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Journey history reconstruction from the soils and sediments on footwear: An empirical approach

Journey history reconstruction from the soils and sediments on footwear: an empirical approach

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Abstract

The value of environmental evidence for reconstructing journey histories has significant potential given the high transferability of sediments and the interaction of footwear with the ground. The importance of empirical evidence bases to underpin the collection, analysis, interpretation and presentation of forensic trace materials is increasingly acknowledged. This paper presents two experimental studies designed to address the transfer and persistence of sediments on the soles of footwear in forensically relevant scenarios, by means of quartz grain surface texture analysis, a technique which has been demonstrated to be able to distinguish between samples of mixed provenance.

It was identified that there is a consistent trend of transfer and persistence of sediments from hypothetical pre-, syn- and post-crime event locations across the sole of the shoe, with sediments from 'older' locations likely to be retained in small proportions. Furthermore, the arch of the shoe (the area of lowest foot pressure distribution) typically (but not exclusively) retained the highest proportion of grain types from previous locations including the crime scene. A lack of chronological layering of the retained sediments was observed indicating that techniques that can identify the components of mixed provenance samples are important for analysing footwear sediment samples. It was also identified that the type of footwear appeared to have an influence on what particles were retained, with high relief soles that incorporate recessed areas being more likely to retain sediments transferred from 'older' locations from the journey history. In addition, the inners of footwear were found to retain sediments from multiple locations from the journey history that are less susceptible to differential loss in comparison to the outer sole. These findings provide important data that can form the basis for the effective collection, analysis and interpretation of sediments recovered from both the outer soles and inners of footwear, building on the findings of previously published studies. These data offer insights that enable inferences to be made about mixed source sediments that are identified on footwear in casework, and provide the beginnings of an empirical basis for assessing the significance of such sediment particles for a specific forensic reconstruction.

Keywords
Environmental trace evidence; footwear; quartz grain surface texture analysis; transfer; persistence; forensic reconstruction

1. Introduction

It is increasingly being recognised that empirical evidence bases are critical in forensic science, to ensure the development of robust and evidence-based practices for the collection, analysis, and interpretation of forensic samples [1, 2]. There is also a growing awareness that an appreciation of the complexity that exists in each forensic case, given that every case is different, needs to be incorporated into the forensic process from crime scene to court [3]. Therefore, the expertise of the scientist in bringing generalizable theory to bear upon the context sensitive variables pertinent to a specific investigation, is important for effective crime reconstructions [4-6]. This holds true for each step of the forensic process from the initial assessment of a crime scene and sample collection, through to the informed analysis and interpretation of a trace material and the derivation of intelligence and/or evidence.

The importance of establishing empirical evidence bases in forensic science has been articulated in the published academic literature [1,7,8,9,3]. More recently it has been acknowledged at the policy level, with calls for research that provides data to support the evaluation of evidential significance through structural studies that consider both the dynamics of various trace evidence indicators (transfer and persistence), and the subsequent development of robust methods for evidence interpretation [2,10,11]. An initial understanding of the nature [12] and dynamics of trace material [13] is of great importance to underpin the interpretation of evidence, and to ensure that the weight and significance of that evidence casework can be reliably and transparently assessed. Indeed, there is a growing body of published literature addressing the importance, and need for, empirical research to understand the evidence dynamics of different trace indicators (examples include [14-21]). Whilst it is not possible to fully replicate all the conditions of a specific forensic case, establishing general trends which can be feasibly recreated in line with case scenarios, offers valuable intelligence when incorporating a sufficient number of samples and experimental runs to account for variability. This approach offers the means to begin the development of empirical evidence bases for the interpretation of specific forms of evidence in forensic reconstruction.

2. An empirical evidence base for environmental trace evidence

The value of environmental evidence in forensic reconstructions is most often as a means of comparison between specimens of a known origin (the crime scene or alibi site) with material recovered from pertinent exhibits (footwear, vehicles, clothing). This approach can offer valuable insights as to whether two samples can be excluded from having a common provenance given the specificity of environmental indicators such as minerals [22-24], biological indicators [25, 26, 15, 27], and chemical composition [28-30].

In order to interpret the significance of environmental trace materials and develop robust forensic reconstructions it is important to base those interpretations on an evidence base [2,3]. Such an evidence base is necessary for the inferences and decisions being made at each stage of the forensic science process (crime scene, analysis, interpretation of that analysis and the presentation of the findings as intelligence or evidence, see Figure 1). The process is iterative rather than strictly linear, yet each stage is contingent on the previous stages [23, 31, 3].

Trace evidence cannot be considered to be pristine [13], but rather a product of many factors that are in operation during pre-, syn- and post-crime events (see Table 1). Given the sequential nature of the forensic process, it is particularly important to understand the dynamics of evidence at the first two stages of the process (transfer **and** persistence/preservation), to ensure robust inferences of the meaning and significance of the trace evidence that is pertinent to forensic reconstructions. This understanding requires consideration of both spatial and temporal aspects, especially when considered in the context of environmental evidence. For example, many of the factors that influence the dynamics of environmental evidence are due to changes that may occur over different time periods including the season in question, and the gap between the crime event and its detection and subsequent investigation [32]. It is also important to consider spatial variation as a result of different environments and localities that may have a bearing on the inferences derived from environmental evidence including different land use, climatic zones, geology [33].

Soil/sediment trace evidence is highly transferable [34] and has significant potential to contribute to the understanding of a journey history pertinent to a forensic reconstruction given the interaction of footwear with the ground. It has been established from experimental studies of sediments [35, 36, 20] and studies that have utilised proxies [37] that the sediments recovered from footwear are highly complex. For example, samples recovered from footwear exhibits are highly likely to be composed of materials derived from multiple provenances. This has a significant impact on the efficacy of some comparative analytical approaches as outlined by Cheshire et al. [29] and must be taken into account during the analysis and interpretation of environmental trace evidence.

This paper presents the results of a series of experimental studies that were designed to assess the behaviour of trace sediments adhered to footwear at different locations across the sole, and over different time periods (days to months). Both studies aimed to assess the presence and extent of mixed source soil/sediment profiles to enable a more rigorous forensic interpretation of provenance and increase the potential value of sediment evidence recovered from footwear. To ensure that the footwear was exposed to forensically relevant conditions, case scenarios were utilised throughout both studies

3. The spatial distribution of sediment on the soles of footwear

This study aimed to develop the work of Morgan *et al*. [37] and Stoney *et al.* [20] through an examination of the spatial trends in trace particulate retention on footwear within the context of pre-, syn-, and post- forensic event scenarios. Two pairs of popular walking shoes (designated T and K respectively) were walked in three different environments sequentially in order to reconstruct the transfer of trace materials to footwear from locations visited before, during, and after the commissioning of a hypothetical crime event. The experiment was repeated to provide eight footwear exhibits for sampling, for effective comparison. Multiple samples were then taken from the soles of each item of footwear to assess the degree of spatial variability in sediments recovered from different parts of the sole.

3.1. Materials and Methods

Three sites were chosen (to represent pre- syn- and post-forensic event locations) that exhibited different geologies within the UK (Figure 2). Site 1 was located in Lytham St Annes on the north-west coast of the UK, an area composed of undifferentiated Triassic sediments of a fine–grained nature. Site 2, the hypothetical crime scene, was Sunnyhurst woodland in the north-west Pennines in Blackburn Lancashire UK. The location was remote and quiet and provided a number of secluded areas that lacked natural surveillance [38], consistent with a number of body deposition sites that have been encountered in UK casework. The underlying geology contrasted to site 1 with complex sedimentary belts that included millstone grit. Site 3 was a popular walking area to the east of Oxford UK which is predominantly underlain by clays and bands of sandy soils. Surficial sediment samples were taken from each location to act as control samples. Indicative quartz grain types for each location were subsequently identified by light microscopy and prepared for analysis by Scanning Electron Microscopy (SEM) (after Bull and Morgan [23]).

The two pairs of walking boots were thoroughly cleaned in a washing machine and then the soles scrubbed with a clean hard bristle brush prior to each experimental run and then worn along a designated transect at each site within a 2-week period. Each transect was chosen to reflect a forensic scenario as closely as possible (site 1 pre-crime event activities, site 2 syncrime event activities and site 3 post-crime event activities). Each shoe was individually packaged in a plastic sample bag, transported to the lab with as minimal disturbance as possible, and then stored for laboratory sample preparation.

A template was created for this study based on Hessert *et al.* [39] that identified nine areas of the sole for sampling to ensure consistency in the collection of material from each of the designated areas of the shoe sole (Figure 3). Due to the potential spatial variability across the sole of a shoe, multiple samples were collected in this manner. The material adhered to each of the nine identified sole areas was removed by careful brushing of the sediments. Fifty quartz grains from each sample were then prepared for SEM analysis of the quartz grain surface textures (after Bull & Morgan [23]).

