Forensic science an introduction to scientific and investigative techniques

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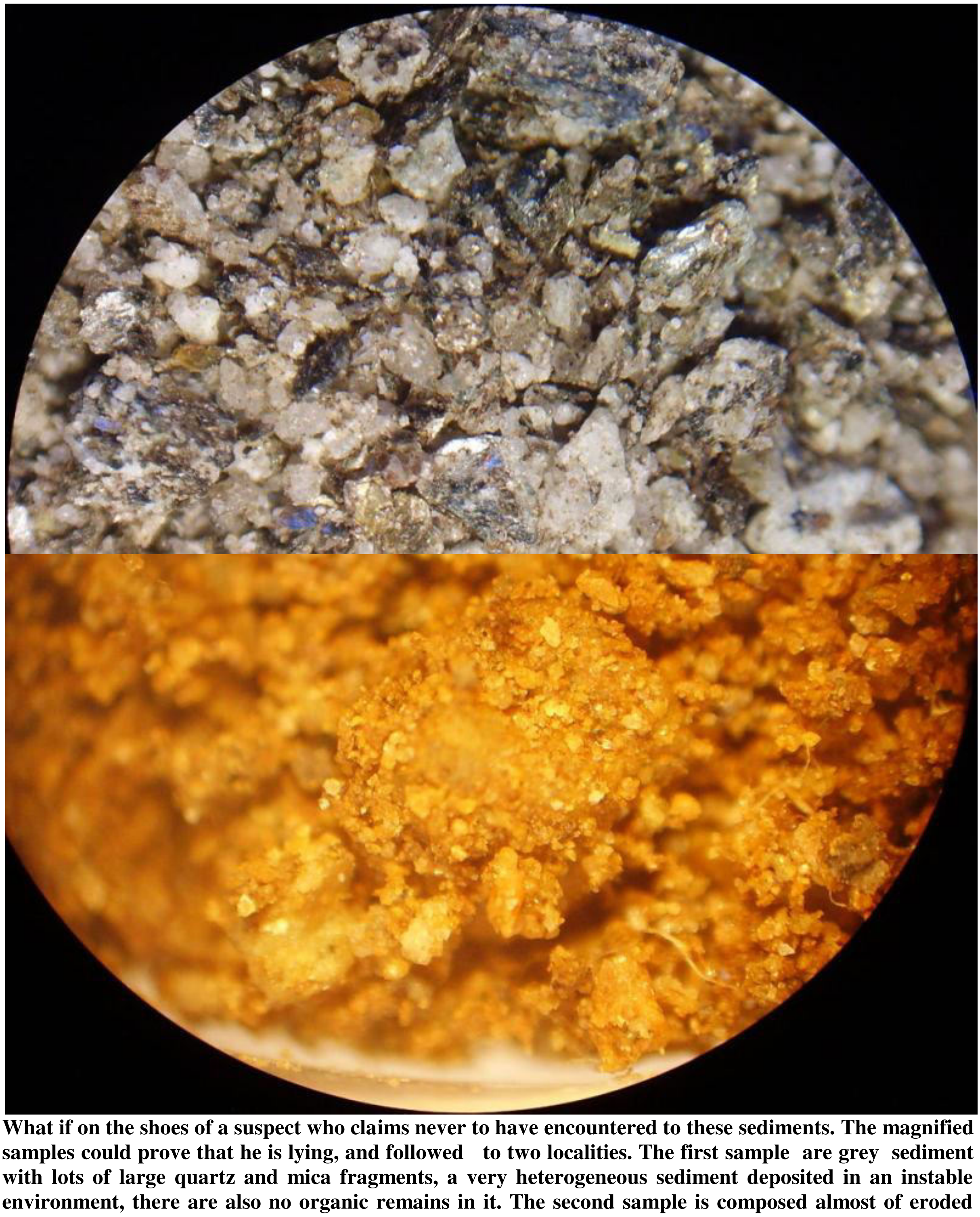

What if on the shoes of a suspect who claims never to have encountered to these sediments. The magnified samples could prove that he is lying, and followed to two localities. The first sample are grey sediment with lots of large quartz and mica fragments, a very heterogeneous sediment deposited in an instable environment, there are also no organic remains in it. The second sample is composed almost of eroded quartz grains, coated with a thin layer of reddish iron oxides - the lack of other minerals is a result of strong chemical erosion, there are also some organic remains. There is forensic evidence against the suspect that he has been on the spot where crime occurred.

Abstract: The Forensic geoscience is based on well established facts and analytical techniques developed throughout the 20th century. Scientific advances in geological and chemical analytical techniques have enabled, for the first time, detailed soil and sediment assay which has been taken up particularly by Indian scientists. A conceptual framework for the Forensic geoscience is reiterated which supports the positive development in the future of Forensic geoscience, soil and sediment analyses. However, this artical seeks to highlight the pitfalls encountered in recent time : application of analytical techniques that are based on one another; the dependence on the exotic components of a sample, whether they are representative or not; the confusion between descriptive; exclusionary and diagnostic techniques, and the failure to comprehend the requirement to exclude rather than to match comparison samples. The application of automated computer driven, multiple-sample analytical machinery is questioned when there is no visual assessment by an operator included in the procedure. Avoiding these pitfalls and adopting the philosophical framework specific to Forensic geoscience will ensure a importance of Forensic geoscience in the field of criminal investigations.

