosensory capacity can be an important component in the forensic tool kit (Rebmann & Edward, 2000). Trained canines have a long history of positive recoveries due to the handler's dedication, as evidenced by the thousands of hours spent training the dogs to track and detect human decomposition. Numerous organizations and clubs throughout the United States have developed stringent training standards and certification guidelines for Human Remains (HR) dogs that are, in most cases, very difficult to pass (Oesterhelweg et al., 2008; Rebmann & Edward, 2000). The best HR dogs are working animals that have an exceptional drive to hunt and a desire to be rewarded.

Several issues to consider when employing HR dogs for an investigation are the previous experience of the K9 team, training records, certification of both handler and dog, safety issues, and the handler's ability to control the dog with a passive alert so as to not disturb the human remains and any evidence in close proximity of the victim. Blind tests are important and involve the use of several dogs, run independently, with the results for each dog kept confidential from other handlers. When multiple dogs hit on a specific locale, our confidence is increased. Weather conditions, duration of time since the victim's death, the geological and ecological conditions of the area (time of day, temperature, wind conditions, barometric pressures) and water internments, among other factors, can all influence which handlers and dogs to bring into the investigative team (K. Kolbert, personal communication, August 13, 2008; Rebmann & Edward, 2000).

Cadaver dogs can also be used to search a suspect's vehicle to detect the presence of decomposition and other bodily fluids. If dogs detect scent, there is strong reason to believe that the victim may have been transported in this vehicle. Various chemical analyses can also be employed to verify the dog alerts (see below). This kind of information can represent a critical lead in missing persons cases.

Many homicide and cold case investigators are familiar with cases where dogs have produced false alerts and it is often assumed that time and resources were wasted as a result of "dog error." It is important to recognize that there is not always a one-to-one correspondence between the dog alert location and the victim's remains, which can be offset by hundreds of feet. Decomposition fluids may have shifted due to site-specific geomorphological and hydrological factors (Figure 1). In such cases, the dogs are not errant, but rather they have detected a scent pool that has been transported from the victim's clandestine position (Rebmann & Edward, 2000). Handlers and dogs are sometimes unjustly criticized and victims have been missed. Reconstructing transport factors and determining the likely location of the victim's remains must be calculated by the forensic scientists who are experts in both geological and hydrological theory and practice (see Harrison & Donnelly, 2009).

Forensic Investigation and Geophysics

Once HR dogs have detected a scent pool, the use of geophysical equipment can be productively employed to identify disturbed soils, graves, metal objects, voids, and rock concentrations, among other features. The most common geophysical methods used in forensic investigations are ground penetrating radar (GPR), magnetometry and electrical resistivity (Cheetham, 2005). Other less common methods include thermal imaging, electromagnetic (EM) induction, gravity and, in some cases, seismic. Highly sensitive metal detectors have been used with positive results especially when looking for bullets, casings, or buried weapons (Rezos, Schultz, Murdock, & Smith, 2010). The scientific literature on geophysical methods in forensic archaeology contains differing opinions about the appropriateness of alternative strategies.

We believe that there are four principles that should guide an investigative team when using geophysics in forensic archaeology. First, for an accurate and effective investigative program, it is essential to have collaboration among law enforcement officials, forensic archaeologists, geophysicists, and geologists during the planning, implementation, and interpretive phases. This is particularly important in data processing and visual exploration of postprocess geophysical images. Second, it is wise to apply multiple geophysical methods so that the particular strengths of each technique are incorporated into the search program. Integrated surveys using magnetometers, ground penetrating radar, resistivity, and thermal camera imaging are especially apt in this regard (Larson & Ambos, 1997). Regardless of the method employed, the survey transects should be no more than 50 cm apart. A person can think of each geophysical measurement as representing one pixel on a computer screen—the larger the number of pixels, the greater the resolution of the subsurface features. Third, the geophysical record can be a by-product of past human behavior and is, in effect, an artifact or evidence that can tell us a great deal about a crime scene (e.g., method of burial, potential presence of weapons, placement of multiple victims, and possible exhumation and reburial elsewhere). Fourth, every effort should be made to employ the newest