3.2. Results & Discussion

Four indicative quartz grain types were identified in the three control sites sampled, as described in Table 2.

The mean (n=9) composition of grains at each spot sampling point on each shoe at the end of the experimental runs is presented in Figure 4. Similarly, the mean values (n=8) for all 8 shoes are presented in Table 3. Grain types 3 and 4 (indicative of site 3) were the predominant grain type present (mean 64.3% and 19.3% respectively) with a good number of grain type 1 (indicative of site 1) also present (mean 14.9%). Very few, if any, type 2 grains (indicative of site 2, the hypothetical crime scene environment) were found (mean 1.8%).

There was a minimal contrast evident between the two pairs of shoes (see Table 3), with the Karrimoor^{TM} boots (K) retaining a higher proportion of type 2 grains in comparison to the Timberland^{TM} boots (T) (2.8% in comparison to 0.8%) and slightly lower proportion of type 3 and type 4 grains (85% (K) and 82% (T)). It was however, interesting that the proportions of type 1 grains were very similar between the two types of shoe (15.3% (K) and 14.5%(T)). The differences between the shoe types are however small, and the general trend observed for both shoes that that the greatest retention on both shoes was of grain types 3 and 4 from the final location, and the least retention on both shoes was from the second location (type 2).

It was possible to discern spatial variability across the sole of the two pairs of shoes (Figure 5 and Table 4). The samples taken from the arch area of the sole (MA and LA) where foot pressure is typically lowest, contained the highest proportion of grain types 1 and 2 (MA: 16.4% Type 1 and 2.3% Type 2; LA: 14.0% and 1.8% respectively) in comparison to the toe and heel areas (T, LC, and MC) which exhibited the lowest (e.g. T: 13.0% Type 1, 0.8% Type 2). These data illustrate that there is complexity in the way sediments are retained across a shoe sole.

The findings from this study support those of Stoney *et al*. [20] who identified that the last location visited was the dominant source of material on footwear soles. However, the findings of this study also indicate that material from prior locations (in this case quartz grains from locations 1 and 2) are not completely lost from the sole, and are potentially preferentially retained in the arch area of the sole. It may also be the case that these grains are retained in more 'recessed' areas of the sole as suggested by Stoney *et al*. [20]. The findings from this present study further illustrate the importance of the magnitude of the pre-, syn- and post-forensic transfer events, and the importance of an appreciation of the chronological stratigraphy, if it is encountered, when seeking to recover and analyse soil/sediment samples.

While the general pattern of the sediments retained on the soles of each item of footwear was relatively consistent (see Figure 4), there were small differences identified between the shoes, particularly with regard to the retention of type 2 grains. Overall the spatial trends across the sole were not as clear in this study as in the previous study utilising proxy sediments (Morgan *et al.* [37]). Unlike the proxy study, it was not possible to identify the individual layers of sediments of different provenance in a similar manner to the findings of Stoney *et al*. [20]. The significant complexity and variability of the behaviour of soil/sediment adhered to the soles of the footwear, provides valuable data indicating the importance of taking appropriate samples and choosing the best forms of analysis for those samples. An appreciation of this complexity should inform our approach to environmental trace evidence identified on footwear during forensic investigations, and arguably more empirical work is required to establish the mechanisms of this form of evidence dynamics.

The results from this study establish that there is a high degree of consistency in the transfer and persistence of sediments on the soles of footwear that have undertaken similar activity. Although these findings are valuable for forensic reconstruction over relatively short time scales, it is also important to understand the dynamics of such trace materials when more than three locations feature in the journey history over longer time periods (months in comparison to weeks).

4. The temporal dynamics of sediments on footwear

In order to address the impact of multiple locations over longer time periods, a third pair of shoes was worn for 30 days over a 4.5 month period. A shoe diary was kept throughout the duration of the experiment and five locations were visited in the UK, Spain and France (Figure 6 and Table 5). Control samples were collected from each discrete location visited, and at the end of each period of wear, a sediment sample was taken from the sole of each shoe.

On each of the 30 days of wear, each shoe was systematically sampled, ensuring that no part of the shoe was sampled twice. Sediment in the sampling area was carefully brushed and retained for laboratory analysis. In a similar manner to the previous study (presented in section 3), 50 quartz grains from each sample were prepared for SEM analysis [23, 40].

4.1. Results & Discussion

Five different and distinctive quartz grain types were identified which corresponded to the five different locations visited throughout the experimental timeframe (Table 5).

Figure 7 presents the results and illustrates that each quartz grain type persisted for relatively short periods of time after its initial introduction to the footwear, with the average length of quartz grain retention on the footwear soles being 8.9 days of wear (with a range of 5-13 days). For example, grain type 3 which was derived from southern Spain was present on the right shoe between days 70 and 87 (13 grains on day 70; 31 grains on day 78; and 3 grains on day 87), following a visit to the location on day 70 (during which time the shoes were worn for 7 days). Similarly, grain type 5 (indicative of the Coutras region in France) was identified on the shoes from day 115 (20 grains on the right shoe) and had fully decayed by day 137 (during which time the shoes were worn for 4 days).

Figure 7 also illustrates the presence of different indicative grain types on the footwear during the timeframe of the experiment. This demonstrates the mixture of quartz types from different provenances present on the shoe sole that occurs over a period of time. Locations 1 and 2 were visited on multiple occasions during the experiment. Locations 3, 4, and 5 were only visited on one occasion. One off transfers from these locations onto the shoes appear to exhibit a clear introduction and subsequent rapid decay phase (Type 3, 4 and 5). Those quartz types to which the footwear were exposed in a more ongoing manner (Types 1 and 2) exhibited multiple introductions and periods of decay in a manner that reflects the multiple additions to the footwear.

The presence of quartz grain type mixtures derived from different provenances, whilst easy to identify on the footwear throughout the experiment, did raise issues for interpretation. During the collection of the soil/sediment samples from the footwear, it was clear that it was not possible to identify the order in which the sediments had been transferred, thus confirming the assertions made by Morgan *et al.* [37] and the observations of Stoney *et al*. [20]. This finding has important implications during each phase of the forensic science process (Figure 1), including supporting the development of an appropriate framework for the optimal collection and analysis of sediment traces from footwear, and the subsequent exclusionary interpretation of its evidential value.

At the end of the experimental period the material from both the sole and the inside of the footwear was collected. Whilst the sole only retained grain types from locations 1 and 4 (left shoe) and 1 and 5 (right shoe), all 5 indicative quartz grain types were found present inside each shoe (see Figure 8). This was a particularly interesting finding and indicates that footwear may act as a depository or a trace material 'trap' over time. The order in which those sediments were collected within the shoe could not be easily determined. Therefore, the value of analytical techniques that do not require the homogenisation of the sample (such as SEM analysis of quartz grain surface textures) and are able to offer an analysis of mixed source samples, is illustrated. This finding provides useful information as to the history of the locations visited by the footwear in question when appropriate samples are collected from inside the shoe rather than from the sole. It is also interesting to note that the final location (location 5) of the journey chronology was not retained on the left shoe, and the frequent visits to location 1 appear to have resulted in a 'background level' of type 1 grains on the soles of both shoes.

5. Implications

These results offer valuable insights into both the spatial (across the sole of a shoe) and temporal (journey history) aspects of sediment transfer to, and persistence upon, footwear.

The findings have implications for the collection, analysis and interpretation stages of the forensic process.

The data highlight that across the sole of a shoe, a similar profile of pre-, syn-, and post-event sediments from three different locations were identified at each sampling point. There appears to be value in collecting multiple samples from the sole of a shoe, in order to identify several sources, especially given earlier locations from the journey history are likely to be present in low proportions. The arch area of the sole (MA and LA) appears to preserve a greater proportion of the poorly retained particulates and may therefore provide a useful sampling location when approaching the collection of environmental indicators from previous locations pertinent to a forensic reconstruction.

These findings indicate that in accordance with previous studies [37,20], the dominant material retained on the sole of footwear is derived from the last location the shoes were worn. The material from previous locations is likely to be only present in low amounts (with a mean 14.9% and 1.8% of grain types 1 and 2 respectively present (Table 3)) and the lack of discernible layering in the sediments (which contrasts with the proxy study of Morgan *et al.* [37] but is in accord with Stoney *et al.* [20]) indicates that analytical techniques suited to mixed source samples (such as microscopy) are needed. This is further corroborated by the findings of Cheshire *et al.* [29] who addressed the analysis of mixed source samples by various elemental analytical approaches and indicated that it was not possible to discriminate between control single source and mixed source samples (derived from the control source locations).

