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Article

# Tracking the Route Walked by Missing Persons and Fugitives: A Geoforensics Casework (Italy)

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**Abstract:** Criminal investigations aimed to track the route walked by Missing Persons and Fugitives (MPFs) usually involve Intelligence analysts, military planners, experts in mobile forensics, traditional investigative methods, and sniffer dog handlers. Notwithstanding, when MPFs are devoid of any technological device and move in uninhabited rural areas devoid of tele cameras and densely covered by vegetation, tracking backwards the route walked by MPFs may be a much more arduous task. In such complex cases, a very efficient approach may consist in comparing the geological traces found on the MPFs with soils and plants exposed in the event scenes. In particular, the search for peculiar or rare particles and aggregates may strengthen the weight of the geological evidence comparisons. A match of mineralogical, textural, and botanical data may demonstrate the provenance of the traces from the soil of a specific site, linking in this way the MPFs to the scene of events. Based on the above, the present paper reports geological and botanical determinations accomplished for a “mediatic” casework. Results allowed to ascertain a general high degree of compatibility among traces collected on the MPFs and on the soil from the scene of events. The most significant positive matches, based on the finding of a ten of peculiar and rare particles and assemblages, allowed reconstructing a route about 1.1 km long, as the crow flies, on the event site. Notwithstanding this procedure was extremely time consuming and available only in a backwards reconstruction linked to the MPFs’ findings, it was of uttermost importance in strengthen the inferences proposed, where other methods could not provide any information.

**Keywords:** geoforensics (forensic geology); sedimentology; provenance; comparative analyses; optical microscopy; SEM-EDS; image analysis; missing persons and fugitives

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## 1. Introduction

Since the 2001 September 11 attacks and the Global War on Terror, the organizational structures and procedures devoted to the search for persons of national and international interest assumed an important role in the global counterterrorism strategies [1,2].

In particular, criminal investigations, aimed to track the route walked by Missing Persons and Fugitives (MPFs) in the urban and rural territory, usually involve Intelligence analysts (IMINT - Imagery Intelligence, OSINT – Open Source Intelligence, etc.), military planners, experts in mobile forensics sniffer, dog handlers, and traditional investigative methods [1,3]. Notwithstanding, to track backwards the route traversed by the MPFs may be a very arduous task, when the MPFs do not bring with them mobiles, GPS or any other technological devices and they move in uninhabited rural areas of the countryside devoid of security or private tele cameras and covered by dense vegetation. In such peculiar circumstances, as demonstrated since the XVIII century [4–6] the mapping of the paths walked by the actors of crimes can be realized thanks to comparative analyses based on geological and soil evidence collected on the crime actors and the scenes of the events, respectively. In Germany, the study of the stains of stratified soil on the footwears and trousers of a homicide suspect allowed the expert Georg Popp to link him to a sequence of different sites of the crime scenes and suspect’s home [4]. Nowadays, once the MPFs are found, dead or alive, a very efficient backwards criminalistic approach may consist in comparing both the geological traces and micro traces found on the MPFs’

belongings (unknown samples, i.e. of unknown provenance) with soils/sediments and plants exposed in the sites of finding, last sighting, *alibi*, and investigative interest (known samples, i.e. of known provenance). A match of the comparative analysis data may demonstrate the provenance of the unknown traces from a site showing analogous microenvironmental characteristics [7].

With this in mind, the present research reports the scientific method and main results of geological comparative analyses, requested by the judicial authority for solving a “mediatic” forensic casework occurred in Italy in the countryside a few years ago. Geological data allowed tracking the route walked by the two MPFs revealing very useful information for the consequent criminological and criminalistic implications.

Notwithstanding the criminal proceeding was archived, the Author preferred to deal with the data and inferences described in the following, presenting MPFs/victims, samples, and sites in anonymously way.

## 2. Geoforensics

Forensic Sciences, based on a holistic approach, use different multidisciplinary and transdisciplinary disciplines, such as criminology and criminalistics (forensic medicine, forensic pathology, dentistry, toxicology, serology, anthropology, archaeology, entomology, physics, biology, chemistry, computer science, geology, and botany) [8,9].

Geoforensics (or Forensic Geology) is a discipline 150 years old, probably originated also before during the Roman empire period. In the historical criminological/criminalistic scenario, a few examples of worldwide mediatic serious crimes solved by forensic geologists may be related to cases of kidnapping and homicide of victims, as in the case of the honorable Aldo Moro (1978, Italy) [10] or the agent of the DEA (Drug Enforcement Administration) Enrique Camarena Salazar (1985, Mexico) [4], or cases of searches for MPFs, such as the terrorist Osama bin Laden (2001, Afghanistan) [11].

Forensic Geology applies principles, methods, and techniques of the earth sciences for solving criminal cases [12–29]. These latter mostly concern crimes against human being (homicides, kidnappings, sexual violence, robbery) and animals, property (burglary, damaging), environment (environmental disaster or pollution) [30–37], and counterterrorism [11]. In particular, in serious crimes occurred outdoor in the countryside, such as homicides or kidnappings, it is high the probability that useful info-investigative diversified data may be obtained especially in ascertainments aimed to define:

1. Their *pre-mortem* presence on the scene.
2. Their walking route on the site.
3. The possible transfer of the victim’s corpse in secondary crimes scenes.
4. The modality of victim’s death.

The stratigraphical approach may be of paramount importance when micro-stratigraphy sequences on belongings of the suspects are recognized and sub-sampled. In such circumstances, the stratigraphy principle of superposition will assist in the reconstruction of the timing of the events (Somma 2023a).