Key words: Forensic geoscience - Philosophy -Soil - Geologic sediment.

One of the most pressing issues in forensic science at the present time is how to cope with the ever increasing complexities of data analysis and interpretation in order for the results to be presented in an unbiased and clear way to court of law. These problems are compounded in Forensic geoscience by additional complications in data acquisition, analysis, interpretation and presentation which are individual to this particular, rapidly expanding, field of forensic enquiry. Observation of the post-2000 scientific published literature confirms the expanding nature of Forensic geoscience, but we must ask ourselves whether this burgeoning of geological applications is but another false dawn in a series of false starts seen throughout the 20th century. Certainly, if we do not learn from mistakes and do not take heed of comments and advice given in the past, then this current resurgence in the use of geo-science applications to forensic problems will once again fail to reach its full potential. This paper introduces the recent developments in Forensic geoscience set within the context of problems which beset the discipline.

What is Forensic geoscience?

Forensic geoscience is a field of enquiry that utilises techniques developed in the geo-sciences (such as geology, geomorphology, botany, biology and statistics) for application to civil and criminal judicial proceedings. Forensic geoscience may include both macro and micro-scale applications (Dawson, Towers, Mayes, Hillier, Fraser and Craig, .2003, France, Griffin, Swanburg, Lindemann, Davenport and Trammell 1992) (Table I).

The macro-scale applications of Forensic geoscience have been reviewed elsewhere, (Ruffell and McKinley ,2005) thus this review considers specifically the role of Forensic geoscience in crime detection at the micro-scale. At this micro-scale the geo-forensic application falls within the aegis of trace evidence analysis, which has developed its own principles and practice since the utilisation of the microscope in forensic enquiry in the 19th century.

The well established principles and protocols of trace evidence studies as applied to hair, paint fragments, glass particulates, fibres, metals etc. have now amalgamated within them the more recent developments of Forensic geoscience (incorporating studies of soils and minerals, pollen and micro-fossils). Whilst such a grouping is seemingly logical, the well developed protocols of the former group of trace evidence analyses do not take into account the nature, philosophy and practice specific to these geoforensic studies. Conversely, the geoforensic trace materials are often analysed and interpreted by a forensic geoscientist in a totally obverse manner in comparison to that of the properly established trace material analyst.

Geoforensic science has relevance to other forensic disciplines. Medical applications include the identification of trace materials adhering to bodies, under fingernails, in nasal passages, in lung and stomach contents and also in the blood system (diatoms; and Funayama , Aoki, Sebetan, Sagisaka and Detection, 1987 , Singh , Kumar, and Thakar, 2006) Pollen; and Mildenhall ,2006, Wiltshire, 2001, Campobasso and Introna, 2001).

TABLE I.—*Macro and micro geoforensic applications.*

Scale	Technique	Purpose	Reference
Macro	Resistivity and electrical tomography	Detecting burial sites	France *et al.* 1992, Buck2003 , Scott and Hunter 2004
	Electromagnetic surveying (EM) and Ground-Penetrating Radar (GPR)	Detecting burial sites	Nobes 1999, 2000
	GPR	Detecting historic mass burial sites Plastic lan dmine detection	Davis *et al.* 2000 Chen *et al.* 2001
	Forensic geomorpholo gy (landscape interpret tation)	Detecting burial sites	Owsley 1995
	Physical probe	Detecting buried objects	Owsley 1995
	Forensic remote sensing (aerial photography,sate llite imagery and global positioning systems)	Environmental forensic applications	Brilis *et al.* 2000,2001, Grip *et al.*2000
	Geographic Information System (GIS)	Spatial analysis of criminal behaviour and criminal ancestry	Canter 2003, Zhivotovsky *et al.* 2001
Micro	Physical characteristics of a soil/sediment sample Binocul a microscopy(mineralogy)	Comparison of samples and/or assessment of the provenance of samples.	Murray 2004, Morgan *et al.* 2006
	X-Ray Diffraction (XRD) (mineralogy)		Brown 2006, Ruffell and Wiltshire2004
	QemSCAN		Pirrie *et al.* 2004
	Quartz grain surface texture analysis		Bull and Morgan 2006
	Particle size analysis		Morgan and Bull in press.
	Colour		Janssen *et al.* 1983, Sugita and Marumo 1996, Junger 1996.
Chemical characteristics of a soil/sediment sample	ICP-MSa and ICP-AESb (elemental chemistry)	Comparison of samples and/or assessment of the	Rawlins and Cave 2004, Jarvis *et al.* 2004
	AAS/Dionexc (elementa lchemistry)	provenance of samples.	Morgan *et al.* 2006, Bull *et al.* 2006
	FTIRd (organic content)		Cox *et al.* 2000
Biological characteristics of a soil /sediment sample	Pollen	Comparison of samples And /or assessment of the provenance of sam ples.	Bruce and Dettmann 1996 , Bryant *et al.* 1996, Szibor *et al.* 1998, Eyring 1996, Horrocks *et al.* 1998 , Horrocks and Walsh 1998 , 1999, Horrocks 2004 , Miller Coyle 2005, Milden hall *et al.* 2006, Montali *et al.* 2006, Wiltshire 2006.
	Bacterial DNA		Horswell *et al.* 2002
	Plant wax signatures		Dawson *et al.* 2003