The data indicate there is a degree of complexity in the way that transferred sediment is retained on the soles of shoes. Similar patterns were identified in the composition of the sediments retained and recovered from across the soles of the first two pairs of boots (T and K) (Figure 5 and Table 3). However, the difference between the samples recovered from the left and right shoes in the temporal study (grains from locations 1 and 4 on the left shoe, and locations 1 and 5 on the right shoe (Figure 8)) when the shoes had been at the same locations at the same time, offers insights into the potential for differential sediment loss from footwear. This has implications for the interpretation of sediments that are present, and perhaps also what is absent, from a shoe sole. This may be due to the higher relief soles of boots T and K in comparison to the third pair of shoes (with a relatively low relief) in the temporal study, which offer more 'recessed areas' [20] for the retention of previously transferred sediments.

When seeking to reconstruct the journey history of footwear, whilst it appears that it will be unlikely to observe chronological layering of sediments on the shoe sole, the inners may be a valuable repository of materials that reflect the longer term journey history of an item of footwear. The findings from the second study displayed the presence of all five indicative grain types from the five different locations visited over a 4.5 month period inside of each shoe, highlighting that the interior of footwear can be a rich source of sediment particles. This contrasts with the outer soles of the footwear that predominantly retained sediments from the most recently visited locations, and suggests that analysis of both the sediments recovered from within and from the exterior of footwear may offer additional insights pertinent to forensic reconstructions where journey history is an important consideration.

6. Conclusions

This series of experimental studies has demonstrated that:

- There is a trend of transfer and persistence of sediment from different locations across the sole of the shoe, with sediments from 'older' locations likely to be retained in small proportions and sediments from more 'recent' locations likely to be retained in the greatest proportion.

- Collecting multiple samples from across the sole of a shoe increases the opportunity of identifying multiple sources of transferred sediments, especially when locations that were visited earlier in the journey history of the footwear are relevant to a specific forensic reconstruction.
- The arch of the shoe (the area of lowest foot pressure distribution) typically (but not exclusively) retained the highest proportion of grain types from previous locations.
- The lack of chronological layering of the retained sediments observed in this study indicates that techniques that can identify the components of mixed provenance samples are important for analysing footwear sediment samples.
- The type of footwear appears to have an influence on what particles are retained, with high relief soles that incorporate recessed areas being more likely to retain sediments transferred from earlier locations within the journey history.
- The inners of footwear are likely to be a source of sediments from multiple locations from the journey history that are less susceptible to differential loss (as with the outer sole) due to the depository nature of the inside of footwear.

This study offers important data that can form the basis for effective collection, analysis and interpretation of sediments recovered from both the outer soles and inners of footwear. The results add to the studies of Morgan *et al.* [37] and Stoney *et al*. [20], to provide insights into the dynamics of sediment transfer and persistence in forensically relevant contexts. The findings offer insights that enable inferences to be made about mixed source sediments that are identified on footwear in casework, and provide the beginnings of an empirical basis for assessing the significance of such sediment particles for a specific forensic reconstruction.

Table 1: Environmental and external factors that may influence the evidence dynamics at different stages of the forensic process prior to the interpretation stage.

Stage of the forensic process	Potential factors influencing evidence dynamics
Division of matter and transfer	Prior movements and transfers involving victim and offender
	Conditions of initial transfer: surface and trace material properties; pressure/ duration of contact
Persistence and tenacity	Persistence of material, a function of surface and trace material properties; suspect/ victim movement
	Secondary transfer from recipient surface to other surfaces
	Offender actions: counter-forensic clean-up (washing, burning, etc.), staging and post-event movements
	Victim actions: struggle, clean-up, and post-event movements
	Witness actions: Clean-up, assistance attempts and accidental disturbance

	Response personnel actions: saving lives, suspect apprehension and accidental disturbance
	Decomposition, predation by animals and insect activity
	Effects of different climatic/ environmental conditions
	Reincorporation/ redistribution of material
Collection	Disturbance/ alteration/ destruction of evidence during transport or storage
	Secondary transfer during packaging or transport
Analysis	Choice of analytical technique(s)
	Destruction/ disturbance of samples during analysis

Table 2: The four quartz grain types identified from the three sites examined during Study 1 (pre- syn- and post-forensic event locations) that exhibited different geologies within the UK

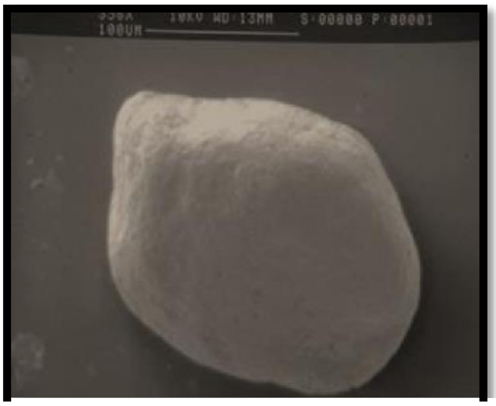
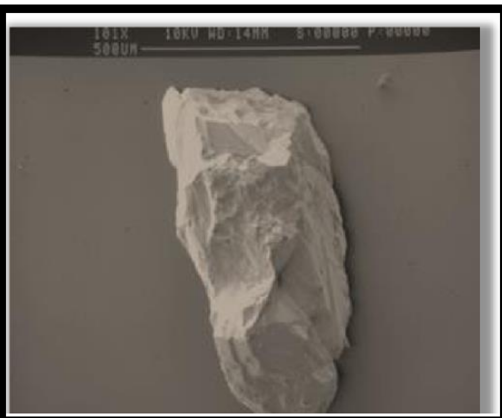
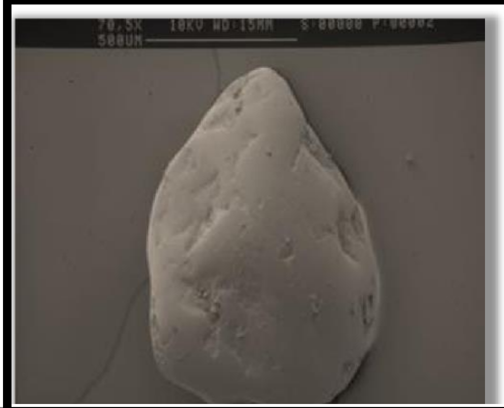
Grain	Description	Location
	**Type 1:** Sub round to round, medium to low relief uni-crystalline quartz with old subaqueous indenters (impacts) with subsequent extensive smoothing and mechanical wash.	**Site 1** **'Pre-crime event'** Coastline of Lytham St. Annes, north-west UK
	**Type 2:** Angular to sub angular mostly unicrystalline with extensive euhedral overgrowths (orthogenic) with no edge abrasion or impactors together with high relief, blocky breakages and sharp conchoidal fractures.	**Site 2** **'Crime event'** Sunnyhurst Woodland, North West Pennines in Blackburn, Lancashire, UK
	**Type 3:** Sub angular to round quartz unicrystalline but often micro-crystalline with extensive quartz overgrowths showing plates and terminations. No mechanical edge abrasion but evidence of extensive chemical solution rounding and etching. Algal filaments evident on many grains.	**Site 3** **'Post-crime event'** Shotover Hill park and woodland, Oxford, UK
	**Type 4:** Rounded to sub-rounded of low relief with old large conchoidal fractures but subsequent extensive chemical solution/precipitation. Often display a 'popcorn-like' appearance.	**'Post-crime event'** Shotover Hill park and woodland, Oxford, UK

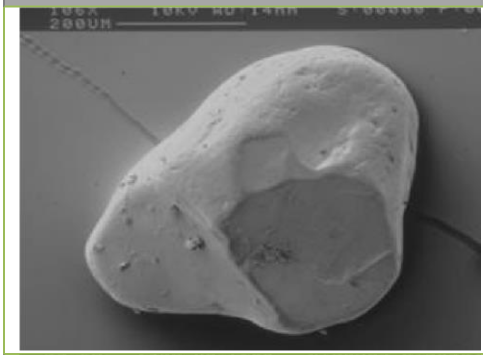
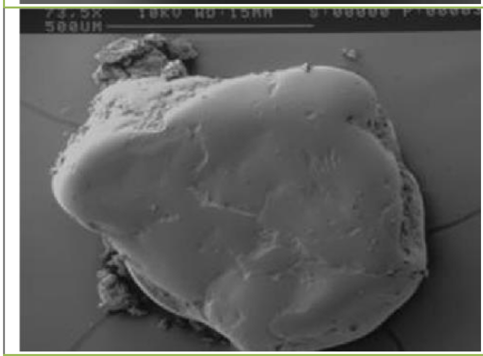
Table 3 The mean distribution of the four quartz grain types present on each shoe sole during Study 1