Main forensic analyses and activities devoted to criminal cases may involve:

- a. Comparative analyses and provenance studies, based on mineralogical, petrographic, sedimentological, palaeontological, and geochemical investigations [38–54]. Forensic comparisons between two or multiple samples of geological and soil traces and micro traces are aimed to ascertain whether they originated from different sources [51]. When specimens result indistinguishable, the possibility that a single source is the provenance area of the samples cannot be excluded [51]. Such investigations may allow to link the actors of a crime (suspect and victim of a homicide) to the crime scene or the scene of events.
- b. Mineralogical, geochemical, and palaeontological analyses.  
These studies, also based on comparative analyses on geomaterials (such as gemstones, fossils, artworks), may allow to ascertain the authenticity and provenance, as in the cases of frauds, product tampering, art crime, conflict minerals, and fossil fakes [51,55–59].

- c. Remote sensing, geological, geochemical activities, together with geophysical shallow prospections and applied geology investigations.

These investigations [60–73], also based on comparative analyses, may allow to characterize the environmental matrices (soil and water) and the related underground in cases of environmental crimes. In particular, the remote sensing surveys for localizing MPFs, dens of terrorists, or in general illicit activities, are carried out on photos, ortho imaging, videos, and photograms, in the visible, ultraviolet, infrared, elaborated in GIS systems [61,62,64–70]. Such investigations may also be applied to depict and search for shallow clandestine gravesites and concealments [74–92].

Main comparative analytical methods are used for characterizing composition, textures, and structures of the inorganic, organic, and anthropogenic components of the geological and soil evidence (Table 1).

**Table 1.** Main methods and techniques usually applied for comparative analyses of forensic geological evidence in laboratory. \* Instruments also portable in the field.

<b>Matrices</b>	<b>Methods and Techniques</b>	<b>Analysed Characteristics</b>
Geological samples	Spectrophotometers / Munsell charts / Computational Methods	Colour
Geological samples	Mechanical siever / Laser Diffraction Particle Size Analyzer / Coulter counter / Particle Size Analyzer through automated microscopy and image analysis for measuring particle size and particle shape	Texture (grain size, morphology)
Geological samples	Optical Microscopy (OM) by stereo microscope*, in transmitted and reflected light, with tele camera and workstation for image analyses	Texture / Structure
Geological samples	Optical Microscopy (OM) by polarizing microscope, in transmitted and reflected light, with tele camera and workstation for image analyses	Mineral composition / Texture / Structure
Geological samples	Powder X-Ray Diffractometry (PXRD)	Mineral composition
Geological samples	Scanning Electron Microscopy with Energy Dispersion System (SEM-EDS) / Quantitative Evaluation of Minerals by Scanning Electron Microscopy (QUEMSCAN)	Composition / Texture / Structure
Geological samples	Scanning Electron Microscopy (SEM)	Composition / Morphology
Geological samples (Fossils)	X-Ray Fluorescence (XRF)*	Elemental qualitative determination
Geological samples	$\mu$ -RAMAN spectroscopy* / FTIR spectroscopy	Molecular qualitative determination
Geological samples	Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) / Inductively Coupled Plasma – Optical Emission Spectroscopy (ICP-OES) / Instrumental Neutron Activation Analysis (INAA)	Elemental quantitative determination

The main parameters and characteristics investigated in the inorganic and anthropogenic fractions may be synthesized as follow (Table 1):

1. Colour.
2. Particle size.
3. Structure and texture.
4. Fossil content.
5. Mineralogy.
6. Chemical and chemical-physical composition.

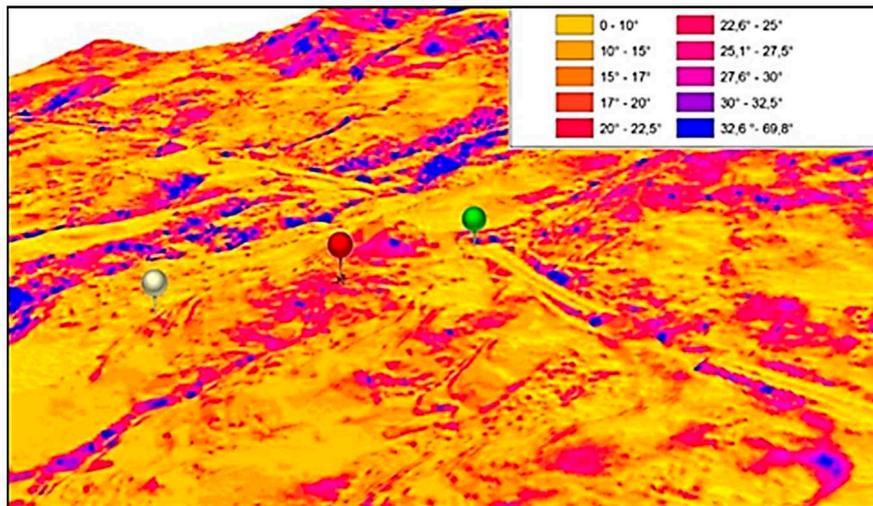
The organic component, vegetal and animal, may be very abundant and important in the sample and once identified must be separated and submitted to the specialistic analyses of forensic botanists and entomologists, respectively. In particular, the finding of plant remains such as seeds, thorns, leaves, and pollens or their associations demonstrated to be very useful for linking evidence to a specific environment of provenance and for dating the period of transfer the trace [10,93–99]. New advances on forensic biology on the vegetal DNA identification may demonstrate the transfer of a specific plant DNA to an actor of crime. Such multi-disciplinary scientific approach on inorganic and organic evidence based on standardized protocols [100] and procedures reported in the international scientific literature may provide very useful data especially in crime scenes occurred in the countryside.