Soil/sediment as geoforensic evidence

It is gradually being recognized that "...much potentially useful information is locked up in even small amounts of soil" (Gallop and Stockdale, 1998) and this can be attributed not only to its "...prevalence at crime scenes and its transferability between the scene and the criminal" (Saferstein,2004) but also to the fact that soils/sediments are comprised not only of naturally occurring rocks, minerals, flora and fauna but also of anthropogenic components such as glass, paint fragments, metallic particles etc. Thus, a sample of soil/sediment recovered from clothing, a vehicle or a crime scene has "...a large, almost limitless number of characteristics which make it unique but which relate to the climate, geology or land use of the site from which the soil was derived",(Brown and Going,2000) indeed there are "...an almost unlimited number of soil varieties and soils change rapidly from place to place even over short distances". (Murray and Solebello ,2002) The value of soil/sediment analysis in providing useful evidence in forensic enquiries lies with the ability of the forensic practitioner to make comparisons between soil/sediment samples and, on occasion, to infer provenance.

The concept of facies and sedimentary units is a keystone to the analysis of soils and sediments in forensic enquiry. A "...sedimentary facies is defined as any aerially restricted part of a designated stratigraphic unit which exhibits characteristics significantly different from those of other parts of the unit". (Moore, 1949) It is, in other words, distinctive as a result of the similarities within the unit and its distinctiveness from other units. Accordingly, it follows that facies are discrete and, therefore, restricted in extent both stratigraphically and geographically. (Blatt, 1972) Thus there is a discernable difference between sedimentary units in the spatial dimension. The most important application of this, therefore, is that sediments are not to be found in a melange of indiscrete units but rather the inter-relationships of sedimentary environments, and hence of facies, are not chaotic or random, but subject to controls such as climate, tectonics and geological setting. (Nichols, 1999) Therefore, soils and sediments have been argued to possess the "...clearest expressions of landscape complexity", their"....spatial variability is high and intricate over short distances, whether in profile or in plan"(Thomas., 2001) As no two similar environments are exactly identical, (Selley., 1996) this characteristic of soils and sediments enables the use of comparison methods in the analysis of trace soil/sediment samples to be used to great effect in forensic enquiry.

However, it is not only the identification of the components of a soil/sediment sample that enables the use of such evidence; it is of great importance that the interpretation of such analysis and their presentation to the court are accurate and meaningful. Indeed, more powerful analytical instruments are constantly being developed providing the potential for greater and greater discriminatory detail of soil/sediment samples in a forensic context to be achieved.(Murrayand Solebello, 2002) It is not the accuracy of such techniques that is questionable as the "...physical evidence cannot be wrong; it cannot perjure itself; it cannot be wholly absent..." rather "...only in its interpretation can there be error".(Kirk ,1974) Such error has the potential for untenable consequences in the forensic arena; the courtroom.

The pbilosopbical framework of forensic geoscience

Whilst Forensic geoscience and the more traditional geosciences may share a Popperian approach to falsification (Popper, 1959, Rhoads, 1996,) and indeed utilise some of the same techniques and information, "...the philosophical approach of the two could not be more contrasting". (Morgan, Bull 2007) The development of Forensic geoscience in the 20th century has been documented (Horswell, Cordiner, Maas, Martin, Sutherland and Speir.2002, Murray, 2002, Tedrow, 1975) and it is clear that many of the major contributions have come from the geosciences. Whilst the development of the analysis of different components of soils/sediments in geological studies by a number of analytical techniques has greatly contributed to the advance of Forensic geoscience, the transposition of techniques from one discipline to another is not simple and should not be done unless consideration of the contrasting approaches is taken into account.

We consider that there are four major facets of the philosophical framework within which geoforensic practitioners should operate: (Morgan and Bull., 2007)

1. The requirement to *exclude* rather than to match comparison samples.
2. The *nature* of analytical techniques (descriptive, exclusionary and diagnostic).

3. The necessity of employing a number of *independent* forensic techniques.
4. The balance between the *"exotic"* and the *"ubiquitous* “component of a sample.

Forensic geoscience deals with a form of physical evidence that cannot be deemed to be unique (in the same sense as a fingerprint or DNA profile). Rather, soil/sediment evidence should be viewed as being of a probabilistic nature. (Broeders, 2006) It is, therefore, not possible to look for a "match" or an association between two samples that are being compared. This attitude contrasts with the approach in the more traditional geosciences where comparisons are made between soil/sediment samples in order to identify similarities so as to classify, date or infer provenance of the samples in question.(Ruffell and Wiltshire,. ,2006, Pye and Croft, 2004)

The geological techniques which are used to assess the characteristics of soil/sediment samples in Forensic geosciences are deemed to be predominantly descriptive techniques. In certain cases these descriptive techniques may prove to be exclusionary and more rarely, diagnostic. One of the biggest problems that needs to be addressed by the geoforensic community is that of the analysis of soil/sediment samples taken from pertinent exhibits comprised of a mixture of soil/sediments from a number of different sources (for example from a vehicle or a shoe). These "anthropogenic" samples are likely to include materials transferred presyn- and post-forensic event. It is, therefore, problematic to undertake analysis of these samples using an analytical technique which requires the homogenisation of the sample prior to analysis. Such a step renders it impossible to assess whether the results derived exclude the sample from the having a similar provenance to the crime scene sample, or whether the exclusion is a false negative result (due to the presence of materials from other sources in addition to the crime scene material). Examples of this have been documented by Morgan et al. and, 2006 and Morgan, and Bull, 2007, Janssen, and Ruhf, 1983.)