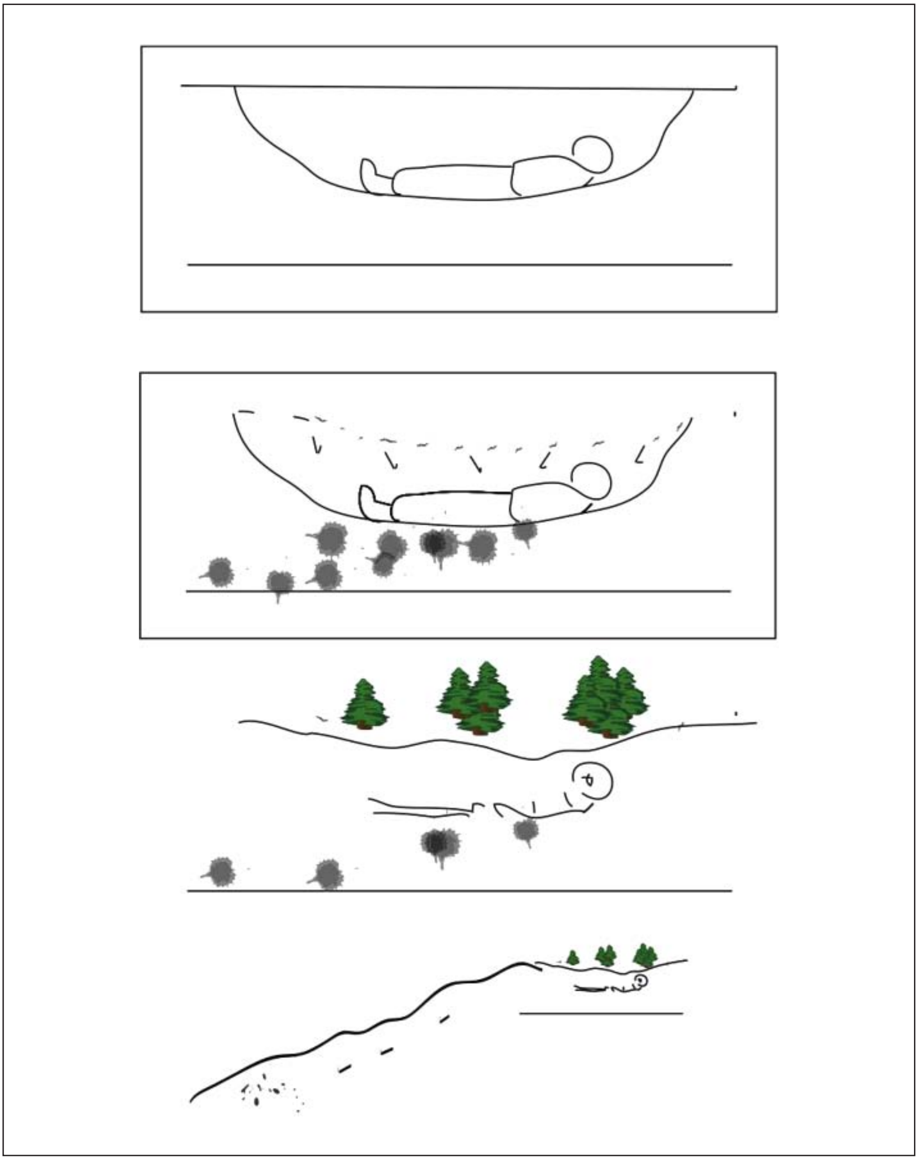

Figure 1. Transport of human decomposition over time and space

cutting-edge technology in forensic geophysics including both advanced equipment and data processing software.

Table 4 lists the equipment alternatives, investigative targets, and advantages and disadvantages of each method. Below, we briefly discuss ground penetrating radar

Table 4. Geophysics and Forensic Investigations

Methods	Application	Measurements	Physical properties	Interpretation	Limitations
GPR	Relies on the properties of transmission and reflection of electromagnetic (EM) wave energy. EM waves centered in the 100 and 500 MHz frequency range are transmitted into the ground from a broadband antenna source in direct contact with the ground's surface.	Distance, time, and amplitudes. EM waves reflect up to the surface antenna when they encounter marked changes in subsurface soils. Graves are detected as anomalies on the instrument screen in real time.	Dielectric, permittivity, electric resistivity, and magnetic susceptibility.	EM wave speed on the screen of the instrument is of great value in the field. Rapidly produced 3D images of subsurface geological structure can be completed using advanced computer software.	Equipment is expensive and there are limited number of experts who conducted GPR studies in a forensic and archaeological context. Natural anomalies are often interpreted as potential graves.
Magnetics	Magnetic survey instruments measures the contrast between very subtle magnetic values of the surrounding natural subsoils in contrast to human-induced magnetic structures produced by metals, burnt soils, and disturbed topsoil.	The cesium vapor magnetometer achieves precision of 0.05 nT (nanoteslas or gammas), which is highly desirable in forensic geophysical surveys. The anomalies in the earth's magnetic field that evidence forensic features are often subtle, with amplitudes on the order of 5 to 10 nT, or approximately 0.01% of the earth's field.	Magnetic properties.	Magnetic data can be interpreted in the field in real time from the instrument screen or as produced by postcollection computer processing. Excellent for detection of metal objects or disturbance of uniform topsoil.	If the area contains trash from historic or modern activities, the forensic evidence becomes compromised. If there are power lines and passing vehicles significant noise is produced, which limited the use of this technique.

(continued)

Table 4. (continued)

Methods	Application	Measurements	Physical properties	Interpretation	Limitations
Resistivity	Detects natural or induced electrical current in subsurface soils. Instrument arrays designed to measure electrical resistivity typically include a power source and two probes that emit an electrical current into the conductive soil, which can be measured precisely. Voltage is measured by two additional probes and the ratio of voltage to current gives resistance	Electrical resistivity instruments are particularly good at measuring the soil's organic content, cation exchange capacity, bulk-density, pore space, moisture rates, and structure/texture compaction	Magnetic susceptibility and electric resistivity.	Current, voltage, distance, and amplitude. Rapidly produced 3D images of subsurface geological structure can be completed using advanced computer software.	Historic and contemporary debris can cause significant noise, which can preclude the use of this instrumentation. Areas subject to surface disturbances like plowing, grading, and paving are serious problems.
Integrated methods	All of the above	All of the above	All of the above	Integrative methods offer the investigative team the best alternative since all the geophysical data can be aggregated and evaluated.	Time consuming and difficult to operationalize the diverse experts. Can be overcome with the pooling of state experts and ERT-like teams.

(GPR), magnetic survey and electrical resistivity; for other methods we refer the reader to *Near Surface Geophysics* by Dwain K. Butler (2005).

GPR

The GPR method relies on the properties of transmission and reflection of EM wave energy (see Larson & Ambos, 1997 for a more detailed explanation). EM waves centered in the 100 and 500 MHz frequency range are transmitted into the ground from a broadband antenna source in direct contact with the ground's surface. These EM waves reflect up to the surface antenna when they encounter marked changes in subsurface soils. For example, the water table often generates a significant reflection, as does a change from compacted soil to loose soil, or from soil to rock walls, or hard pack to excavated pits or voids. The operator looks for irregular patterns that stand out from the natural geomorphological structures of the earth's subsurface. Previous work has demonstrated the effectiveness of GPR in imaging burials, weapons, and voids or holes below floors or the earth's surface (Ambos & Larson, 2002; Cheetham, 2005; Conyers & Goodman, 1997; Goodman, 2009; Larson, Lipo, & Ambos, 2003). Although one drawback of the GPR method in other applications is that most of the signal strength is dissipated relatively close to the ground surface, restricting the penetration to about 2 meters, this limitation does not typically affect forensic investigations because victims are most often found within the top 1 meter of the surface.

The GPR screen provides real-time imaging which can be tremulously useful for forensic investigations. Subsurface features generate most GPR reflections and the source of the anomaly is usually positioned immediately below the source antenna. As the GPR operator walks the source–receiver antenna along each north–south survey line, a continuous profile section is generated, information is collected in a data logger, and profile lines are immediately transmitted to a computer system. The continuous GPR cross-sections often give the appearance of hyperbolic reflection from a point source such as a recent burial (Ambos & Larson 2002; Conyers & Goodman 1997; Goodman, 2009; Larson & Ambos 1997). Although GPR profile data are sometimes directly interpretable from visual inspection in the field, in most instances, the data must be computer processed using three-dimensional imaging software to reveal subsurface forensic features.

Magnetometry

The goal of magnetic survey in forensic prospection is to measure the contrast between magnetic values of the surrounding natural subsoils relative to the magnetic properties of features associated with human activities. In our archaeological work, we have employed the EG + G Geometrics 858 cesium vapor magnetometer (CVM) and gradiometer (CVG) to detect recently disturbed soils, pits, graves, metal objects, and burnt areas (thermoremanent magnetization). The G-858 system includes an electronic console and a hand-held counterbalance staff with mounted sensors. The console emanates audible tones to indicate magnetic field changes and to assist the operator's pace, collects the field data, and displays the magnetic data, position, and information mapped during field operations on a LCD screen. Data are stored in a nonvolatile RAM (250,000 compressed magnetic readings and associated positions and times) for playback and editing in the field.