On the base of the above, it is evident that the ascertainment of the compatibility or similarity among geological and soil traces and micro traces of unknown provenance and soils and sediments of known provenance may assume a fundamental role in the geoforensics investigations. Notwithstanding, a simple compatibility among forensic specimens may not be decisive if not supported by strong geological, biological, physical, and chemical evidence. As a matter of facts, in contrast with individual characteristics (DNA, fingerprints), the geological and soil evidence being provided of class characteristics [9] needs to be carefully investigated for obtaining assessable data. The main task for achieving a high probatory value of the evidence presented to the court should be aimed to gain the highest number of geological characteristics and peculiar particles [4] to compare.

If the wide range of compared characteristics will provide evidence that there is a match or not among compared forensic specimens, it is possible to link or exclude with a high level of probability, the actors of a crime with or from the criminal act ascertaining that the compared specimens possess features analogous to those of a specific microenvironment from which these may derive [19,23].

## 2. Criminal Casework

A few years ago, an Italian locality of the countryside was the sad scenario of a criminal case of presumed kidnapping, concluded after sometimes with the finding of the human remains of two subjects. One day, the two left their home, and after a car accident, they quickly abandoned their car and belongings, departing the site. They disappeared into thin air, and nobody saw them in the surrounding areas. A few days after their disappearance, the two MPFs were found lifeless in two separate sites not too far from the site of the car accident (Figure 1). Victim 1 was found about 1.1 km away, as the crow flies, from the place of the last sighting (Figure 1), under an infrastructure, a few meters away. One shoe was found on the ground near the corpse, the other one in suspension attached to a shrub. Victim 2 remains were approximately at 0.5 km from the site of the car accident, halfway between it and the place where victim 1 was found (Figure 1). The body was found skeletonized and bones were found dispersed in an area (wide about 800 m<sup>2</sup>) of the dense Mediterranean maquis.



**Figure 1.** 3D model of the slope, elaborated in ArcGis, showing the localization of the car accident site (green sphere), the victim 2's finding site (red sphere), and the victim 1's finding site (whitish sphere). Legend: Ranges of inclinations of the slope. Source: Author.

The shoes of victim 2 were found at a few tens of meters of distance from the remains, at higher altitude.

The judicial authority disposed an impressive investigation, covering a wide spectrum of traditional and scientific investigations in the field of inter- and trans-disciplines, usually used for characterizing at 360° serious crimes happened outdoor in the countryside, such as legal medicine, forensic pathology, odontology, entomology, toxicology, veterinary, psychiatry, engineering, computer science, physics, geology, and botany.

In particular, considering that the two MPFs had not with them any mobile, GPS, or electronic device, the judicial authority gave to the Author the task to ascertain the active *pre-mortem* presence of the two MPFs in the event site and reconstruct the route walked by them, if possible.

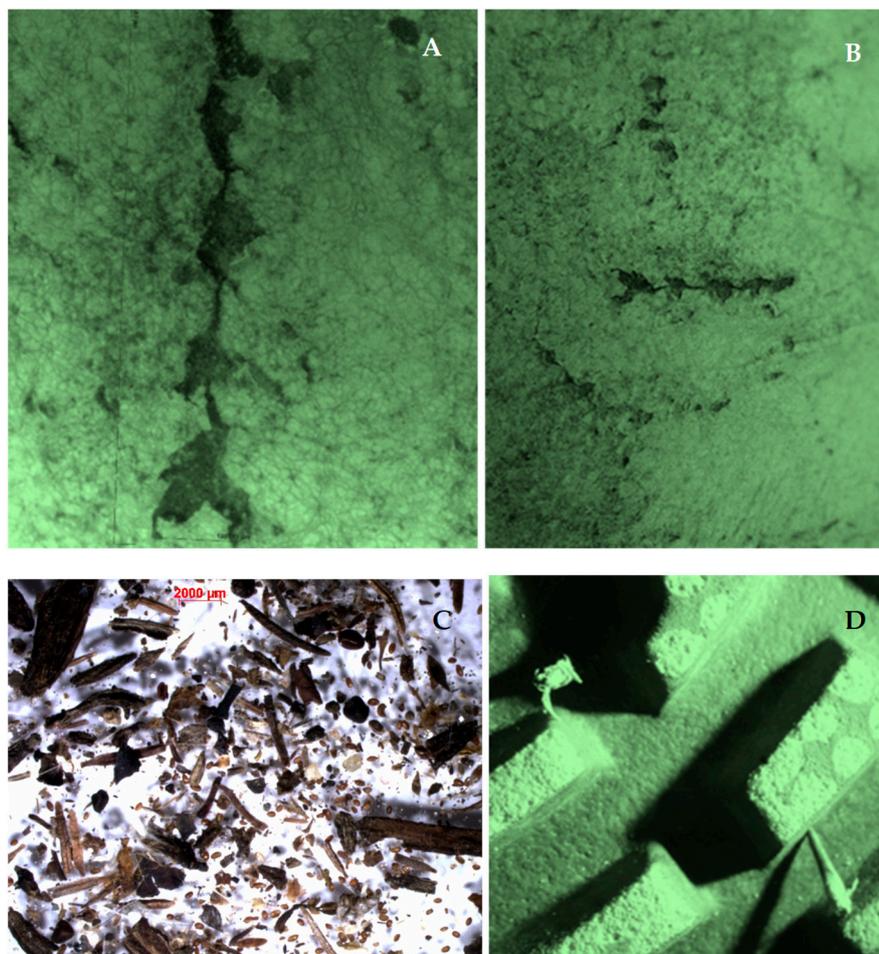
## 2. Materials and Methods

Notwithstanding geological and botanical traces are mostly provided of class characteristics, a sort of “fingerprint” of the specimens [101] may be identified by means of a careful examination of both peculiar and rare grains [4], minerals, composition, textural features and peculiar assemblages of minerals and vegetal remains studied in both the unknown and known specimens to be compared. A clever expert should be able to carry out comparative analyses based on a wide range of parameters and characteristics.