There is general consensus amongst the geoforensic community that a number of analytical techniques should be employed in the analysis of soil/sediment samples. (Brown, 2000, Lornbardi.1968). However, whilst some practitioners advocate the use of certain suites of analytical techniques, (Croft,and Pye, 2004, Pye ,Blott, Croft and Carter ,2006) We contend that it is of greater importance that the third facet of the geoforensic philosophical framework is adhered to. A suite of techniques that measure characteristics of the soil/sediment sample that are dependent upon each other may well provide corroborative results, but such results cannot be deemed to strengthen the interpretation of the original analysis. (Morgan, Freudiger-Bonzon, Bull and Morgan, 2002)

The colour, elemental composition and particle size distribution of a soil/sediment sample will all be dependent to some extent on the mineralogy of that sample. To present the findings of these four different analytical techniques to a court and assert that the agreement in the findings adds weight to the strength of that evidence is not a tenable position. Techniques that can be considered to be more independent may include, for example, mineralogy, pollen, quartz grain analysis, and anthropogenic additions such as paint and fibres.

The decision to look for the ubiquitous or "exotic" component of the soil/sediment sample must be reached with care and will depend upon the particular geoforensic case in question. The "exotic" component of a soil/sediment (such as an anthropogenic addition, or a rare or highly place-specific pollen grain; see Morgan et al.., 2006) may prove to be a diagnostic feature that enables the exclusion of particular samples from the enquiry. Caution must be taken, however, to ensure that when very small quantities of samples are being compared, the "exotic" component is representative of the parent sample and the original source. It is possible that due to their very nature, "exotic" components may only be found in very low concentrations in a sample assay. There is a possibility that such "exotic" components may not be represented in two samples taken from the same source site, which may lead to the problem of an untestable false-negative exclusion. Conversely, whilst the ubiquitous component of a soil/sediment is highly likely to be represented in all samples taken from the same source, it is possible that due to its ubiquity it can only provide descriptive evidence (rather than being diagnostic and/or exclusionary). To complicate the matter further, we must also assess whether the "exotic" component is indeed truly exotic, or whether it is far more common than is thought. The presence of an element or combination of elements identified by high powered analytical techniques may not have been routinely sought before and in consequence no detailed micro-scale database exists to confirm or reject this "exotic" designation.

TABLE II.—*the conceptual framework of forensic geoscience: the order of events.*

Order of events	Considerations	Relevant precepts	
1. Transfer	Sample character acquisition	— Primary, secondary, one and two way	Division of matter.
		Pre-, syn and post-forensic event transfers.	Locard "Every contact leaves a trace".
2. Persistence and Tenacity		Persistence of trace physical evidence; 2-stage decay (Bull *et al.*) Trace evidence can persist up to the order of days/weeks.	Fibres: Pounds and Smalldon Robertson and Roux; Glass: Koons *et al.* , Curran *et al.*, Brewster *et al.* ;
		Many forms of trace evidence (soil, glass, fibres) have demonstrated significant tenacity: this is good for sample availability, but pre-, syn- and post-forensic events may confuse matters.	Foam: Wiggins *et al.* ; Hair: Dachs *et al.* Morgan *et al.*
3. Collection	Sampling	— Comparable samples are required.	Gilbert and Pulsipher, Warren, Nocerino *et al.* , Morgan *et al.* ,
		Samples taken must be representative of the parent material.	McKinley and Ruffell
4. Analysis	Type of investigation	— Compare and Exclude (Morgan *et al.*, Morgan and Bull,1 Ruffell and McKinley) Anthropogenic (mixed) *vs* natural (not mixed) Case by case variation	Seek-and-Find (Provenance)(Rawlins *et al.*, Wiltshire, Brown)
	4a.Type of sample 4b.Size of sample		
	4c.Which techniques?	Techniques for comparison	Techniques which are able to identify
		— If samples could have mixed provenanceit will not be possible to use techniques which require sample homogenisation for analysis. Exotic components may be useful (mineralogy, pollen, quartz). Independent analytical techniques are needed.	— Geographical indicato rs such as pollen, minera logy, quartz grain surface textures. — Independent forms of analysis needed.
5. Interpretation	5a. Is there a database?	Localised databases constructed from the analysis of samples from exclusionlocations may be adequate.	Large scale micro-detail databases highly desirable.
	5b. Is it possible to apply statistics?	Some statistics may be possible provided that the conditions of the multivariate statistical test are met (*e.g.*CDF)	Not possible until comparator samples are provided. On occasion it may be possible to und ertake comparison with large-scale database sam ples.
	5c. Elimination of bias?	A number of different operators working independently on the anal ysis of samples (independent analysis of the same technique, independent nalysis by way of different techniq ues). Coding samples enable analysis without any reference to their source.	
	5d. Role of experi mental studies	Crucial to establish the nature, transfer, persistence, tenacity and	