The cesium vapor magnetometer was engineered to achieve precision of 0.05 nT (nanoteslas or gammas), which is highly desirable in forensic geophysical surveys. The anomalies in the earth's magnetic field that evidence forensic features are often subtle, with amplitudes on the order of 5 to 10 nT, or approximately 0.01% of the earth's field (Breiner, 1973). Our previous research reveals that gradiometer values for forensic and archaeological features typically range from −25nT to +25nT. This instrument is also particularly useful for the search and discovery of buried weapons, ammunition, bomb-making materials, and hidden containers. Measurement speed of the cesium magnetometer (10 measurements every second) and other factors, such as quicker equipment set up, data logging, and reduced number of crew, allow for both a significantly greater number of magnetic measurements (more than 16,000 measurements per 20 m × 20 m unit with transect intervals of 50 cm) and greater aerial coverage per field day (Larson & Ambos, 1997).

The gradiometer system predominantly employed for forensic survey entails the use of two sensors in vertical and horizontal modes. There are significant advantages in measuring the vertical magnetic gradient, particularly when mapping shallow targets (Hansen, Racic, & Grauch, 2005), in that it displays improved resolution of multiple targets and separates the nearby from more distant objects. Controlled experiments conducted by Geometrics, Inc. found that, by using this mode, especially when combined with 3D postprocessing software, many small surface anomalies (e.g., burials, weapons, bullets, shell casings, and so forth) become more evident.

Electrical Resistivity

Electrical resistivity is becoming a tool of choice when the goal is to detect recent subsurface disturbance. Whenever human activities affect surface soils, the dirt's electrical properties are significantly changed relative to adjacent unaltered soils. Specifically, when solid-state compaction soils, like clay sediments or hard-packed dirt, are turned over or excavated, organic material from the surface, wind-blown sands, rock and the remains of the victim are often mixed in with the redeposited soils making the electrical properties of the clandestine grave dramatically different from the surrounding natural soils (Figure 1). Electrical resistivity instruments are particularly good at measuring the soil's organic content, cation exchange capacity, bulk-density, pore space, moisture rates, and structure/texture compaction (Zonge, Wynn, & Urquhart, 2005).

Instrument arrays designed to measure electrical resistivity typically include a power source and two probes that emit an electrical current into the conductive soil, which can be measured precisely. Voltage is measured by two additional probes and the ratio of voltage to current gives resistance, as reflective of Ohm's law.[1] Thus, an electrical current is passed through the ground between electrodes and the resistivity of the subsurface soils is measured and correlated with material types. Condensed moisture or noncompacted fill in a burial pit will typically exhibit variable resistivity and is easily distinguished from the general soil matrix of the area. Again, data are collected and downloaded to a computer for postsurvey processing, using a number of software programs that can produce both two- and three-dimensional images.

Some conditions diminish the effectiveness of electrical resistivity in finding graves. Dry soils and areas that have been plowed or frequently disturbed by modern activities may result in poor conductivity. Survey measurements may be too broad in coverage or the results are of very poor resolution. Tree roots often interfere with the resistivity surveys in heavily wooded areas.

Geophysical applications are just another part of the forensic investigative toolkit and have successfully aided in the discovery of clandestine graves, buried narcotics, hidden weapons, and other evidence. It is important that geophysicists who volunteer to help law enforcement not promise more than can be delivered and it is important that law enforcement officials recognize that geophysical anomalies may be natural objects below the ground surface. Finding a grave using this technology alone is remote. The decision to excavate must be based on multiple lines of evidence and professional expertise.

Advanced Analytical Soil Technologies

Clearly, the art of finding clandestine graves is currently going through a fundamental change. Research into understanding how a canine's odor recognition system functions, being able to probe deeper and more accurately into the subsurface using a variety of modified geophysical techniques, utilization of very sensitive thermal imagery, careful chemical evaluations of nearby vegetation, and utilizing the unusual properties of bone (resonance, piezoelectricity, inorganic composition, and odor) are dramatically changing the tools available to law enforcement in being able to locate graves—regardless of the grave's age or surrounding taphonomy. The analysis of soil chemistry at a possible homicide site can be very useful and may provide the investigative team specific chemical information relative to the presence of buried human remains.

Two of the new technologies we have developed that will improve our ability to detect the presence of human remains specifically deal with understanding human decomposition. The entire decompositional process, through three processes (autolysis, putrefaction, and diagenesis), result in the liquification of soft tissue and the eventual dissolution of bone. As both soft tissue and bone are comprised of organic and inorganic components, these end up being partitioned in the soil column, are incorporated into the water table or are liberated as gases at the soil/air interface. Decomposition can take place in a buried environment, in the trunk of a vehicle, underneath a structure, or inside a building or room. Chemical trace elements are absorbed in soils, wood, carpet, and so forth and can be important evidence especially when a victim's body has been removed to another location. Regardless of the mechanism, the final disposition of these chemicals is one of dispersion and dilution from the initial site of deposition.

For many years, we have evaluated the volatile organic compounds (odors), which are liberated during the decomposition of human remains (e.g., Bull, Berstan, Vass, & Evershed, 2009; Vass, Bass, Wolt, Foss, & Ammons, 1992; Vass et al., 2008). Nearly 500 chemicals are known to be liberated during the decompositional process and these have been recorded in a decompositional odor analysis (DOA) database (Vass et. al., 2008). Additionally, a number or inorganic chemical species are also liberated which can stay elevated for decades in the area of a clandestine grave or surface decompositional event.

Based on years of collected data and the establishment of these databases, we have conducted a number of soil chemistry analyses that identify the specific trace elements or compounds that signal the presence of human decomposition. Additionally, we have developed a portable sensor system designed to be used in the field to detect trace volatile organic compounds associated with buried human remains called the LABRADOR (light-weight analyzer for buried remains and odor recognition). Both of these advances are briefly described below.