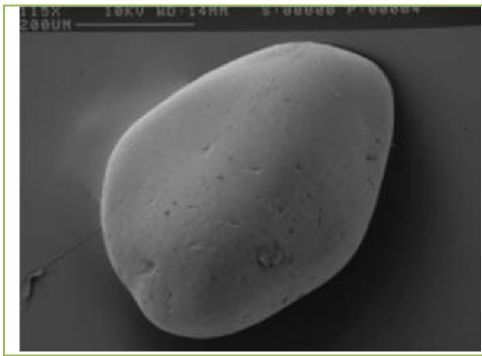
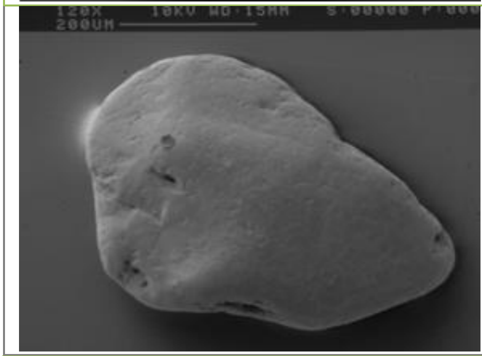
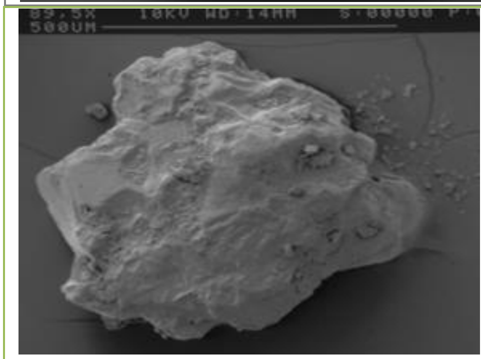
Shoe samples	% Type 1	% Type 2	% Type 3	% Type 4
Shoe T (n=4)	14.5	0.8	67.5	17.5
Shoe K (n=4)	15.3	2.8	61.0	21.0
Shoes T and K (n=8)	14.9	1.8	64.3	19.3

Table 4 The mean percentage of the four quartz grain types at each designated area of the shoe soles sampled during Study 1

Area on sole	% Type 1	% Type 2	% Type 3	% Type 4
T	13.0	0.8	67.9	18.5
H	14.4	2.0	66.6	17.0
4	11.5	2.3	67.0	19.5
3	15.9	1.5	64.8	18.1
MT1	10.9	1.0	66.8	21.4
MA	16.4	2.3	59.5	21.9
LA	14.0	1.8	66.1	18.1
MC	14.6	2.0	63.1	20.3
LC	14.4	0.8	65.4	19.5

Table 5 The five quartz grain types [23] identified from the five locations visited and collected from footwear during Study 2

Grain Type	Description	Indicative Region
	**Type 1:** Sub-angular to sub-round grains with diagenetically smoothed surfaces and conchoidal and late grain breakages.	**Location 1** Oxford, UK
	**Type 2:** Angular, sub-angular to subround grains, with extensive solution and characteristic agglomerates.	**Location 2** London, UK

	**Type 3:** Very well rounded grains exhibiting impact pits and chemical weathering v-pits.	**Location 3** La Cala de Mijas, Spain
	**Type 4:** Sub-angular/sub-rounded grains with extensive solution.	**Location 4** Ramsgate, UK
	**Type 5:** Distinctive micro-crystalline, angular and high relief grains with euhedral crystal faces	**Location 5.** Coutras, France

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Highlights

- The transfer and persistence of sediment onto different locations across the sole of footwear is tested.
- A lack of chronological layering was identified.
- The importance of techniques that can distinguish between multiple provenances is demonstrated.
- Inners of footwear may be rich sources of material indicative of a journey history.
- Data can inform the collection, analysis and interpretation of sediments from footwear in forensic reconstructions.

Figure 1 The forensic science process in forensic reconstruction

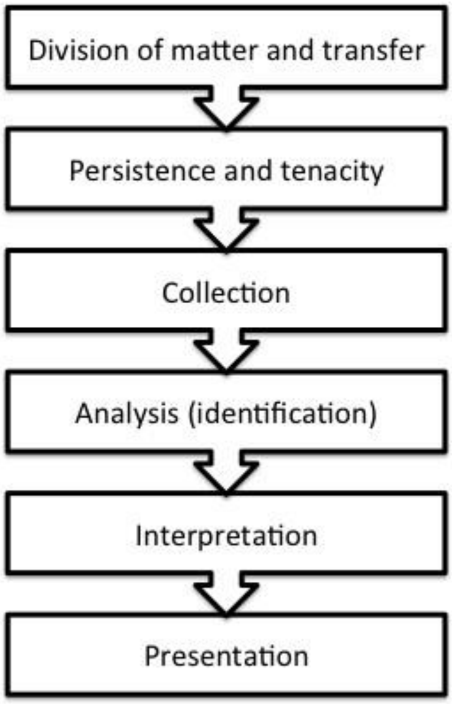


Figure 2: Map of three sites visited during Study 1

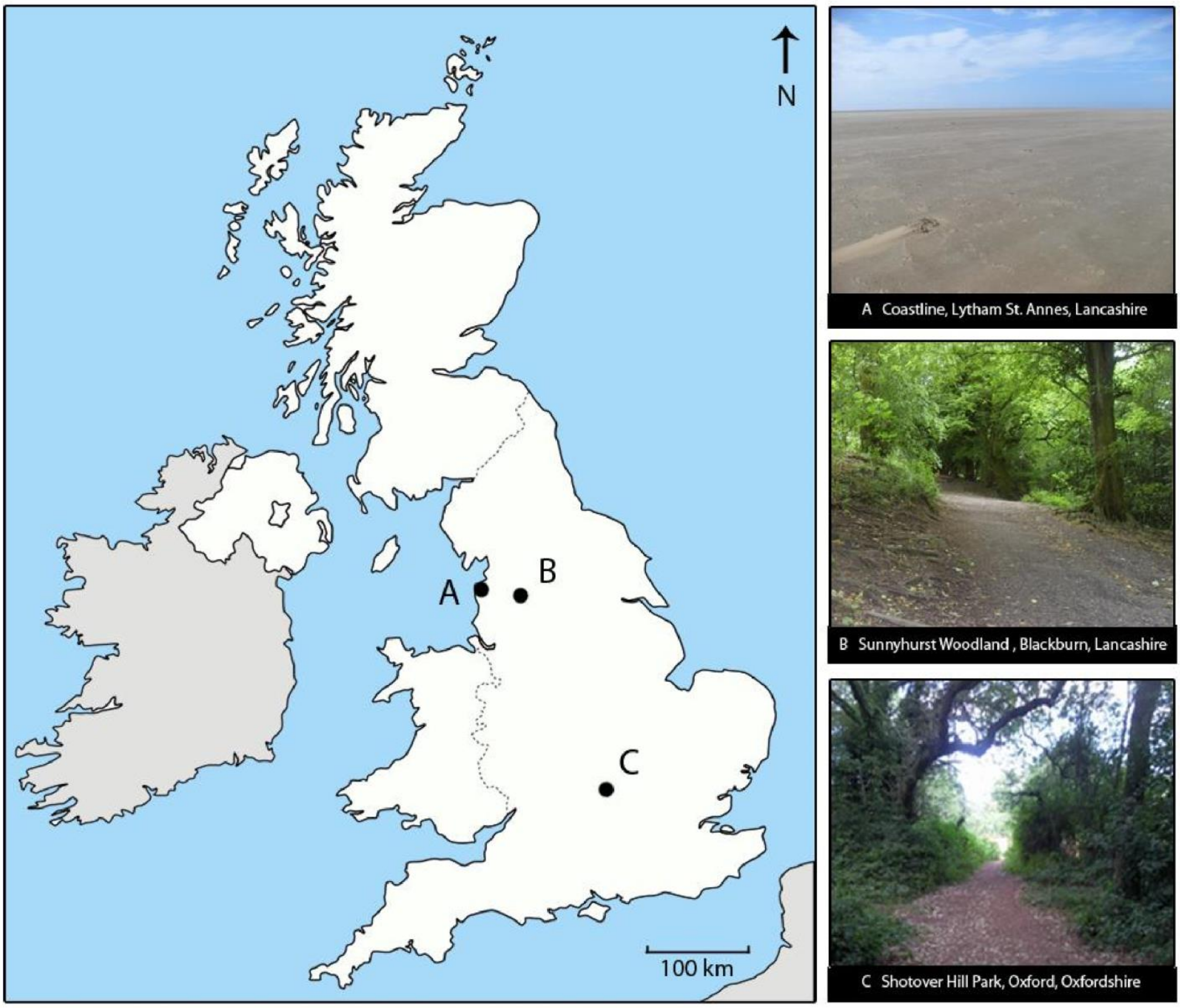


Figure 3 The demarked sampling areas of the shoe sole used in Study 1 (taken from Hessert et al. 2005)

