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The use of grain size distribution analysis of sediments and soils in forensic enquiry

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Abstract

The use of grain size distribution analysis in forensic enquiry was investigated with reference to four forensic case studies which contained the type of sample restraints and limitations often encountered in criminal case work. The problems of the comparison of trace and bulk samples are outlined and the need for multiple sample analysis is highlighted. It was found that the problems of soil analysis, particularly when the soil was recovered from anthropogenic sources, focused on the lack of identification of pre-, syn- and post-forensic event mixing of materials, thus obscuring the recognition of false-negative or false-positive exclusions between samples. It was found that grain size distribution analysis was a useful descriptive tool but it was concluded that if it were to be used in any other manner the derived results should be treated with great caution. The statistical analyses of these data did not improve the quality of the interpretation of the results.

Keywords: Forensic science; Grain size distribution analysis; Sediments and soils

1. Introduction

One of the fundamental and most ubiquitous tests undertaken during the analysis of sediments and soils in geological investigations is that of grain size distribution analysis (for example [1–4]). The various size ranges and proportions of material identified during grain size distribution analysis encompass materials of sub-micron size through clays, silts, sands and gravels. Whilst a variety of different techniques has been employed during geological analyses to present these distributions [5 6], the ultimate aim of the researcher has been to describe the sediment and provide some environmental or palaeoenvironmental information as to the mechanisms by which the deposit has been transported and deposited to its final resting place [1]. Grain size distribution analysis is now being employed routinely during forensic casework analysis [7,8] although it will be shown in this paper that there are problems in using this well-established geological technique in forensic investigation in any way other than as a descriptive mechanism.

The characteristics identified by analysing the grain size distribution of a sample are dependent on a number of controlling factors irrespective of whether we are investigating geological or forensic samples. Initially, the make-up of the grain size distribution of a sample depends upon the make-up of the grain size distribution of the source materials. This may be another sediment sample, or indeed be the weathered or eroded product of rock strata. The transportation of the sediment from its source or sources will further affect the grain size distribution of the final sample. The mechanism of transportation (wind, water, or gravity) will winnow the various sediments in accord with the capabilities of the energy conditions of transportation. Finally, the grain size distribution of a sediment will be dependent upon the syn- and post-depositional processes which prevail (winnowing, pedogenesis, chemical alteration etc.). Another factor complicates the issue. A soil is a three dimensional structure comprising discrete sedimentary and pedogenic layers. The individual layers often have very different grain size distribution characteristics. A sediment body may also reflect temporal variations in deposition which are recorded in grain size distribution variations down-section. As will be illustrated later, it can be very foolhardy to compare the grain size distribution of a sediment taken from a taping, a trace sample

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and a 1 kg bulk sample without exercising great caution in the interpretation of the results. All three samples may derive from the same geographic location but all may differ fundamentally in their grain size distribution with the possibility of subsequent interpretation producing a false-negative result [9].

Forensic enquiry however, takes this complicated relationship a little further. The grain size distribution of a forensic sample must now take into account alteration and mixing of soil from different sources caused by the movement of the material by anthropogenic effects on footwear, clothing and vehicles. Thus, not only is there a complication of mixing to consider in forensic enquiry but there is also the thorny issue of selective transfer, persistence and decay of materials which will alter the grain size distribution curve further [10].

The forensic scientist must ask why they wish to undertake grain size distribution analysis of a sample. Here, the ultimate aim is to compare a number of samples of soil or sediment from a suspect or their belongings with a comparator group of samples located at or about a forensic incident or scene of enquiry. Fundamentally, the forensic geoscientist seeks to exclude samples from having been derived from the comparator source [11,12]. Analysis is therefore descriptive (as is often the case with geological enquiry) or on occasion exclusionary. Samples that are analysed by descriptive analytical techniques may, due to their differences identified by that descriptive technique, be exclusionary and/or diagnostic in nature. If two samples are, for example, different in colour, they can be considered exclusionary and so the descriptive technique becomes diagnostic. However, if two samples have the same descriptive characteristics (for example, colour) it cannot be argued with any sense of propriety that the samples are diagnostically similar and therefore must be related by provenance to each other.

Similarly, two soil samples that are compared in a forensic investigation may exhibit very similar grain size distributions. This may be due to the fact that they are derived from a very similar provenance but may equally be due to having been derived from different locations with a similar environmental history. Likewise, the two samples may exhibit different grain size distributions even if they have derived from the same source due to the ‘three-dimensional nature of the soil profile’ mentioned above or indeed due to different sample sizes being compared to each other; for example 1 g of soil compared to 1 kg of bulk sample from the same source.

So grain size distribution analysis has many of the same pitfalls as the descriptive technique of colour analysis, although this does not stop the publishing of reviews of grain size distribution analysis in the forensic literature [7,8]. Equally, the transposition of the geological interpretations and parameters using grain size distribution analysis does not fit well in many of the exploratory studies which investigate the efficacy of grain size distribution analysis in forensic situations. Some authors have acknowledged the difference between geological and forensic approaches and have attempted to assimilate their experimental work to approximate real forensic case situations [13]. There appears to be no merit in highlighting the ability of a new, or even an old analytical technique for grain size distribution analysis using obviously different samples, taken from grossly different environments, often many miles apart [14]. It should be remembered that the quality of the results is matched only by the quality of the input [15].

The intention of this paper is to review the claims of the current literature on forensic applications of grain size distribution analysis and to provide casework examples where grain size distribution can provide some interesting and sometimes compelling interpretations useful in forensic enquiry. Some of the examples however, illustrate false-positive results and so provide a cautionary tale.

2. A literature review

Grain size distribution analysis of a soil or sediment sample by means of sieving was introduced into the forensic science literature as early as 1956 [11,16] as a well established geological technique [1,4,17]. As is the case with many of the ‘borrowed’ analytical techniques that have been applied to forensic investigation, a relatively large sample size (in the order of grams) is required for accurate and reproducible results to be obtained compared to what is usually available in forensic analysis. Dudley [18] pointed out in 1977 that the amount of sediment available in a forensic sample will generally preclude such geological techniques from being employed in routine forensic science analysis. He went on to propose a method for establishing particle size distribution of soil and sediment samples using a Coulter Counter, which was able to provide reproducible results for smaller quantities of sample (200 mg), and to provide discriminatory power between samples from different sources. Now there is a whole range of laser granulometers which can, at least for the same machine, reproduce grain size distribution curves from very small amounts of material (less than 10 mg) which in itself provides further problems for the forensic analyst (see Section 3.4).

The early work of Dudley was developed by Wanogho et al. [19,20] who demonstrated that it was possible to establish soil sample discrimination and provenance by comparing the median particle size, modal class interval of particle size and percentage of organic matter of different soil samples. Further work produced greater discrimination between samples by using a combination of the Coulter Counter and Automated Image Analysis systems in the analysis of samples. More recently still, Murray and Solebello [17] advocated direct observation and measurement by microscopy for forensic grain size distribution analysis.

Junger [21] and Sugita and Marumo [22] have both demonstrated the benefits of using grain size distribution analysis in combination with other analytical techniques in the quest to provide discrimination between samples. They showed that by utilising both colour analysis and grain size distribution analysis that soil samples from a particular geological area could be distinguished. These works however, are both based on experimental studies and may not approximate forensic casework reality. Restrictions such as limited sample size and mixing from a variety of different host materials and sources are not taken into account. Using either or both of the techniques of grain size distribution and colour it would prove practically