Chemical Soil Analysis

Chemical soil analyses fall into two main categories: (a) organics (volatile and nonvolatile); and (b) inorganics. Regardless of which category is applicable to a particular scene, collection of soil from the suspect area and collection of control soil off-site should be standard protocol for any outdoor crime scene. The amount of soil collected varies with each scene, but usually corresponds to a volume of between 25 and 100 ml (about a hand-full) and collected at a depth about 3 to 6 inches. Due to the rapid loss of volatile organic chemicals from soil, it is best to quickly store the samples in precleaned glass jars or vials fitted with Teflon-lined caps which are specifically made for the collection and preservation of soil samples. Metal evidence cans and food storage jars should be used only if appropriate soil collection jars or vials are not available (Vass et al., 2008).

Obvious locations for collecting soil samples for chemical analysis include those containing stains, odors, visual deposits, underneath tissue or areas of adipocere, and areas of canine alerts. Soil samples that are highly saturated with water are usually more difficult to work with and may require additional sample preservation to prevent loss of analytes. Realizing that surface decompositional events are highly alkaline and burials are acidic can also be useful to investigators for helping to identify soil samples for collection. In this case, pH paper can be used to determine whether a soil is more acidic or basic relative to a control soil sample of similar composition.

Organic chemicals. Some of the most reproducible organic chemicals associated with decomposition are compounds called volatile fatty acids. There are more than 20 of these compounds, but only a few, when found in elevated amounts in the environment, signify a potential soft-tissue decompositional event. These include propionic, isobutyric, n-butyric, isovaleric, and n-valeric. These are useful as they are not typically found in the environment, are water soluble and are not volatile if the soil is basic (>7.0 pH units). These acids can be readily extracted from the soil and analyzed using standard laboratory instrumentation such as a gas chromatograph. Soil (as well as other types of evidence) can also be analyzed for the presence of volatile gases known to be associated with decompositional events (Vass et al. 2008). Soil intended for this purpose is best collected using the 40 ml precleaned glass volatile organic analysis vials fitted with caps and a Teflon-lined septum, described earlier. The Teflon-lined septum provides a convenient means of using a syringe to withdraw a few milliliters of headspace from the vial for analysis.

In general, there are approximately 30 volatile organic chemicals, which are reproducibly generated during decomposition events. Some, such as carbon tetrachloride, are considered human specific (Vass et al., 2008). These chemicals can be broadly grouped into chemical classes and include sulfur compounds (dimethyl disulfide, sulfur dioxide, carbon disulfide, dimethyl trisulfide), aromatic compounds (benzene, ethyl benzene), aldehydes and ketones (nonanal, decanal, acetone), fluorinated compounds (dichlorodifluoromethane), chlorinated compounds (chloroform and carbon tetrachloride) and simple hydrocarbons (hexane) among others (Vass et al., 2008). A typical laboratory analysis of these constituents is conducted by withdrawing a few milliliter of headspace from the soil sample using a syringe and then injecting it into a gas chromatograph/mass spectrometer. Through the use of cryofocusing techniques, it is possible to extract and concentrate the chemical vapor components from the headspace before injection onto the column of the gas chromatograph. The gas chromatograph then separates the individual constituents in a complex mixture and they are identified one at a time using the mass spectrometer.[2]

Inorganic chemicals. As soft tissue decomposes, inorganic chemicals are also left behind. The most common ones include chlorides, sulfates, sodium, potassium, calcium, magnesium, and ammonium (Parkinson et al., 2009; Vass, 2010; Vass et al., 2008). These salts are water soluble and easily extracted from the soil. Elevated levels of these salts, compared with control samples collected nearby, can be used to identify areas of interest for decomposition and can also be used for the determination of postmortem interval (Vass et al., 2008). Additional inorganic indicators for decompositional events include the presence of nitrates and phosphates, which rapidly increase early in the decomposition cycle and then rapidly decrease again as the bacterial populations die. Metals including cadmium, cobalt, copper, and zinc tend to be slightly elevated in soil associated with human decomposition, whereas iron and silicon display an initial rapid increase in abundance and then fall to a stable level which is slightly elevated relative to the level in the control soil (Vass et al., 2008). The more common bone components such calcium and magnesium may stay elevated for as much as several decades depending on environmental conditions.

In almost all cases, the concentration of both organic and inorganic markers in control soils are usually very low, although some organic markers may be elevated due to the presence of plant material and some inorganic markers may be elevated due to high natural levels in a particular soil. The analysis of the inorganic chemicals can be conducted by universities, private laboratories, or forensic laboratories using a variety of common instrumentation such as inductively coupled argon plasma spectroscopy (ICAP) or Inductively coupled plasma mass spectrometry (ICP-MS). It is also important to know that these types of collections, as well as the odor-based sensors discussed below, can be used to map the plume migration. This can be done by gridding off sections and using this as a basis for a methodical collection and analysis of soil samples in an effort to detect the greatest concentration of chemical signatures and then mapping this in relation to the topography of the area in question.

Fieldable Chemical-Sensing Equipment

Laboratory-based chemical analysis of soil samples is an excellent way to detect, identify, and quantify chemical compounds that are potentially associated with the decomposition of buried human remains. The downsides of this approach are as follows: (a) it requires the collection and preservation of samples; (b) a laboratory equipped with the proper analytical tools such as a GC/MS with special inlets; (c) the cost can be expensive; (d) the results are not real time, and (e) multiple resampling events might have to be conducted to accurately define the location and extent of a chemical plume. Alternatively, it is far more efficient to perform chemical analysis on-site using real-time sensors or fieldable analytical systems that can provide a rapid indication of the types and abundance of chemicals present.

Fieldable chemical analyzers are available that are very similar laboratory-based analytical instruments. They include gas chromatographs, mass spectrometers, infrared spectrometers, and ion mobility spectrometers among others. These analyzers have the advantage of high sensitivity, high specificity, and the ability to resolve the individual constituents in complex mixtures. The downside of these technologies is that they are still relatively expensive, costing US$100,000 or more in some cases.

The lower cost alternative to fieldable chemical analyzers is portable chemical sensors. These devices generally utilize combinations of small, lightweight sensing elements such as electrochemical cells, heated metal oxide semiconductors, nondispersive infrared (NDIR) devices, surface acoustic wave (SAW) devices, microcantilevers, and coated crystal microbalances. Although these devices generally do not have the specificity of a true chemical analyzer such as a gas chromatograph or mass spectrometer, they can be combined together to form the electronic equivalent of a nose, producing unique patterns of response for different chemicals or mixtures of chemicals. The advantage of chemical sensors is that they can provide true real-time response, are low cost, do not require much power, are lightweight, and can be used in a wide variety of different instrument configurations for different applications.

The light-weight analyzer for buried remains and decomposition odor recognition (LABORADOR) is an example of a chemical-sensing device that was specifically designed for locating chemical scent plumes associated with human decomposition.