		method of collection (tenets 1-4) of trace evidence in order to be able to carry out appropriate analysis, inte rprettation and presentation (tenets 5-7). Reproducibility of results – it is important to be able to establish the reproducibilityof analysis and inte rprettation of a particular form of trace evidence.	
6. Presentation	6a. Role of graphical representation of findings.	— This is an ethical question as well as a methodological one. On some occasions graphics derived from statis tical analysis can provide compe lling confirmation of the findings.1 Howe ver, the jury are not experts and such graphics can provide a simpli fication of reality which may undul ysway a ‘non-expert’ jury.	
	6b. Explanation to the court.	— The results should be explained to the court with an awareness of the limitations of the analytical techni ques employed. Statistical data and derived graphics will only be as good as the original data but may still oversimplify reality. Introduction of the defenders fallacy must be avoided. The expert witness must remain dispassionate when providing an opinion derived from such analysis.	
	6c. The influence of evidence on the court.	The CSI effect? Negatively:	Positively:
		— Can influence the jury with regard to the strength and reliability of forensic evidence presented. Can influence the jury with regard to the absence of forensic evidence.	— Forensic evidence may clarify contradictions Of personal testimony. Jury may expect a greater degree of evidence before declaring a verdict.
		Jury may not be aware of the limitat ions of both the forensic evidence pre sented or the fallibility of the exp ert witness presenting it.	The jury may be conve rsant in the perils of stati stics due to media covera ge of disgraced expert witnesses (e.g. Dyer) and so may not be swayed by persuasive Sound ing figures and arguments.
		May mean the jury demand unrea sonable levels of physical evidence in trials.	

Such a philosophical framework has been presented by (Morgan and Bull,2007) but it is important to note that this is a very recent addition to the published literature. Many geoforensic practitioners (often with a geoscience background or training) continue to approach geoforensic case work with a geoscience mind set. There is currently a debate amongst different laboratories and scientists, but it is undeniable that it is of great importance that a framework is agreed upon in order that the field of Forensic geoscience may become a robust scientific discipline.

The conceptual framework of Forensic geoscience : the order of events

Given the nature of Forensic geoscience and the methods by which analysis of soils/sediments is approached, it is now necessary to consider the order of events which lead to sample characterisation, analysis, interpretation and presentation. We present here a conceptual framework that builds upon the earlier work of Inman Rudin. (2002) within which all forensic investigations generally operate. There are six fundamental tenets upon which the process of forensic science (including Forensic geoscience) rests. They are:

1. Division of matter and transfer.
2. Persistence and tenacity.
3. Collection.
4. Analysis (identification).
5. Interpretation.
6. Presentation.

It will only be possible to analyse and identify trace physical evidence (tenet 4) if the evidence has previously divided from its parent material and transferred (tenet 1), persisted and exhibited sufficient tenacity to persist under the specific circumstances of a particular crime event (tenet 2), and been collectecl in an appropriate manner (tenet 3)-The interpretation and presentation of the analysis (tenets 5 and 6) will, in turn, rely on appropriate and accurate analysis and identification. The seq Lience of these events are summarised in Table II Morgan, and Bull. 2007, Brown. 2006, Wiltshire 2006, Ruffell 2005, Wiltshire. 2006, Brown, 2000, Murray, 1975.

Acquisition of sample characteristics (tenets 1 and 2)

The division of matter (the fractionation of sediments from the parent body) is necessary for the generation of physical evidence. In the forensic context it is then necessary for the transfer of evidence to take place from the forensic event site to either another location, or clothing or objects associated with the perpetrator (shoes, clothing, vehicles etc.). It is then not only important for the evidence to persist upon the personal items associated with the perpetrator, but also for the evidence to be recognised and collected. Finally, an appreciation of the tenacity of this transferred evidence (normally regarded as trace evidence) is required before an interpretation statement can be provided for the court. This is of course the idealised scenario. In reality, there are significant complexities concerning the transfer, persistence and tenacity of trace evidence.

The transfer of evidence is founded upon the central thesis evoked by Edmond (Locard, 1930) that "every contact leaves a trace". Locard export Linded upon this original premise by stating that"....whenever two objects come into contact, there is always a transfer of material. The methods of detection may not be sensitive enough to demonstrate this, or the decay rate may be so rapid that all evidence of transfer has vanished after a given time, Nonetheless, the transfer has taken place".(Murray and Tedrow. 1975)These contacts may involve one-way, or indeed, two-way transfer; the latter may occur where, for example, evidence from the perpetrator is deposited in a room and evidence from the room is deposited on the perpetrator (for a recent example see Bull et al. Cox, Peterson, Young, Cusik and Espinoza.,2000). Furthermore, such contacts leading to the transfer of trace evidence may be both primary and secondary. Primary transfer occurs when, for example, the perpetrator directly makes contact with a particular source of evidence. Secondary transfer may occur if the perpetrator, who has transferred evidence upon his person from a primary transfer, makes a secondary contact and transfers evidence collected from the primary transfer onto another object or person (for example see Grieve and Biermann Grieve and Biermann, .1997).