With this in mind, the comparative analyses were performed tracing the “fingerprints” of both geological trace evidence (related to the two MPFs and their belongings) and soils (related to the event scene and localities of investigative interest).

Geological trace evidence (unknown samples) was sampled searching for traces under magnifying glass (10x, 20x, 30x) on the two cadavers during the autopsy, and successively on their belongings and skeletal remains by using a stereomicroscope in the laboratory of forensic geology. Special attention was devoted to the footwears, being these latter in strictly contact with the topsoil during the movement of the MPFs. Such contact, as stated by the Locard exchange principle, may allow an easy transfer of inorganic and organic (plant and small animal remains) particles from the topsoil to the footwears, linking in such a way the subject to a specific site [102,103].

The MPF 1's shoes resulted to be very dirty and scratched (Figure 2A,B), very rich in vegetal material (mostly seeds and thorns inside the shoes and fixed on the soles and laces, Figure 2C) and with inorganic traces (Figure 2C).



**Figure 2.** Microphotographs taken under stereobinocular microscope and reflected light. A-B) Deep scratches of the leather of the MPF 1's shoes upper part, presumably due to the impact and abrasion of thorny plants during the walking of the MPF 1. C) Most common appearance of questioned trace showing a very abundant vegetal component (*Erica arborea* leaves, capsules, and seeds, branches, thorns, and humus collected in the internal part of the shoes, see later), transferred to MPF1's shoes inner part during the walking in a woody area. D) Two thorns of *Cytisus infestus* fixed in the sole of the MPF 2's shoes, transferred during the walking of the MPF 2's shoes during the walking in the scene of events. Plants determined by Fabio Mondello. Source: Author.

The MPF 2's shoes were intact, pair up, and with inorganic and vegetal traces (mostly thorns fixed on the soles).

Multiple soil evidence (known specimens) was collected on the sites of the human remains' findings (known samples) and the localities trampled by the victims with the same footwears, in the days immediately before the disappearance event, for exclusion purposes. For the same aim, footwears of the two MPFs were also sized for characterizing the usual type of traces present.

A few hundreds of samples were collected overall.

Multiple geological trace and soil evidence was firstly analysed under stereomicroscope [4], as it was. Specimens were treated, sieved, and separated. Soil samples were sieved mechanically or analysed by laser diffraction technique. Trace samples were separated on the base of the diameter by means of image analyses. Different sub-samples on the base of the grain size were obtained.

Optical analyses in stereomicroscopy and SEM-EDS were aimed at investigating the following main parameters and characteristics: color, coating, shape, habitus, luster, particle size, texture, fossil content, mineralogy. Stubs of the samples with selected particles were prepared for the SEM-EDS forensic characterization, in order to investigate both morphological features at higher magnification and composition. Smear slides of the specimens were observed under petrographic microscope for an expeditious characterization of mineralogy and fossil content. The different classes of parameters

and characteristics were quantitatively characterized counting each particle of specimen (at least 100 particles for sample) for the most widespread grain sizes. Particle morphometry was determined by means of image analysis software. The Riley Sphericity ( $\sqrt{\frac{D_i}{D_c}}$ ) ( $D_i$ : the diameter of the largest inscribed circle,  $D_c$ : the diameter of the smallest circumscribing circle) was applied for the two-dimensional sphericity measurement. The roundness was determined by means of comparative charts.

The protocols used for geological analyses were conformed with how willing in Bourguignon et al. (2019) [100] and the international literature.

Botanical evidence was collected on the victims, their belongings, or separated from the geological trace evidence. Vegetal elements were sampled on the plants growing on the sites of the events and other sites of investigative interest or separated from the soil evidence. Morphological determinations on plants (*algae* included) were accomplished under microscope by experts in systematic botany.

Particle size analyses and separations were performed by using:

1. Mechanical sieve (Retsch AS 200 control model) with sieves (2000  $\mu$ , 1000  $\mu$ , 500  $\mu$ , 250  $\mu$ , 125  $\mu$ , 63  $\mu$ ).
2. Laser diffraction granulometer (Malvern Instruments Mastersizer 2000) equipped with workstation (Malvern Instruments) (Figure 3A).
3. Motorized stereomicroscope equipped with Zeiss digital camera and workstation (image analysis software for morphometric investigations, Zeiss AXIOVISION) (Figure 3B).

Analyses were performed on particles contained in Petri capsules, glass slides, smear slides, stubs with carbon adhesive, by using the instruments provided of the following characteristics:

1. Stereomicroscope (Leica MZ 12, magnifications from 8X to 100X).
2. Motorized stereomicroscope with reflected and transmitted polarized light (Zeiss Stereo Discovery.V20; magnification from 3.8X to 530X with optical zoom) equipped with Zeiss digital camera and workstation.
3. Motorized petrographic optical microscope with reflected and transmitted polarized light (Zeiss Imager.M2m model, magnifications from 25X to 500X) equipped with Zeiss tele camera and workstation (Figure 3B).
4. Optical microscope for biological use (Leitz Laborlux 12, magnifications from 40X to 1000X equipped with 12 MP digital camera (Apple Inc.).
5. SEM (FEI QUANTA FEG 450 model, operating in low vacuum, chamber pressure of 50 Pa at 20.00 kV equipped with an energy dispersive X-ray analyser (SEM-EDS) and workstation (AMETEK) (Figure 3C).