Figure 2. The light-weight analyzer for buried remains and decomposition odor recognition (LABORADOR) is an example of a chemical sensing device that was specifically designed for locating chemical scent plumes associated with human decomposition

This device is portable and is operated in a manner very similar to that of a conventional metal detector. It has 12 different solid-state chemical sensors located in the sampling head, which continually draws a flow of air across the sensors. The sensor head is normally held as close to the surface of the ground as possible where the chemical vapors emitted from the soil are at their highest concentration (Figure 2). No sample preparation is required and the response time to indicate the presence of chemical vapors is typically only a few seconds. Bar graphs on the front panel of the device indicate the response level of each sensor and an audible tone is also generated which increases in volume when chemical vapors are detected. Although the LABRADOR is not as sensitive as a canine's nose, it does have the advantage over a dog of being able to display the intensity of a chemical plume. Therefore, using a device such as the LABRADOR in conjunction with dogs can help to pinpoint the location where the scent is most intense.

The process of collecting soil samples in the field is relatively straightforward and can be of great value in the identification of a suspected area for clandestine graves. For comparative purposes, it is very important to collect both on-site and off-site (control) samples. Experience and accumulated knowledge suggest that a soil-sampling strategy be considered for suspected areas of human remains, but in-field expertise will be needed to determine transfer direction and plume movement of human decomposition.

Forensic Archaeology and Evidence Collection

Forensic archaeology is the study of material evidence that is the product of human activity, in the form of artifacts (e.g., weapons, clothing, narcotics) and subsurface features (e.g., clandestine graves, storage pits, tunnels) found at the scene of a crime. Investigative efficiency and effectiveness is often dependent on organizing the best team, asking the right questions, and seeking the not so obvious evidence that may be present. As archaeologists, we choose units of observation, sample the archaeological records, and structure our evidence-collection strategies in purposeful ways (Popper, 1979). Contemporary forensic archaeology must be undertaken with full knowledge about what evidence may be present at a crime scene. Like biochemistry, engineering, and other disciplines, the methods of measurement in forensic investigations must be reliable, accurate, and replicable (see generally *Daubert v. Merrill Dow Pharmaceuticals*, 1993; Fradella, O'Neill, & Fogarty, 2004). Commitment to the principles of modern scientific methods, which are grounded in impeccable empirical work and the gathering of facts, are essential to *best practice* in forensic work.

The search for clandestine graves should involve controlled pedestrian "walk-overs," HR dog searches, geochemical assessments, and geophysical survey. Investigative teams will typically identify several potential targets. The targeted areas should be designated potential legal crime scenes and all activities conducted within the set boundaries must follow local evidence-collection protocols. All surface materials are potential evidence, requiring care so as not to disturb the scene by trampling and other activities. It may be useful to erect platforms over the site to minimize contamination and all field scientists and investigators should wear investigative clothing to protect the evidentiary integrity of the site. An excellent list of activities required at a homicide crime scene is provided in Geberth (2006) and these same standards should also apply to clandestine grave investigations (see also National Institute of Justice, 2000).

Subsequent activities should include careful subsurface exploration. Specifically, each targeted area should be carefully examined with troweling, small incremental borings, shovel test pits, column samples, and other less invasive test excavations methods. If preliminary examination produces negative results, the lead detective, in consultation with the forensic experts, may elect to expose a larger area using mechanical equipment. This option is chosen only when efforts are exhausted by means of careful troweling and hand excavations. It is extremely important that forensic experts stay close to the mechanical excavation equipment (under safe conditions) so that if burial pits or human bone are encountered, the mechanical equipment can be shut down immediately. HR dogs and portable sensor equipment may be brought into the dig area at any time to help determine the direction for additional excavation. The idea is that we may be able to use the portable sensor or HR dogs to detect the flow of human decomposition back to its source, the victim. Feedback from the forensic

Table 5. Excavation Activities

Prepare recovery plan
Careful collection of all potential evidence on scenes surface
Complete surface survey using all resources
Identify potential clandestine grave areas
Conduct geophysical surveys
Erect platforms if necessary
Pin point source of order or chemical signature
Probe area and small-scale test excavations
Move to careful soil excavation with mechanical equipment
Identify human remains with assistance of forensic staff
Finalize recovery plan with collection of all forensic/trace evidence
Conduct excavation with forensic protocols
Conduct careful exposures to expose burial pit and human remains
Restrict excavation to only exposure
Recovery victim using forensic platform
Contain soil matrix and victim in special in situ collection body container
Carefully transport back to forensic laboratory

geomorphologists and hydrologists is critical to the investigative effort. Table 5 is a checklist of various activities that can be employed in clandestine searches and exploratory excavations.

Postdiscovery Excavations

In cases when the victim is found, forensic archaeologists will typically excavate in and around the victim under very careful controls for the specific purpose of retrieving all human remains and potential evidence related to the crime. The soil is usually sieved through one-quarter or one-eight inch mesh screens and investigative teams carefully examine all objects left in the screen (Dupras et al., 2006). It is critical that members of the excavation team take all necessary measures to protect themselves from biological hazards during the investigation.

To address challenges that can compromise the investigation, such as environmental conditions, lighting, and time constraints, missed evidence, we propose here that rather than processing the soil and related evidence in the field, a new strategy be adopted whereby all of the soils and remains of the victim are collected in situ. This can be accomplished by excavating a pedestal (soil matrix) around the victim followed by slowly undercutting the pedestal and incrementally sliding a forensic platform (12 inches) under the victim and soil deposit. The in situ soil matrix and victim are then placed in a specially designed evidence bag and shock-resistant container, which is then carefully transported back to the forensic laboratory for scientific processing under extremely well-controlled laboratory conditions. Care must be taken to insure that the soil under the victim is not broken or disturbed as evidence below the victim can be critical to the case (e.g., shoe prints, cigarette butts, weapons, ligatures, and so forth). Before leaving the crime scene, all of the soil that remains below the burial pit is processed in the field by careful screening with one-sixteenth inch mesh to make certain that no human remains or associated evidence were missed.

We also propose that during the excavation, the forensics team employ computerized digital photographic enhancement techniques, 3D Leica Geosystems ScanStation, and other full-station mapping instruments to insure precision and quality control over evidence collection (Galvin, 2009). The resulting three-dimensional images are extremely helpful for investigators, witnesses, and jurors to understand better the position of the victim and related evidence. In effect, they can fly through a crime scene with high resolution and accuracy by means of computer technology.