The persistence of trace evidence has long been recognised as an important property and much work has been undertaken to determine the decay curves of various forms of trace evidence over time. The seminal works of Pounds and Smalldon (Pounds and Smalldon., 1975) (Pounds and Smalldon. 1975); and Robertson et al., Morgan, Bull. investigating the persistence of fibres on clothing, is paralleled by work undertaken on a number of different forms of trace evidence in a whole series of studies published over the last ten years (see Table II under persistence precepts for a brief summary). The persistent nature of these different forms of evidence, and particularly soils and sediments (Bull, Morgan, Sagovsky and Hughes.2006) can present problems for the forensic geoscientist. The problem is simply that the longer trace evidence can remain on an object, the greater the chance that there will be an amalgamation of trace evidence from pre-, syn- and post-forensic event transfers. The inability to separate two or three phases of evidence introduction will severely curtail the use of that trace evidence in the forensic context unless the multiple provenances can be identified.

Identification of sample characteristics (tenets 3 and 4)

NATURE

In order to identify the characteristics of a sample, it is necessary to establish the philosophical standpoint to be adopted and the nature of the geoforensic investigation. In terms of the philosophical approach, it is at this point in the order of events (Table II) that the relevant philosophies of geoforensic analysis and geological analysis diverge. The nature of the geoforensic investigation will generally take one of two distinct forms; those that seek to compare and exclude samples that have been collected from a suspect, crime scene and/or victim and those where only samples from the suspect have been collected which require a "seek and find" approach to provide an indication of the provenance of the soil/sediment sample (Table II).

In a comparative investigation the forensic geoscientist needs to compare samples in order that they can be excluded from having derived from the source of a comparator sample. It is very difficult to state that a sample has, or most likely has, derived from a forensic scene as geo-forensics is one of the more probabilistic sciences. Broeders, 2006, Kiely Kiely.,2006, summarises the situation that exists in the United States of America. He identifies the terms allowed by the courts to support the identification of a crime scene item with a sample from the defendant as such:

—match (usually limited to fingerprints and ballistics);
—compatible with;
—consistence with;
—similar in all respects;
—not dissimilar;
—same general characteristics;
—identical characteristics;
—could have originated from;
—can not be excluded.

In the United Kingdom some practitioners provide a scale of 1 to 10 where 1 shows no scientific evidence and 10 shows extremely strong scientific evidence. Unfortunately this quantification is at best subjective and at worst, as we shall see later, biased. It is perhaps worthy to note here that the forensic geoscientist should really present his/her findings in the form of either "I can exclude these samples from having any association with the comparator sample" or "I cannot exclude these samples from having an association with the comparator sample". When the second statement is corroborated by a series of independent analytical techniques imparted upon the sample, the strength of that evidence is increased. The matter of the influence of such a series of statements on the jury is discussed further on.

Perhaps one of the most difficult tasks that face the forensic geoscientist is that of the so-called "seek and find" investigation. This type of analysis involves the study of the sample characteristics in order to attempt to provide an indication as to the provenance of a sample of unknown origin (for a recent example see Brown. 2000). This is often accomplished by the identification of the miner-alogical and geological nature of the soil in addition to its botanical components which may include pollen, spores, macro and micro fauna (Table II). The characteristics of that soil are then used to exclude areas which could not possibly be the source of the material in order to refine the area for initial searches to be made. Guesses (albeit informed — but they are still guesses) concerning the type of vegetation, geology, geo-morphology, land-use, presence or absence of water features and nearness to roads, are all used to hone down the search area to a number of more likely sites. These sites are then investigated one by one and soil/sediment samples collected. Exclusion principles are then applied until comparator samples are found and analysed that cannot be excluded. This process has become known as "environmental profiling". (Mildenhall, Wiltshire, Bryant. 2006)

Practice

It will always be important to assess each case on its own merits, taking into account the specific auxiliary factors that are pertinent. The samples that are provided and the questions asked of those samples will differ and thus the practice of identifying sample characteristics will vary accordingly at both the collection and analysis stages.

Collection.—It is crucial for the success of subsequent geoforensic analysis, interpretation and presentation that the collection of soil/sediment samples is carried out accurately, appropriately and effectively. Not only must the sample taken be representative of its source, but it must also be of a form that is directly comparable with samples taken from a suspect, the belongings of a suspect or a victim (Table II). The scope of the geoforensic analysis will be reduced if incomparable samples are provided for analysis such as fine grained materials recovered from clothing for comparison with a bulk sample taken from a crime scene (for a recent example see Morgan *et al.* Morgan, Wiltshire Parker, Bull.2006*).*

Analysis.—"If the law has made you a witness, remain a man of science; you have no victim to avenge, no guilty person to convict and no innocent person to save. You must bear testimony within the limits of science." (Hiss, Freund and Kahana.)