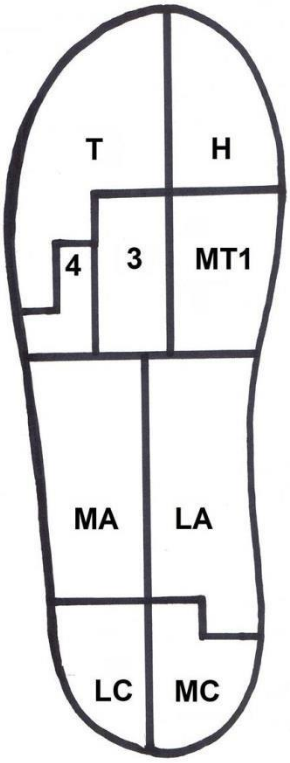


Figure 4 The percentage of grain types present on each shoe sole during Study 1

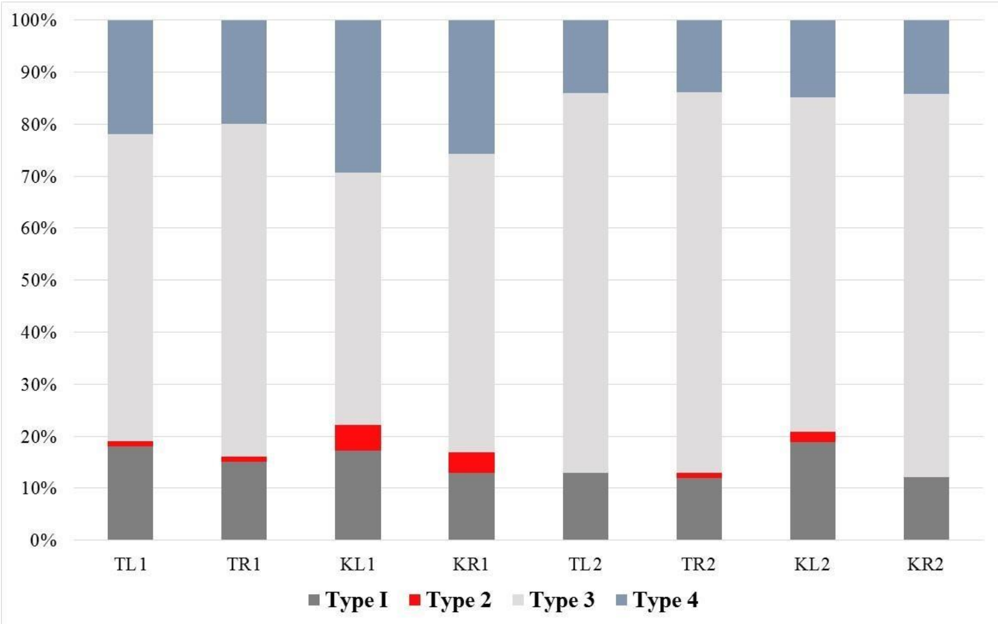
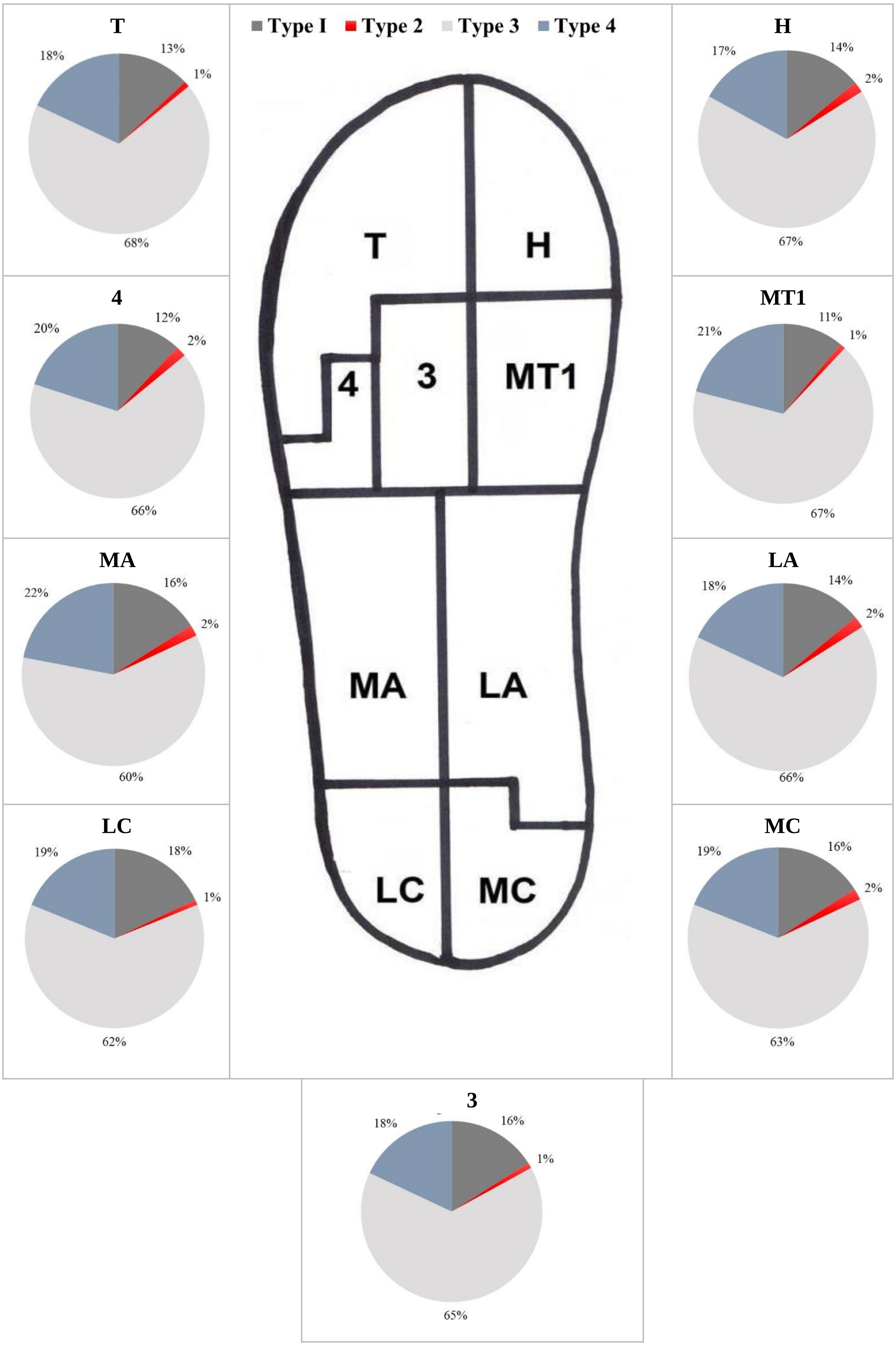


Figure 5 Mean spatial distribution of the different quartz grain types across the soles of the shoes in Study 1