All of these activities are a more labor-intensive strategy compared to traditional methods; however, once the remains of the victim and burial soil matrix are back in the forensics *clean room* laboratory, the results can significantly contribute to a more robust scientific and legal investigation. It insures that all materials deemed as evidence are collected including artifacts and ecofacts. Each item of evidence is subjected to various material analyses, such as ICP-MS, high-resolution soil studies, environmental scanning electron microscopes examinations (ESEM), and DNA studies, which all ultimately inform the investigative program designed to solve the crime.

DNA evidence may well exist in the soil matrix collected in situ and for this reason alone we need to reconsider appropriateness of traditional field excavation methods. DNA evidence is arguably the most important evidence used in homicide investigations. Our ability to retrieve old DNA is becoming more viable due to recent advances in technology. For instance, hair found on clothing, wrappings, weapons, or under the fingernails of the victim from a context 40 years or older can be used to derive a DNA profile (Butler 2009; Liu et al., 2008; Melton, 2009; Melton, Dimick, Higgins, Lindstrom, & Nelson, 2005; National Institute of Justice, 2002). Carefully documenting all aspects of the excavation and tasks conducted under the *recovery plan* is essential to the case and must be filed immediately with the appropriate jurisdictional entity.

It is recommended that forensic scientists and legal experts design search and excavation programs to comply with the *Daubert*'s framework for the admissibility of scientific evidence. That is, all clandestine grave investigative activities should meet five criteria: techniques must be subject to empirical testing; strategies must appear in peer-reviewed scientific literature; that known error rates are statistically calculated based on controlled experimentation; demonstrative evidence of maintenance of standards and controls during a specific investigation; and that methods employed are generally accepted in the scientific community (see Fradella et al., 2004). The trial judge ultimately makes the decision regarding admissibility of evidence based on their knowledge about the scientific nuances of clandestine grave investigative methods and techniques. Such awareness should be based on experience derived from current continuing education programs and workshops for judges as well as prosecutors, defense attorneys, and law students.

Protocols for the Public Discovery of Human Remains

The discovery of human remains by the general public is a common occurrence throughout the United States. The number of reports by hikers, naturalists, and hunters are difficult to estimate, but a Google search of "human remains discovered" under the category of News shows literally thousands of hits. Representatives from medical examiners' or coroners office are typically first responders to the discovery of human remains, but do not have the expertise necessary to access and evaluate a crime scene. We suggest that first responder teams should always include an investigative detective, crime scene expert, and forensic anthropologist to insure that the site is observed by professionals and that important evidence is not overlooked. Before removing the remains, it is very important that law enforcement and forensic experts determine if a homicide may be involved. In addition, forensics experts and HR dogs can be very helpful in aiding to complete the recovery of the remains, especially if scavengers have been active.

At present the percentage of discovered human remains and correlative identification of the missing victim is very low. In effect, when human remains are discovered by the public they become yet another missing persons case. More often than not, unidentified human remains cases remain unsolved indefinitely because of limited budgets and too few trained personnel (Ritter, 2007). Under many jurisdictions, these remains are eventually buried or cremated, precluding any future investigative opportunities whatsoever (Ritter, 2007).

This is a major problem that has been recognized by both Federal and state agencies. The NamUs database management system, which was developed by the U.S. Department of Justice and became fully operationalized in 2009, matches unidentified remains with missing persons database systems nationwide. At present, there are 6,145 open unidentified human remains cases in the database (over 34,000 remain to be entered) and, as of this writing, only 192 of these cases have been solved. That means that 97% are still open and this list grows each month. The missing persons database lists thousands of individuals, but it vastly underrepresents the true number of missing persons because the majority of states are not legally required to report missing persons above the age of 18. Estimates of missing persons cases for the past 20 years are staggering, with hundreds of thousands reported, many of whom disappeared under suspicious circumstances (Ritter, 2007).

We argue that it is now time to fully support a national program with specific protocols for DNA collection for missing persons, derived from personal objects, so that DNA matches can be performed when human remains are discovered. It is now possible to make a DNA profile of human remains within hours of the discovery (Liu et al., 2008). Professionals and volunteers are needed to help families deal with not only the tragedy of losing a family member, but with filing forms, reports, and collecting DNA samples to submit to local and national agencies.

Concluding Remarks and Recommendations

The purpose of this article is to contribute to a dialog about how law enforcement and forensic experts can improve investigative methods and techniques in the search, discovery, and collection of human remains and associated forensic evidence. We have advocated several new methods not previously employed in clandestine grave investigations and we argue that interdisciplinary research and field investigations hold the key to our ability to respond more effectively. We recognize that not all issues relevant to cold case and missing persons investigations were discussed and we clearly have a long way to go before any of us can rest. Furthermore, we understand and appreciate that each case is different, and jurisdictions across the country have different policies, personnel, needs, and budgets.

Exceptional investigative work and employment of the best search methods can place the investigative team in the general area of a victim, however, various conditions and constraints can preclude discovery including the following: Transport of human remains by erosion or other hydrological processes; placement of a victim under a road, building or other structures; removal of a victim's remains by the assailant and reburial elsewhere; relocation and destruction of human remains by scavengers; and a myriad of other factors. In response, law enforcement professionals and forensic experts are motivated to improve their investigative methods by striving for excellence/success, knowing that each new case will scientifically contribute to our knowledge base.

The report to the federal government by National Research Council of the National Academy of Science, *Strengthening Forensic Science in the United States: A Path Forward* (2009), strongly recommends the development of guidelines for all forensic analyses and reports as well as standards for training forensic scientists and homicide investigators. We agree and, in response, we urge the formation of a statewide steering committee, with members representing large and small law enforcement programs and scientists from all fields of forensic investigation (both academic and nonacademic). The committee's specific goal would be to establish directions and guidelines for actions to be taken regarding the discovery of human remains, clandestine grave searches, follow-up excavations, and related evidence-collection protocols. It would be prudent for local law enforcement agencies to organize and pool their experts and resources under specialized search units operating under specific state protocols. Under this model, law enforcement groups could bring their collective expertise and operate programmatically at both the local and statewide levels instead of reacting on a case-by-case basis. This kind of effort will go a long way toward meeting the challenges of conducting criminal investigations that will help insure prosecution of the guilty and exoneration of those that have been wrongly suspected or accused.

In the United States, an army of dedicated local, state, and federal law enforcement officers work is committed to upholding the law and ensuring that the best methods and investigative strategies are employed. Forensics research is grounded in the application of scientific principles, techniques, and methodologies in an investigative and legal context. We argue that the administration in law enforcement agencies has a responsibility to educate their staff and to implement the most advanced techniques available, and that the federal government has the responsibility to fund interdisciplinary research and promising innovations. This is consistent with the call for greater support for forensics work voiced by a wide variety of law enforcement organizations and forensic societies.