In undertaking the analysis of soil/sediment samples in the context of a forensic investigation it is essential that the geoforensic practitioner "remains a man of science" and adheres to an appropriate geoforensic philosophical framework (as discussed previously). Once the nature of the investigation has been identified and appropriate samples provided, it will also be important to assess the types of samples that have been provided for analysis. In general, there will be two types of geoforensic sample; those that have a "natural" origin (such as those taken from a grave site, or a crime scene) which have invariably been taken from a single source, and those that are "anthropogenic" in nature (such as samples taken from vehicles, footwear and clothing) which have the potential to be derived from a number of provenances and may include soil/sediment from pre-, syn- or post-forensic event sources.

In any investigation where there is a possibility that anthropogenic samples may be present, it is of great importance that appropriate forms of analysis are undertaken (as will be discussed more fully later). In addition to the type of sample presented for analysis, in each geoforensic case it is also important to assess the size or quantity of the samples. In order to make accurate and meaningful comparisons between samples, it is crucial that the size of the smallest sample is taken into account. The amount of sample available will have a direct bearing upon the number of techniques that it will be possible to apply to that sample and should also dictate the order in which techniques arc undertak-en (Palenik's sequence as documented in Murray and Solebello 2002). If a particular analytical technique is destructive to the sample, it must be undertaken after other techniques have been applied to the samples in question. Once these factors (generally particular to each individual case) have been taken into account, it is then possible to plan which forms of analysis are appropriate for the samples which may also yield useful information, and the order in which to carry them out.

The analytical techniques that will be appropriate and yield useful information will vary depending upon the aim of the investigation (Table II). For "seek and find" investigations it is important to carry out techniques that will yield useful information regarding the provenance of those samples. In a "compare and exclude" investigation there may be a wider range of techniques that can be applied to achieve the exclusion of samples which do not necessarily infer provenance.

In its broadest sense there are two types of analytical test that can be undertaken in geo-forensic soil/sediment analysis. The first involves some degree of direct visual analysis by the operator and the second involves automatic scanning of a sample or aliquot. This latter form of analysis is popular at present, because it enables rapid sequential analysis of many samples, automated to the point that operator presence is not necessary. The problem, however, is encountered if the sample preparation for such analyses requires ho-mogenisation of the samples either in powder, pellet or solution form.[1] This may, therefore, go some way to explain why the microscope (light or electron) is a popular "look see" method of analysis. Some of the more sophisticated modern analytical techniques enable visual selection of sample areas for "spot analysis" and this is surely preferable to the "black-box" approach of full automation. However, even this concession provides new problems to consider; sample analysis of a small area of, for example a quartz sand grain, may provide chemical detail of adhering cement coatings. Before this can then be used as a comparative exclusion technique with other sand grains taken from other samples, a sufficient and representative area of the grain must be analysed and all of the grains from the original sample must also be analysed. Far too often the occasional spot analysis, unrepresentative of the whole, is used to exclude (or even worse, include) samples.

Multielemental analyses by automated machines such as ICP or electron probe produce more problems. It is possible to analyse the concentrations of vastly different element suites; some analysis may be undertaken using 20 or 25 elements or compounds, some 50 or more and in some cases even more than that. There are no direct micro-detailed databases which can readily be used in a geo-forensic context and meaningful forensic interpretation cannot be assured. It must always be remembered that these machines were developed as an analytical tool for chemists, geologists and other natural scientists; none of the machines were developed for forensic analysis and hence, have inherent drawbacks. A recent development, however, that of the QemSCAN, utilises the visual qualities of an electron microscope together with the real-space resolution of elemental and mineralogical analyses. (Pirrie Butcher, Power, Gottlieb and Miller. 2004) The problems of representativeness of analysis and the problems of the designation of "exotic" *versus* the ubiquitous without the aid of a pertinent database still exist. The machine, however, does lend itself well to the possibilities of exclusion.

Interpretation - soil evidence as a probabilistic science (tenet 5)

"...we must always remind ourselves that our system of criminal justice resides in a world of probability"." (Kiely.2006)

The large and impressive databases which exist for fingerprints and DNA comparisons do not, unfortunately, exist in geoforensic soil/sediment analysis. Typically a localised database is constructed for a particular case with perhaps nine or more samples taken around an incident site and many others then taken for exclusion purposes. These are then compared to materials recovered from a suspect or belongings of a suspect. The result may be that of 60 or 70 samples taken, the only ones that cannot be excluded from having derived, at least in part, from the forensic scene in question may be those associated with a suspect. The forensic geoscientist can go no further than to seek to exclude by using as many relevant independent analytical techniques as possible. Larger scale databases produced by soil surveys or geological surveys serve only to provide broad li-neation and exclusion of samples in most instances, but can serve to concentrate analysis in a particular spatial area clue perhaps to the unusual or distinctive mineral assemblages, pollen types etc. Smaller scale databases at a micro-detail level are only recently being constructed, but even these are of limited spatial extent. (Bull and Morgan. 2006)

Once analysis has been completed, the data set produced is often sought to be summarised or given a statistical relevance by the application of multivariate statistical techniques. The drive for such statistical comfort stems in large part from the experiences of DNA analysis.(Broeders.2006) Here probability rules; many cases have fallen as a result of the inaccurate terminology used to summarise the probability of an association of the DNA results. This has an unfortunate knock-on effect for Forensic geosciences. Whilst we accept the summary statistics may be useful and simple correlations may help the jury to understand the significance of the results, even these simple parametric and nonpara-metric tests are open to much abuse. We remember occasions in court when standard deviation — should it be 2 standard deviations or 3 standard deviations was the argument — was determined for three samples. We remember commenting to the advocate that if there were only 2 samples the relationship could have been expressed as a straight line!