<u>Figure 6</u> Map of three sites visited during Study 2

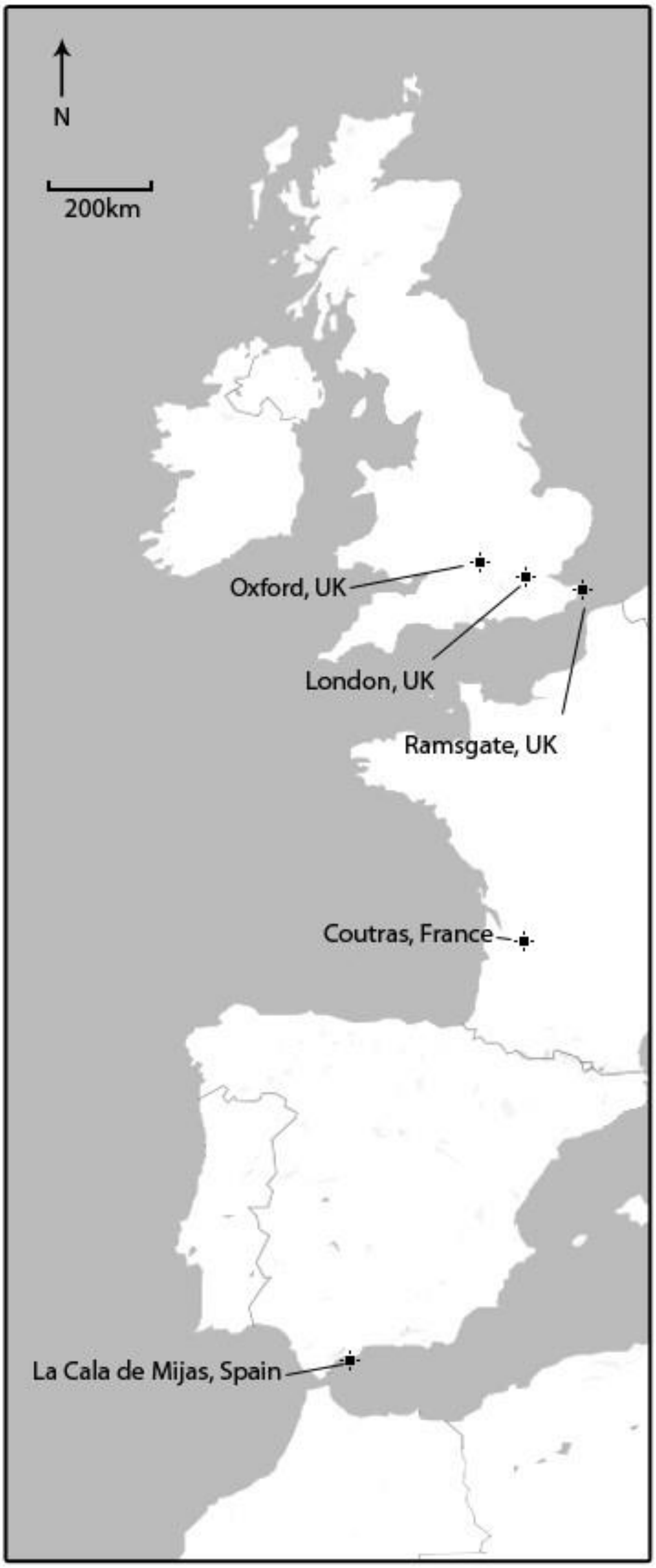
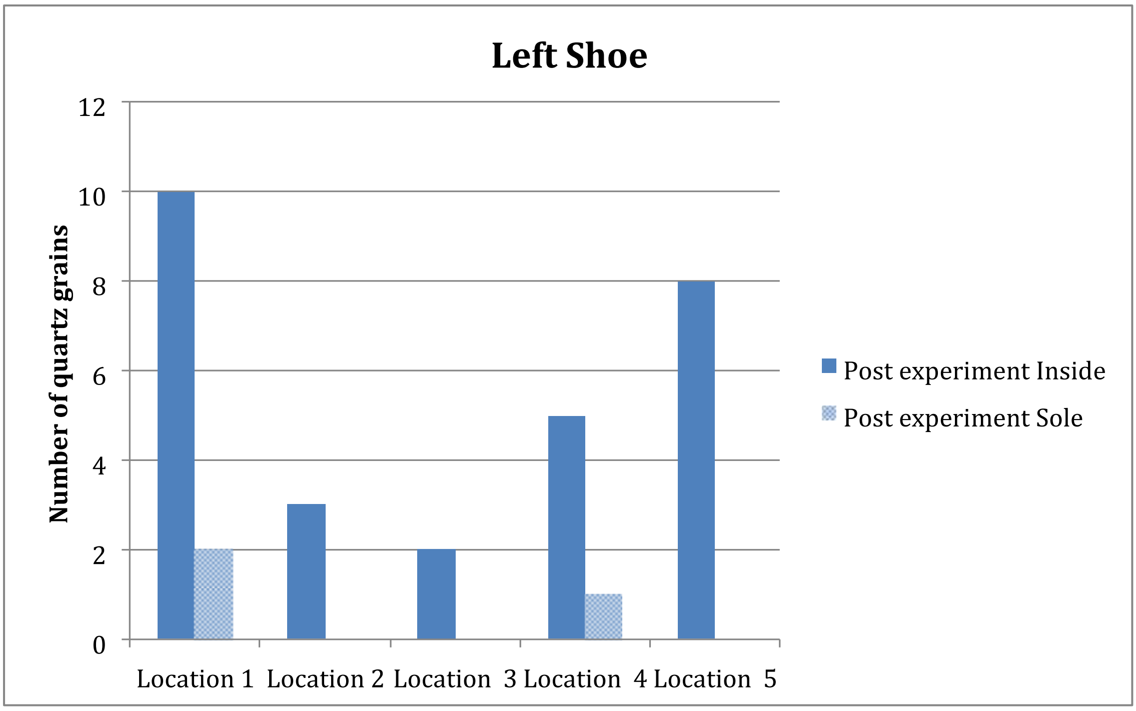
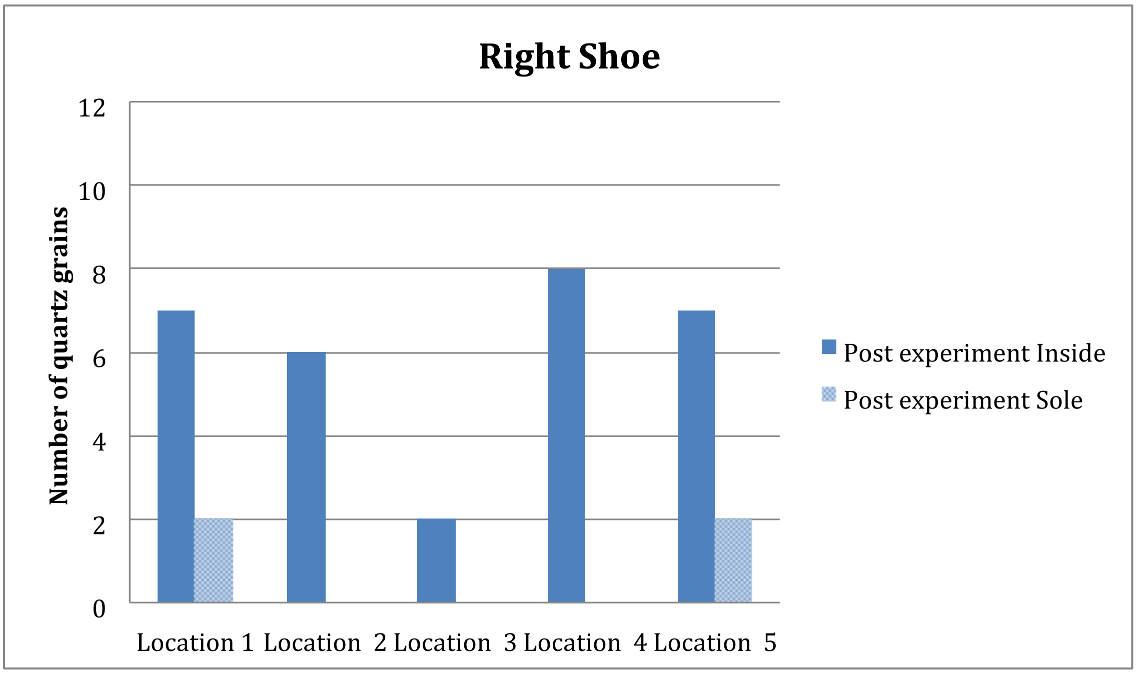

N
200km
Oxford, UK
London, UK
Ramsgate, UK
Coutras, France
La Cala de Mijas, Spain

Figure 7 Graphs to illustrate the persistence of quartz grain types on footwear soles during Study 2. For each graph y-axis: number of grains, x-axis: number of days.

Figure 8 Graph to illustrate the quartz grain types present inside and on the sole of the footwear at the end of Study 2.





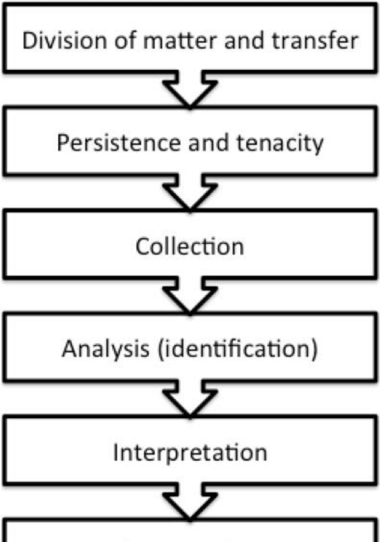
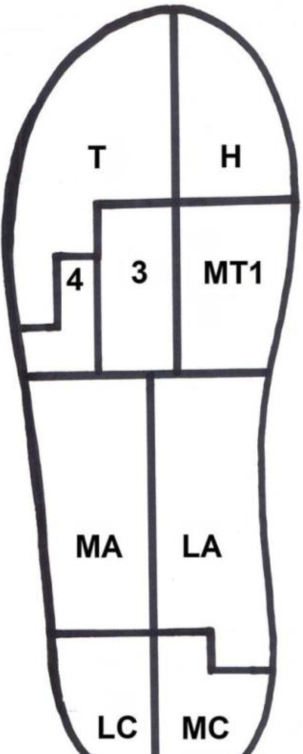