When we count the number of persons who go missing each year and the number of recovered human remains that go unidentified, it is clear evidence of a national tragedy (Ritter, 2007). These cases are extremely difficult to solve, but it is incumbent on the forensic science community to do all we can to improve our investigative techniques. Two important steps we can take immediately in response to this tragedy are the following: (a) greater emphasis on the collection of DNA samples from unidentified human remains, and (b) insuring that DNA samples are collected for missing persons (such as hair from a comb, saliva from a toothbrush, or touch DNA from personal items) or, if unobtainable, a DNA sample from a close family member. DNA evidence is considered by most forensic investigators to be a *gold standard* for investigative work. The cost of processing DNA samples has decreased dramatically in the past few years and there is now a national facility to assist law enforcement and victims' families with their efforts to solve crimes and retrieve the remains of a child, mother, father, wife, husband, or friend. Local administrators and members of the local district attorney's office need to be aware that many cases have been and can be solved and time and resources are needed to continue this effort, even in these difficult economic times.

For those new to forensic investigations and human remains recovery, it is important to realize that this type of work is personally demanding requiring a strong disposition and a great deal of patience. It is a field that is intellectually challenging. Today's advances in soil analysis, geophysical technology, recovery methods of old DNA, and other new developments have given us an opportunity to explore a crime scene in ways that were unthinkable just a few years ago. Advances in forensic science have allowed us to move beyond restrictions of our human senses, to use chemical analytical techniques that measure trace elements in parts per billion, and geophysical spectra that are invisible to the human eye. In effect, our investigative search engine keeps getting better as each new technology comes online.

Last, we suggest that there is a need for a national organization or society of professionals in law enforcement and forensic science whose members are specifically involved in homicide investigations with annual meetings that incorporate cross discipline training devoted to advancing clandestine grave detection methods and post-discovery excavation techniques. Forensic methods used to discover and excavate clandestine graves must be subject to scientific validation studies that involve controlled/staged test excavations of human remains, diverse categories of evidence, and variation in excavators' experience. We must attempt to establish confidence levels of alternative excavation techniques that predict statistical probability of *maximum recovery* of human remains and all associated evidence. This kind of scientific assessment or threshold study could be conducted under the funding umbrella of the proposed National Institute of Forensic Science (see National Research Council , 2009). In the end, our ability to recover victims will increase and, even though our failures will continue to outnumber our successes, we will help to respond to this national tragedy.

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Notes

1. Ohm's Law was named after Georg Ohm, a German physicist who in 1827 measured voltage and electrical current that was passed through various lengths of wire, which allowed him to derive a calculation of a material's conductivity. Specifically, he established the fundamental relationships related to voltage, current, and resistance. In effect, his discovery provided a basis for using electrical current to measure resistance of a given soil type and, if present, any intrusive materials (Zonge, et al., 2005).
2. Gas chromatography (GC)—mass spectrometry (MS) allows the researcher to extract elements distributions in a given material. Basically, the GC separates chemicals as determined by their volatility, or ease by which they evaporate into gas. The gas product is measured by the mass spectrometer and identifies and quantifies the chemical constituents. It is extremely sensitive and can detect elements in part per million. It has been used with great success in forensic investigations and is particularly well suited to investigations of soil chemistry and human decomposition (see Meier-Augenstein, Liu, & Jehuda, 2010).

References

Ambos, E., & Larson, D. (2002). Verification of virtual excavation using multiple geophysical methods: Case studies from Navan Fort, County Armagh, Northern Ireland. *Interface Archaeology and Technology, Archaeological Record, Society for American Archaeology, 2*(1), 32-38. Retrieved from http://www.saa.org/Portals/0/SAA/Publications/thesaaarchrec/jan02.pdf

Blackledge, R. D. (Ed.). (2007). *Forensic analysis on the cutting edge: New methods for trace evidence analysis*. New York, NY: John Wiley.

Bohan, T. L. (2010). Strengthening forensic science: A way station on the journey to justice. *Journal of Forensic Science, 55*(1), 5-7.

Brauman, J. (2010). Science in court. *Nature, 464*, 325.

Breiner, S. (1973). *Application manual for portable magnetometers*. San Jose, CA: Geometrics.

Bull, I. D., Berstan R., Vass, A. A., & Evershed, R. (2009). Identification of disinterred grave by molecular and stable isotope analysis. *Journal of Forensic Science Society, 49*(2), 142-149.

Butler, D. K. (2005*). Near-surface geophysics*. Tulsa, OK: Society of Exploration Geophysicists.

Butler, J. M. (2009). *Fundamentals of forensic DNA*. San Diego, CA: Academic.

Cheetham, P. (2005). Forensic geophysical survey. In J. Hunter & M. Cox (Eds.), *Forensic archaeology: Advances in theory and practice* (pp. 62-92). New York, NY: Routledge.

Connor, M. A. (2007). *Forensic methods: Excavation for the archaeologist and investigator*. New York, NY: AltaMira.

Conyers, L. B., & Goodman, D. (1997). *Ground-Penetrating radar: An introduction for archaeologists*. Lanham, MD: AltaMira.

Daubert v. Merrell Dow Pharmaceuticals, Inc., 509 U.S. 579 (1993).

DNA Initiative. (n.d.). *Advancing criminal justice through DNA technology*. Retrieved from http://dna.gov

Dupras, T. L., Schultz J. J., Wheeler, S. M., & Williams, L. J. (2006). *Forensic recovery of human remains: Archaeological approaches*. Boca Raton, FL: Taylor & Francis.

Federal Bureau of Investigation. (2007). *Handbook of forensic services*. Washington, DC: U.S. Department of Justice.

Federal Bureau of Investigation. (2010). *Crime in the United States, 2009*. Washington, DC: U.S. Department of Justice. Retrieved from http://www2.fbi.gov/ucr/cius2009/data/table_01.html

Fradella, H., O'Neill, L., & Fogarty, A. (2004). The impact of *Daubert* on forensic science. *Pepperdine Law Review, 31*, 323-361.

Galvin, B. (2009) Getting the big picture. *Law Enforcement Technology, 36*(10), 68-75.

Geberth, V. J. (2006). *Practical homicide investigation: Tactics, procedures, and forensic techniques*. Boca Raton, FL: CRC/Taylor & Francis.