### 3. Results on the Comparative Analyses

#### 3.1. Geological Evidence

Samples resulted to be made of sandy to silty hyaline siliciclastic grains mainly composed of mono-mineral grains/clasts of quartz with different intensity yellow to orange Fe-coatings, minor opaque yellow ocher lithoclasts of quartzarenites, and microfossils (benthic foraminifera).

Mineralogical, petrographic, and sedimentological examinations on the geological trace and soil evidence revealed that these were mainly composed of an analogous mineral assemblage. Notwithstanding the mineralogical homogeneity, seven main classes of grain typologies were identified on the base of different mineralogical and textural characteristics and parameters (luster, coating, color, shape, habitus, roundness, and sphericity) examined under stereobinocular reflected and transmitted light microscope, scanning electron microscope with an energy dispersive (SEM-EDS) X-ray analyser for X-ray microanalyses.



**Figure 3.** Instrumentations. A) Laser diffraction granulometer (Malvern Instruments Mastersizer 2000). B) Workstation - Motorized stereomicroscope with reflected and transmitted polarized light (Zeiss Stereo Discovery.V20, on the left), motorized petrographic optical microscope with reflected and transmitted polarized light (Zeiss Imager.M2m mode, on the right), and image analysis software (Zeiss AXIOVISION, in the center) - Forensic Geology laboratory, MIFT Department, University of Messina. C) SEM (FEI QUANTA FEG 450 model) equipped with EDS system and workstation (AMETEK) - Laboratory of microscopic analyses, Engineering Department, University of Messina. Source: Author.

The identified grain characteristics and parameters were described for each class. About one thousand of medium-fine to very fine sandy grains were analysed in the unknown samples as well as in the known samples, in the complex (Table 2, Figure 4).

**Table 2.** Characterization of the different types of grains identified in the forensic unknown and known samples of the case work.

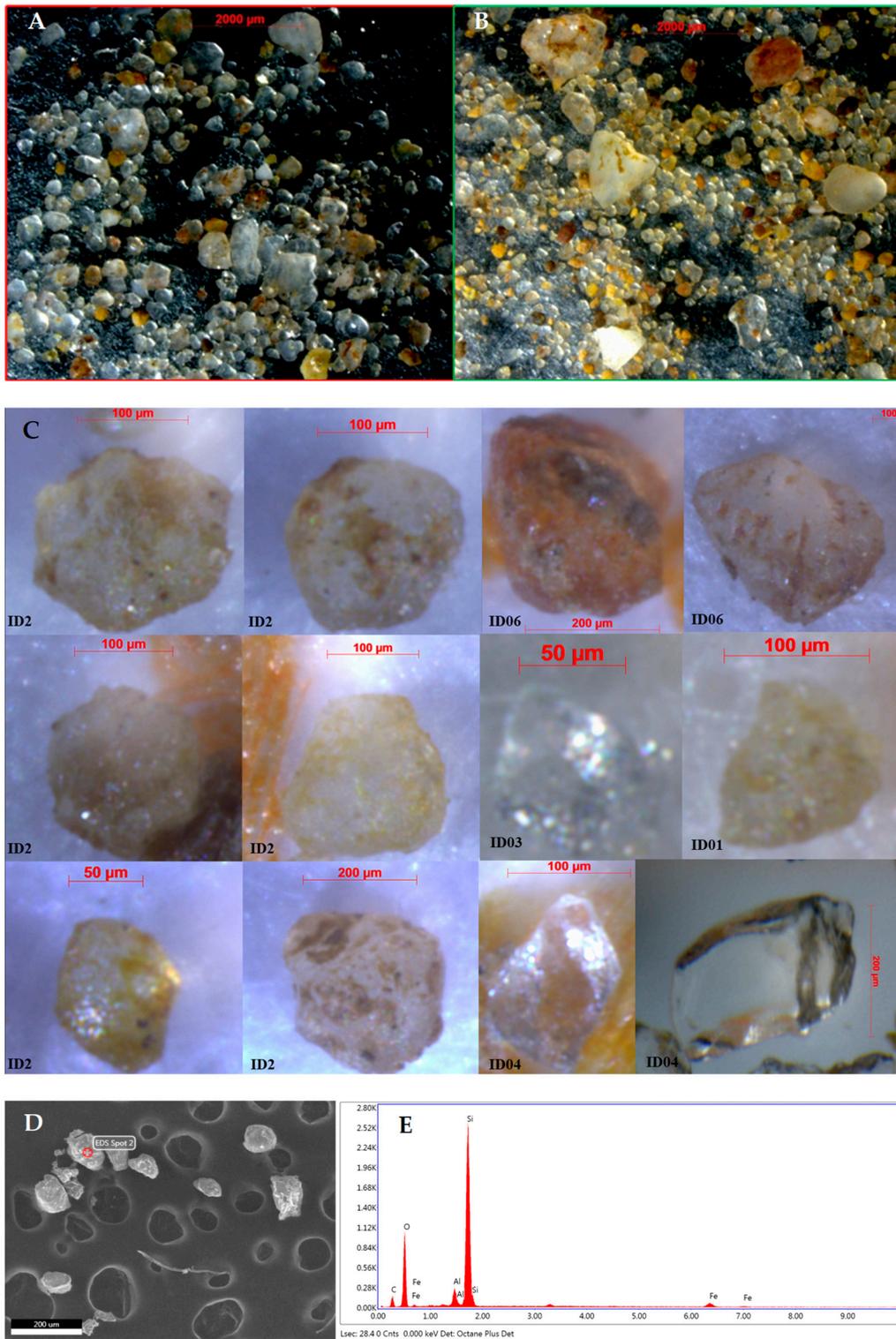
<b>Class ID</b>	<b>Description</b>
ID01	Hyaline grains predominantly rounded and triangular in shape with yellow/orange coating, which gives the grains a hyaline appearance with more or less marked yellow/orange “spots” up to straw yellow / orange / reddish.
ID02	Rounded hyaline grains with evidence of the original crystalline habitus with yellow/orange coating, which gives the grains a hyaline appearance with more or less marked yellow/orange “spots” up to straw yellow/orange/reddish with minor percentage of sub-angular clasts.
ID03	Predominantly rounded and spherical hyaline grains without coating.
ID04	Hyaline grains with rounded tabular crystalline habitus and without coating.
ID05	Rare hyaline grains of smoky gray color and without coating.
ID06	Rounded and spherical hyaline clasts with yellow/orange coating, which gives the clasts a hyaline appearance with more or less marked yellow/orange “spots” up to straw yellow / orange / reddish with a smaller percentage of sub-angular and lamellar grains.
ID07	Opaque grains mainly yellow ocher and fossil forms (mainly benthic foraminifera) with a smaller percentage of opaque brown or light grains.