Division of matter and transfer
Persistence and tenacity
Collection
Analysis (identification)
Interpretation

Figure
1


N
A
B
C
A Coastline, Lytham St. Annes, Lancashire
B Sunnyhurst Woodland , Blackburn, Lancashire

Figure 2



T
H
4
3
MT1
MA
LA
LC
MC

Figure 3

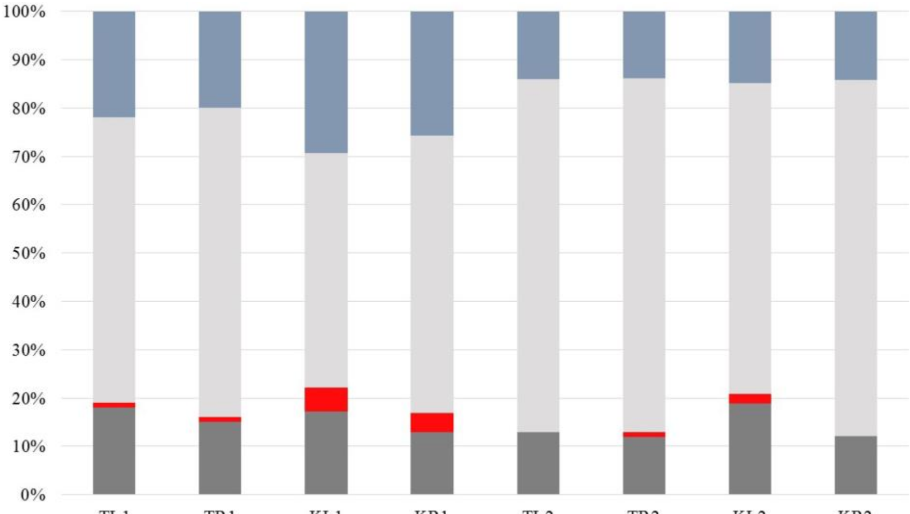

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%

Figure 4

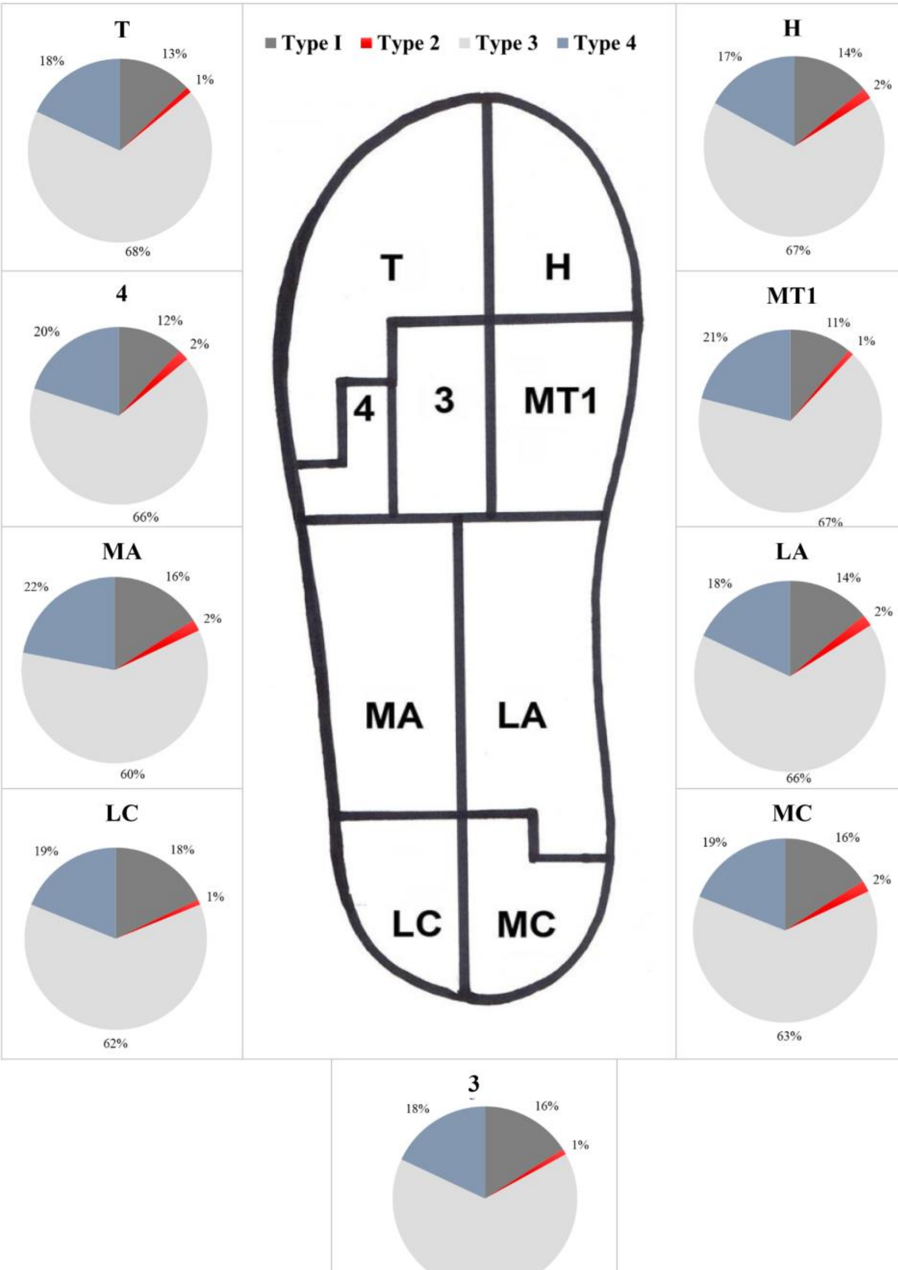

Type I
Type 2
Type 3
Type 4
T
13%
1%
68%
18%
H
14%
2%
67%
17%
4
12%
2%
66%
20%
MT1
11%
1%
67%
21%
MA
16%
2%
60%
22%
LA
14%
2%
66%
18%
LC
18%
1%
62%
19%
MC
16%
2%
63%
19%
3
16%
1%
18%
T
H
3
4
MT1
MA
LA
LC
MC

Figure 5

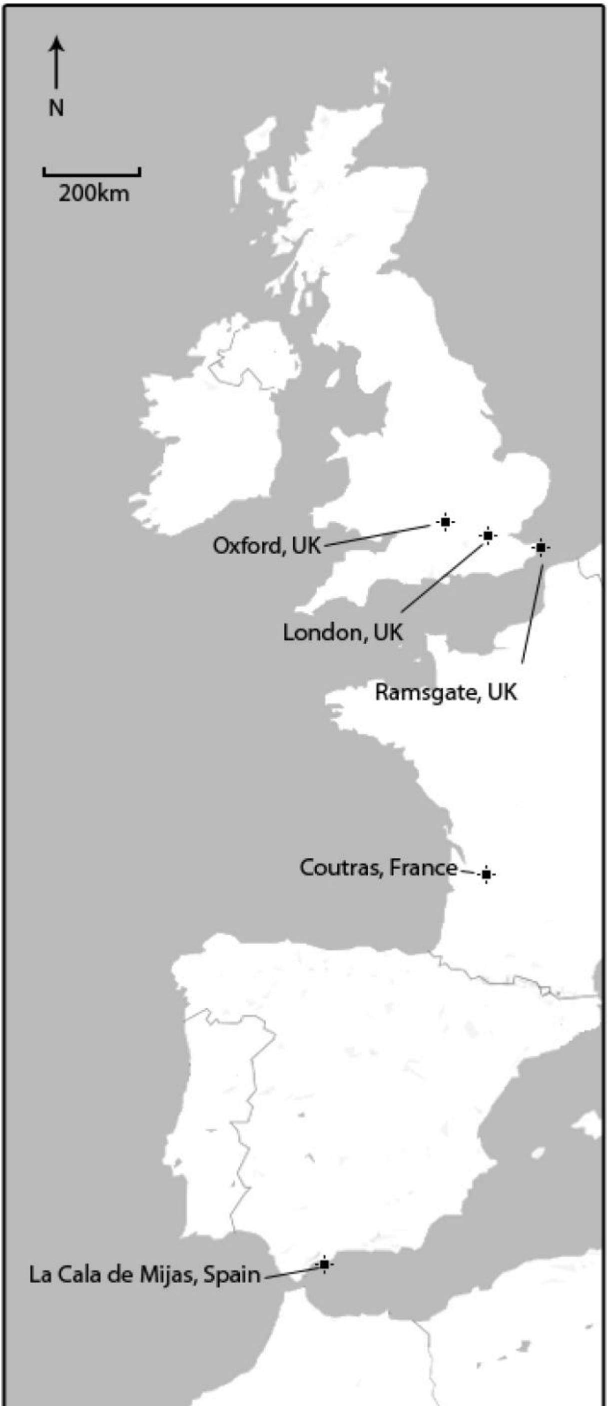
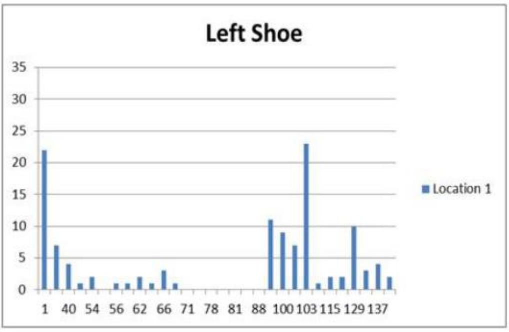
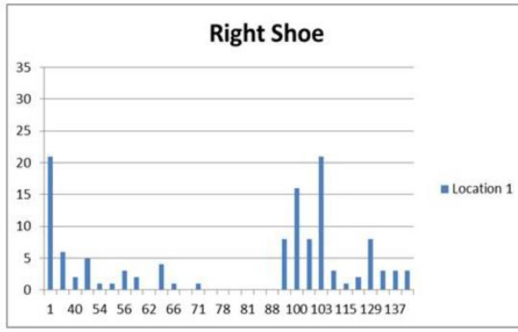