Goodman, D. (2009). GPR for archaeology. In S. Campana & P. Salvatore (Eds.), *Seeing the unseen: Geophysics and landscape archaeology* (pp. 229-244). Boca Raton, FL: CRC/Taylor & Francis.

Green, R. E., Krause, J., Ptak, S. E., Briggs, A. W. Ronan, M. T., Simons J. F., . . . Paabo, S. (2010). A draft sequence of the neandertal genome. *Science, 328*, 710-722.

Hansen, R.O., Racic, L., & Grauch, V. J. S. (2005). Magnetic methods in near-surface geophysics. In D. K. Butler (Ed.), *Near-surface geophysics* (pp. 151-176). Tulsa, OK: Society of Exploration Geophysicists.

Harrison, M., & Donnelly, L. J., (2009). Locating concealed homicide victims: Developing the role of geoforensics. In K. Ritz, L. Dawson, & D. Miller (Eds.), *Criminal and environmental soil forensics*, London UK: Springer.

Hinkes, M. (2006). Forensic anthropology in cold cases. In R. H. Walton (Ed.), *Cold case homicides: Practical investigative techniques* (pp. 369-384). Boca Raton, FL: CRC/Taylor & Francis.

Holden, C. (2009). Forensic science needs a major overhaul, panel says. *Science, 323*, 1155.

Hughes, V. (2010). Science in court: Head case. *Nature, 464*, 340-342.

Hunter, J., & Cox, M. (2005). *Forensic archaeology: Advances in theory and practice*. London, UK: Routledge.

Killam, E. W. (1990). *The detection of human remains*. Springfield, IL: Charles C Thomas.

Larson, D., & Ambos, E. (1997). New developments in geophysical prospecting and archaeological research: An example from the Navan complex. *Interface Archaeology and Technology: Bulletin of the Society for American Archaeology, 15*(1), 10-16. Retrieved from http://www.saa.org/Portals/0/SAA/publications/SAAbulletin/15-1/SAA11.html

Larson, D., Lipo, C., & Ambos E. (2003). The application of advanced geophysical methods and engineering principles in an emerging scientific archaeology. *First Break: Journal of the European Association of Geophysics and Engineers, 21*, 51-62. Retrieved from http://www.csulb.edu/~clipo/papers/LarsonLipoAmbos2003.pdf

Liu, P., Yeung S., Crenshaw, K. A., Course C. A., Scherer J. R., & Mathies R. A. (2008). Real-time DNA analysis at a crime scene using a portable microchip analyzer. *Journal of Forensic International Genetics, 2*, 301-309.

Meier-Augenstein, W., Liu, R. H., & Jehuda, Y. (2010). *Advances in forensic application of mass spectrometry*. Boca Raton, FL: CRC/Taylor & Francis.

Melton, T. (2009). Mitochondrial DNA examination of cold case crime scene hairs. *Forensic Magazine, 6*(2), 12-16.

Melton, T., Dimick, G. Higgins, B. Lindstrom L., & Nelson, K. (2005). Forensic mitochondrial DNA analysis of 691 casework hairs. *Journal of Forensic Science, 50*(1), 1-8.

Michaelis, R. C., Flanders, R. G., & Wulff, P. H. (2008). *A litigator's guide to DNA: From the laboratory to the courtroom*. San Diego, CA: Academic.

National Crime Information Center. (2009). *NCIC Missing person and unidentified person statistics for 2008*. Washington, DC: U.S. Department of Justice, Federal Bureau of Investigation. Retrieved from http://www.fbi.gov/about-us/cjis/ncic/ncic-missing-person-and-unidentified-person-statistics-for-2008

National Institute of Justice. (2000). *Crime scene investigations: A guide for law enforcement*. Washington, DC: U.S. Department of Justice, Office of Justice Programs (NCJ 178280). Retrieved from http://www.ncjrs.gov/pdffiles1/nij/178280.pdf

National Institute of Justice. (2002). *Using DNA to Solve Cold Cases*. Washington, DC: U.S. Department of Justice, Office of Justice Programs.

National Research Council. (2009) *Strengthening forensic science in the United States: A path forward*. Washington, DC: National Academies Press.

Oesterhelweg, L., Krober, S. Rottmann, K., Willhoft, J., Braun, C. , Thies, N., . . . Gehl, A. (2008). Cadaver dogs: A study on detection of contaminated carpet square. *Forensic Science International, 174*(1), 35-39. Retrieved from

Parkinson, R. A., Dias, K. R., Horswell, J., Greenwood, P., Banning, N., TiIbett , M., & Vass A. (2009). Microbial community analysis of human decomposition on soil. In K. Ritz, L. Dawson, & D. Miller, (Eds.), *Criminal and environmental soil forensics* (pp. 379-394). Heidelberg, Netherlands: Springer.

Popper, K. R. (1979). *Objective knowledge: An evolutionary approach*. London, UK: Oxford University Press.

Rebmann, A., & Edward, D. (2000). *Cadaver dog handbook forensic training and tactics for the recovery of human remains*. Boca Raton, FL: CRC/Taylor & Francis.

Rezos, M. M, Schultz, J. J., Murdock, R. A., & Smith S. A. (2010). Controlled research utilizing a basic all-metal detector in search of buried firearms and miscellaneous weapons. *Forensic Science International, 195*(1), 121-127.

Ritter, N. (2007). Missing persons and unidentified remains: The nation silent mass disaster. *Journal National Institute of Justice, 256*, 2-7.

Vass, A. A. (2010). The elusive universal post-mortem interval formula. *Forensic Science International*, Advance online publication. doi:10.1016/j.forsciint.2010.04.052

Vass, A. A., Bass, W. M., Wolt, J. D., Foss, J. E., & Ammons, J. T. (1992). Time since death determinations of human cadavers using soil solution. *Journal of Forensic Science, 37*, 1236-1253.

Vass, A. A., Smith R. R., Thompson, C. V., Burnett M. N., Dulgerian, N., & Eckenrode, B. A. (2008). Odor analysis of decomposing human remains. *Journal of Forensic Science, 53*, 384-391.

Walton, R. H. (2006). *Cold case homicides: practical investigative techniques*. Boca Raton, FL: CRC/Taylor & Francis.

Willerslev, E. (2003) Diverse plant and animal genetic records from holocene and pleistocene sediments. *Science, 300*, 791-795.

Zonge, K., Wynn J., & Urquhart S. (2005). Resistivity, induced polarization, and complex resistivity. In D. Butler (Ed.), *Near-surface geophysics* (pp. 265-299). Tulsa, OK: Society of Exploration Geophysicists.

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