Grains appeared mostly rounded with minor percentage of sub-angular clasts whereas the Riley sphericity resulted to be equal to 0.8 both in both the unknown and known samples.

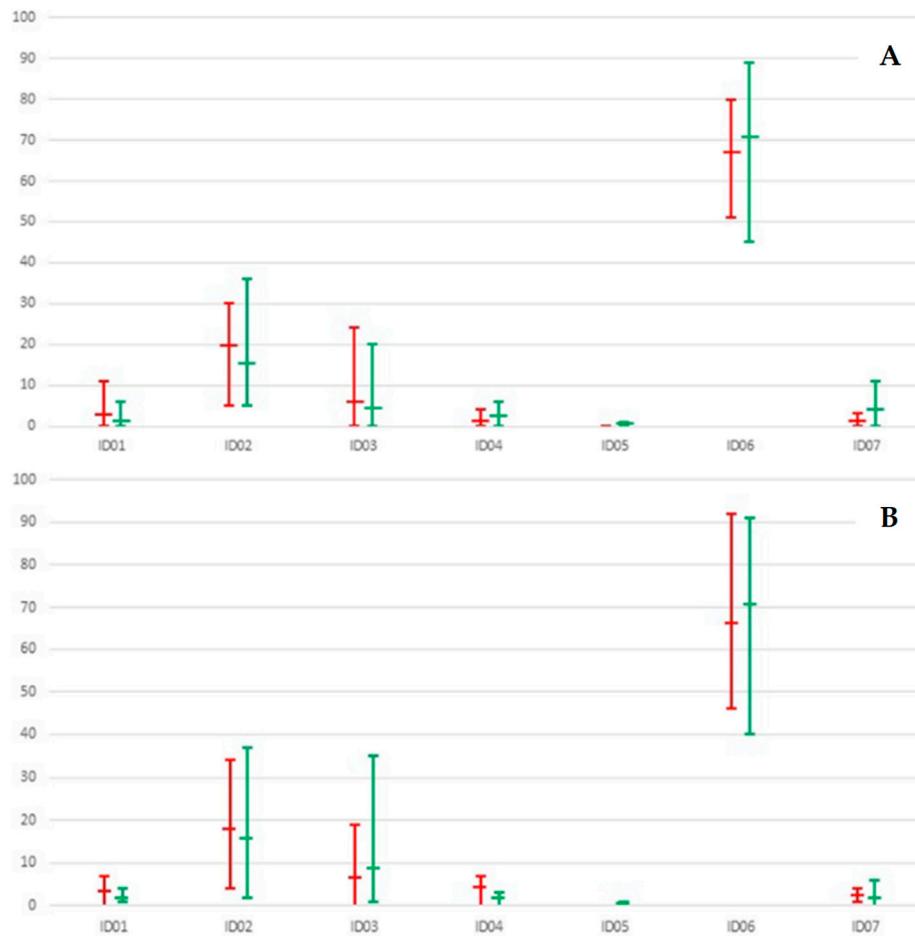
Additional comparisons, accomplished in order to exclude possible previous traces in the victims’ questioned samples related to their staying with the same footwears in the sites visited in the days immediately before the tragic event, allowed to ascertain the absence of particles composed of mono- and polymineral assemblages of metamorphic rocks typical of the soils collected in these other locations of investigative interest.

Two (250-125  $\mu$ , 125-63  $\mu$ ) and three (250-125  $\mu$ , 125-63  $\mu$ , <63  $\mu$ ) grain sizes were identified as the most representative ones of both the unknown and known samples. The distribution of the quantitative data related to the seven class characteristics of the unknown and known samples, reported for both the 250-125  $\mu$  and the 125-63  $\mu$  grain sizes, showed an optimal overlaps and trends (Figure 5). In particular, three main classes were prevalent in both unknown and known samples. These were in order of abundance (Table 2, Figure 5):

- i. ID06 - Rounded and spherical hyaline clasts with yellow/orange coating with a percentage of sub-angular and lamellar grains.
- ii. ID02 - Rounded hyaline grains with evidence of the original crystalline habitus with yellow/orange coating.
- iii. ID03 - Rounded and spherical hyaline grains without coating.