Some forensic geoscientists utilise Pearson's correlation coefficients for vast sets of chemical data and disregard those associations that are not statistically relevant enough highlighting only the successes. Of course, this is not good science and tends to stress matching rather than excluding and with it all the inherent probabilities discussed previously. The lack of independent variables within the same data set does not appear to deter the use of Pearson's correlation coefficient. Such is the situation in the criminal law court because the advocates, when alerted to these problems, choose not to challenge on the basis of statistical relevance or rigour lest they lose the interest and attention of the jury.

Further problems exist when applying what amounts to being black-box analyses to forensic data sets (cluster analysis, canonical discriminant function analysis, principle components analysis etc.). The derived graphical representations often look very compelling for the jury but since the graphs are produced in two-dimensional format and often represent three-dimensional relationships these facts can be lost at the jury level. Indeed the very groupings and classifications produced often demonstrate fragility and are open to many vagaries as found within geological samples. (Morgan and Bull.2006, Isphording.2004)

Statistical summaries and analyses can be used, however, wittingly or unwittingly, to influence the interpretation of a data set depending on whether one is prosecuting or defending. This becomes extremely pertinent in the British and American systems where trial by jury (with the occasional exception of Diplock cases) is the normal state of affairs. The classic case of the Defender's fallacy is as pertinent to forensic geoscientists as it is to any other form of forensic data interpretation. (Thompson and Schumann.1987)

Another very important aspect of interpreting the analytical data derived from geoforensic analysis is that of bias. Whilst it is widely accepted that".. .an expert witness should employ sound and methodologically rigorous reasoning processes avoiding bias and partisanship no matter who is paying their fees I in reality, truly achieving such a state can be difficult. It is beneficial to code geoforensic samples prior to analysis and interpretation of the results. It may also be advantageous for not only other independent forms of analysis to be undertaken, but for both similar analyses and independent forms of analysis to be canied out by independent laboratories. Corroborative results from similar and independent analytical techniques will add weight to the conclusions reached from the resultant data. This is, however, not always possible in reality, but it should perhaps be higher on the agenda.

Finally, the role of experimental studies in aiding the interpretation of geoforensic analysis should be highlighted. In order to make accurate and meaningful interpretations, it is crucial that the nature, transfer, persistence and tenacity of a form of trace evidence (tenets 1 and 2) and the most efficient methods of sample collection (tenet 3) are recognised. Indeed trace sediment analysis lends itself quite properly to repeated experimental reconstruction and much work has been undertaken in this area (Table II).

A note of caution must be introduced regarding a more recent trend in experimental Forensic geoscience. There has been a proliferation of papers identifying the developments and capabilities of particular analytical techniques intended, in the first instance, for geologists or chemists. The remit of many of these papers is to select a number of samples, some from distinctly different environments or provenances, and then analyse those samples using the relevant state of the art machine to show that the machine can indicate, from the results produced, that the samples are different. However, the problems of sample representativeness, homogenisation and mixing outlined throughout this paper are still pertinent, notwithstanding the fact that the original sample collection procedure or experimental design do not mimic the reality of a forensic case where far more subtle variations and differences exist to complicate the matter.

Presentation (tenet 6)

"You cannot separate, for trial purposes, forensic evidence from the testimony of forensic experts"(Kiely.,2006) The role of an expert witness and the evidence that they provide in a court room is not only a methodological question, but also an ethical one. It is not for the forensic geoscientist to proffer any opinion as to the guilt or otherwise of the defendant, rather it is to present their findings as impartially and clearly as possible. The issues surrounding the presentation of evidence to a jury are presented in Table II.

The major hurdle to overcome is how to make the evidence precise and correct whilst all the time making it comprehendible for the jury. This is no different a problem than that encountered by other forensic expert testimonies. As discussed previously, the use of multivariate statistics and their associated graphical packages have the potential to aid the interpretation of results of geoforensic analysis. (Morgan and Bull, 2006) It is important, however, to be aware of the impact such graphical presentations of findings may have on a jury. Whilst on certain occasions they may corroborate the results of the analysis and provide a compelling image of the exclusions derived, in another case, where similar forms of analysis were employed and similar exclusions derived, the same multivariate statistics and associated graphical presentation may not provide such a clear and compelling image. It is, therefore, pertinent to ask whether or not such graphical images should be used to present the results of geoforensic analysis to a jury who may not be well versed in the strengths, weaknesses and limitations of a particular analytical technique and the subsequent statistical packages used to compute the images.

The so-called "CSI effect" may have a bearing on how the analysis and findings of Forensic geoscience are presented to the court. Whilst there have been a number of reports that juries may now demand unreasonable levels of physical evidence to reach a verdict, these claims are tempered by those that suggest that the jury are better informed and able to understand the intricacies of the analysis of trace physical evidence.(Houck,.2006) The presentation of evidence to a court must take into account the no expert nature of the jury all the while being sensitive to any factors or methods of presentation that may unduly sway or influence them.

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