N
200km
Oxford, UK
London, UK
Ramsgate, UK
Coutras, France
La Cala de Mijas, Spain

Figure 6


Left Shoe
35
30
25
20
15
10
5
0
1 40 54 56 62 66 71 78 81 88 100 103 115 129 137
Location 1


Right Shoe
35
30
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10
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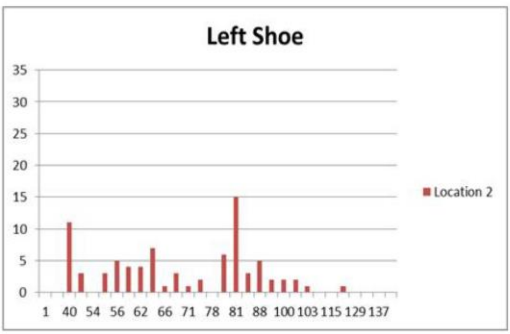
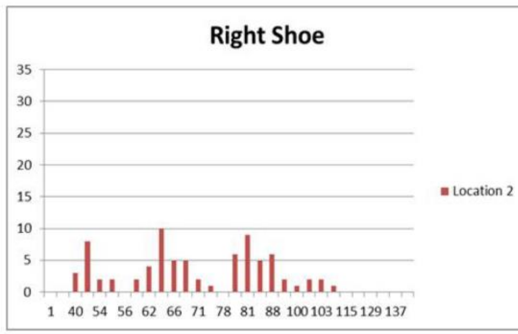
1 40 54 56 62 66 71 78 81 88 100 103 115 129 137
Location 1


Left Shoe
35
30
25
20
15
10
5
0
1 40 54 56 62 66 71 78 81 88 100 103 115 129 137
Location 2


Right Shoe
35
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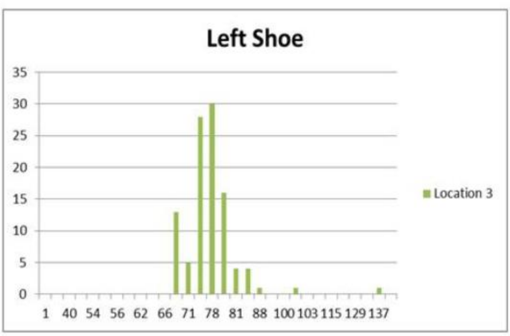
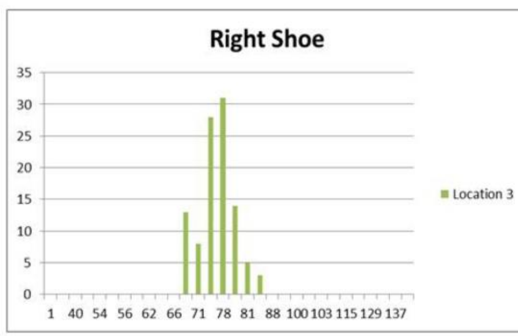
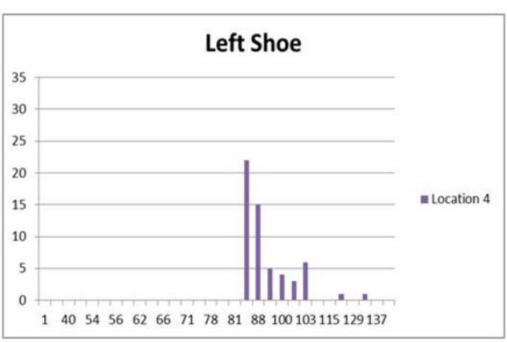
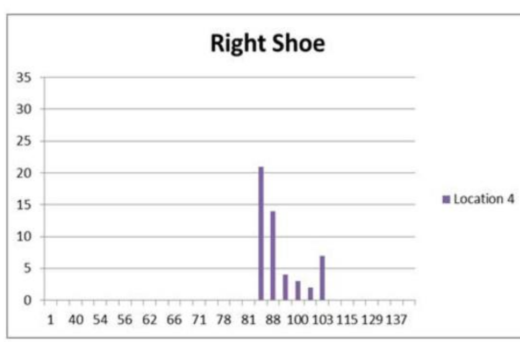
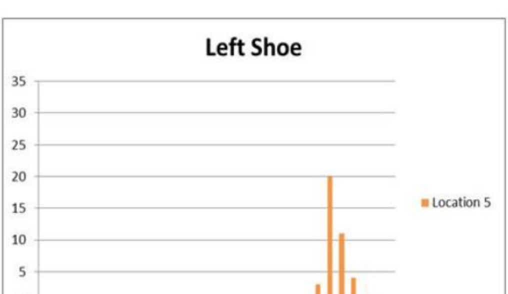
25
20
15
10
5
0
1 40 54 56 62 66 71 78 81 88 100 103 115 129 137
Location 2


Left Shoe
35
30
25
20
15
10
5
0
1 40 54 56 62 66 71 78 81 88 100 103 115 129 137
Location 3


Right Shoe
35
30
25
20
15
10
5
0
1 40 54 56 62 66 71 78 81 88 100 103 115 129 137
Location 3

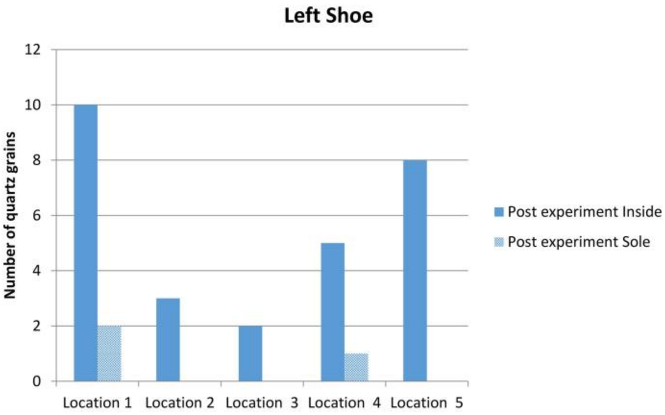

Left Shoe
35
30
25
20
15
10
5
0
1 40 54 56 62 66 71 78 81 88 100 103 115 129 137
Location 4


Right Shoe
35
30
25
20
15
10
5
0
1 40 54 56 62 66 71 78 81 88 100 103 115 129 137
Location 4

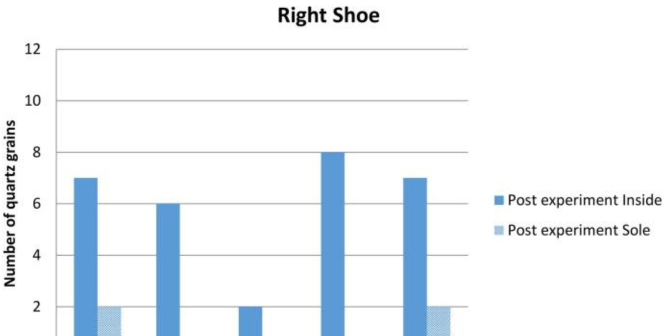

Left Shoe
35
30
25
20
15
10
5
Location 5


Right Shoe
35
30
25
20
15
10
5
Location 5

Figure 7



Left Shoe
12
10
8
6
4
2
0
Number of quartz grains
Location 1
Location 2
Location 3
Location 4
Location 5
Post experiment Inside
Post experiment Sole



Right Shoe
12
10
8
6
4
2
Number of quartz grains
Post experiment Inside
Post experiment Sole

Figure 8