**Figure 4.** A-D) Microphotographs taken under stereobinocular microscope with reflected light of sandy grains of quartz. A) Unknown trace evidence observed with dark background. B) Known evidence observed with dark background. C) ID1-4 ID6 class grains of quartz observed with mm-sized background. D) SEM micrograph of unknown sample with ID02 class grain. E) SEM-EDS spectrum of quartz grain with Fe coating (spot 2 in Figure 4D). Source: Author.



**Figure 5.** Comparisons of the percentages of the 7 class characteristics recognized in hundreds of unknown (red line) and known (green line) samples (from the event sites), reported for the 250-125  $\mu\text{m}$  grain size (A) and the 125-63  $\mu\text{m}$  grain size (B). Minimum, medium, and maximum values (horizontal traits) are also shown. Source: Author.

### 3.2. Botanical Evidence

Forensic botany was applied for the present casework in order to corroborate the forensic geology investigations. The amount of the vegetal material was prevailing on the inorganic grains. The vegetal fraction separated from the geological traces related to the unknown samples from the MPFs and their belongings and observed under stereomicroscopy, microscopy, and SEM-EDS system, resulted composed of plant fragments or entire elements of branches, twigs, leaves, thorns, capsules, fruits, seeds, pollen, herbaceous fragments, wood, vegetable debris, decomposing organic material (humus), and *algae* (including diatoms).

The main 12 species of remnants of traces of the identified terrestrial plants were [98]:

1. *Erica arborea* (leaves, capsules, seeds).
2. *Quercus suber* (leaves, flowers, seeds).
3. *Olea europaea* (leaves, seeds).
4. *Cistus monspeliensis* (leaves, seeds, capsules, etc.).
5. *Pistacia lentiscus* (leaves, seeds).
6. *Myrtus communis* (leaves, seeds).
7. *Cytisus infestus* (branches, legume, thorns).
8. *Smilax aspera* (leaves, thorns).
9. *Rosa sempervirens* (thorns).
10. *Rubus ulmifolius* (thorns).
11. *Rosacea Amygdaloidea* (thorns).
12. *Cynara cardunculus* (thorns).

Peculiar particles were considered the thorns and seeds being the most abundant vegetal component sampled on bodies, clothing, and footwears of both MPFs.

Over 522 seeds of *Erica arborea* and 81 thorns ascribable to *Rosa sempervirens*, *Rubus ulmifolius*, *Rosacea Amygdaloidea*, *Cynara cardunculus*, *Cytisus infestus*, and *Smilax aspera* were found in the shoes of victim 1, mostly inside the shoes and planted on the soles, respectively. Another peculiar material was represented by an aggregate made up of remnants of freshwater *algae* found in the sole of one victim 1's footwear [98].

Only 16 thorns ascribable to *Rosa sempervirens* or *Rubus ulmifolius*, *Cynara cardunculus*, *Cytisus infestus*, and *Smilax aspera* were found planted on the soles of the shoes of victim 2. No traces of *algae* were found except a unique diatom [97,98].

The same 12 species of terrestrial plants above reported were also found in the vegetation present in the sites of the events and in the vegetal component of the soils collected from this area.

On the base of the above, four main macro-areas with different botanical characteristics were distinguished during remote sensing and field work. The identified macro-areas were [98]:

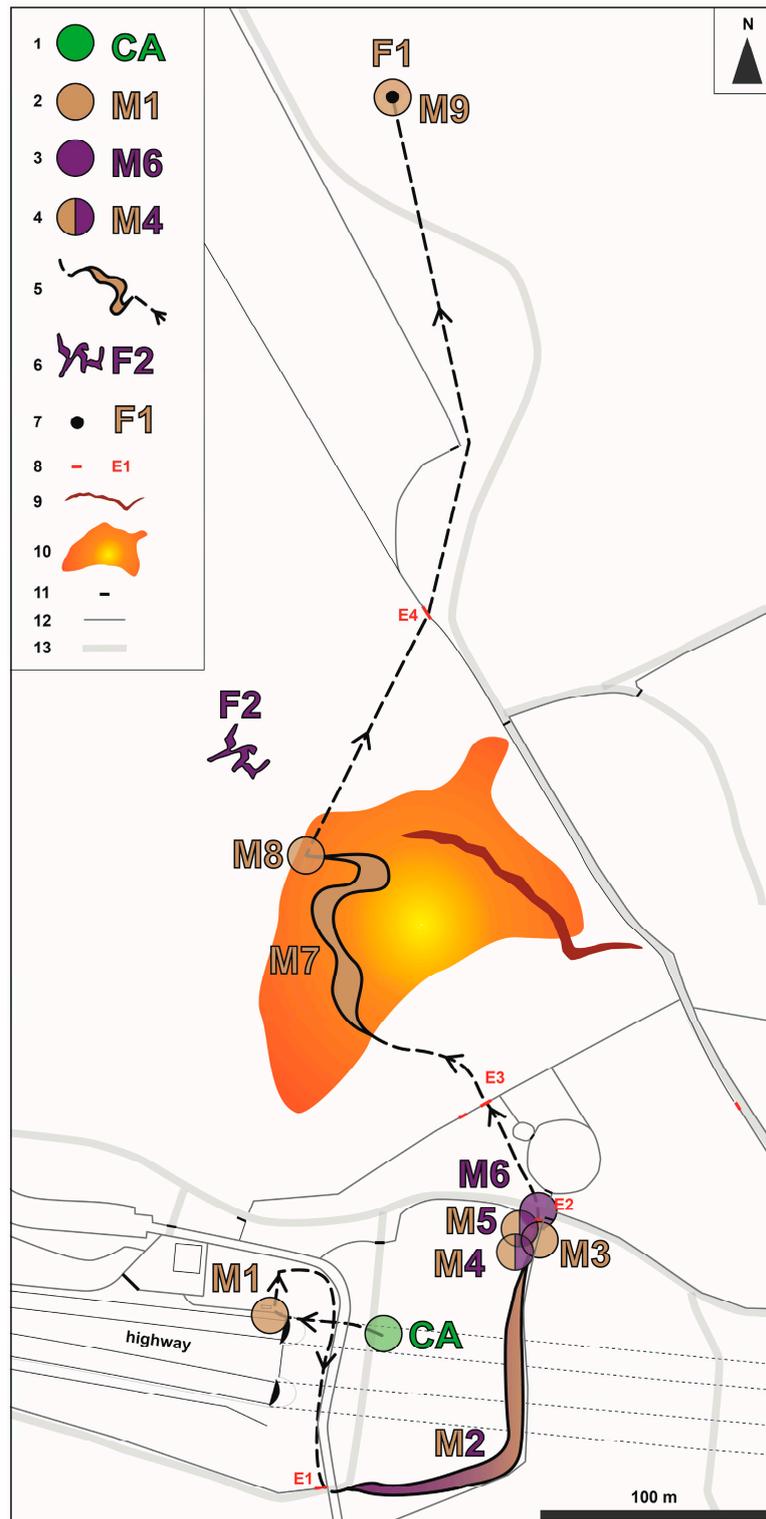
1. Shrub formation with Mediterranean maquis (prevailing macro area).
2. Area inside the highway perimeter.
3. Meadow area with anthropic pressure from pasture with some puddles of freshwater with *algae*.
4. Tree formation dominated by Sughera (*Quercus suber* L.) with a circumscribed zone showing abundant concentration of *Erica arborea* shrubs wood and soils rich in fresh to decomposed seeds of *Erica arborea* (about 6000 seeds of *Erica arborea* were examined and counted in the soils).

### 3.3. Tracing the Route Walked by the Two MPFs

During investigations, great attention was also devoted to the specific search for rare or peculiar particles or assemblages of inorganic and vegetal origin. This examen allowed to recognize in the unknown samples:

1. Rare particles of calcite and dolomite.
2. Peculiar compositions of clay minerals rich in calcium phosphate.
3. Peculiar assemblages of different classes of mineral grains.
4. Vegetal remains of mm-sized thorns of *Cynara cardunculus* and *Rosa sempervirens*, seeds of *Erica arborea*, and assemblages of *algae*.

The same rare and peculiar materials were also recognized in some specific sites of the scene of events, as specified in the following. Geobotanic data on the unknown samples resulted to be typical of microenvironments very similar to those identified in the scene of events. These results were of paramount importance in allowing investigators and judicial authority to link the MPFs to specific sites of the scene of events and in tracing the route of both the MPFs, obtained from 9 specific microenvironments recognized in the scene of events. Figure 6 and Table 3 illustrate the sequence and distribution of the match points and match linear belts (M), from which the path was delineated by means interpolation of matching sites and 4 exit/entry points (E1-4), recognized in the event scene, starting from the site of the car accident site (CA). The localizations of the two different finding sites of the human remains (F1 and F2) were also reported.



**Figure 6.** Route walked by the two MPFs in the scene of events. The route was reconstructed interpolating the starting point of the car accident (CA) with the 9 match points and linear belts (M), and the Exit/Entry sites (E). Legend: 1) CA – Car Accident; 2) M1 – Match point (MPF 1); 3) M6 – Match point (MPF 2); 4) M4 – Match point (MPFs 1-2); 5) - Match linear belt; 6) F2 - Finding site of victim 2; 7) F1 - Finding site of victim 1; 8) E1 – Exit/Entry (rudimental wood gates and holes in barber wire); 9) Physical barrier due to climbing thorny plants; 10) Sughera wood with *Erica arborea* plants. 11) Gate; 12) Limit of property; 13) Dirty roads. Source: Author.

**Table 3.** Sites selected for linking MPFs to the event sites and reconstructing the route walked by them.

<b>MPFs/Victims</b>	<b>Acronyms</b>	<b>Typology of Sites for Linking MPFs to Event Site</b>
MPF 1 – MPF 2	CA	Car accident site (Route start point)
MPF 1	M1	Match point
MPF 1 – MPF 2	M2	Match linear belt
MPF 1 – MPF 2	E1	Exit (rudimental wood gate)
MPF 1	M3	Match point
MPF 1 – MPF 2	M4	Match point
MPF 1 – MPF 2	M5	Match point
MPF 1 – MPF 2	E2	Exit (rudimental wood gate)
MPF 2	M6	Match point
MPF 1 – MPF 2	E3	Entry (hole in the barber wire perimeter)
MPF 1	M7	Match linear belt
MPF 1	M8	Match point
Victim 2	F2	Finding site of skeletonized human remains
MPF 1	E4	Exit (hole in the barber wire perimeter)
MPF 1	M9	Match point
Victim 1	F1	Finding site of human remains (Route end point)

### 3.3.1. Car Accident (Table 3, Figure 6)

The car accident occurred among two vehicles inside a tunnel of the highway. After the crash, the two subjects abandoned their vehicle and went out of the tunnel, reaching a lateral gate of the highway.

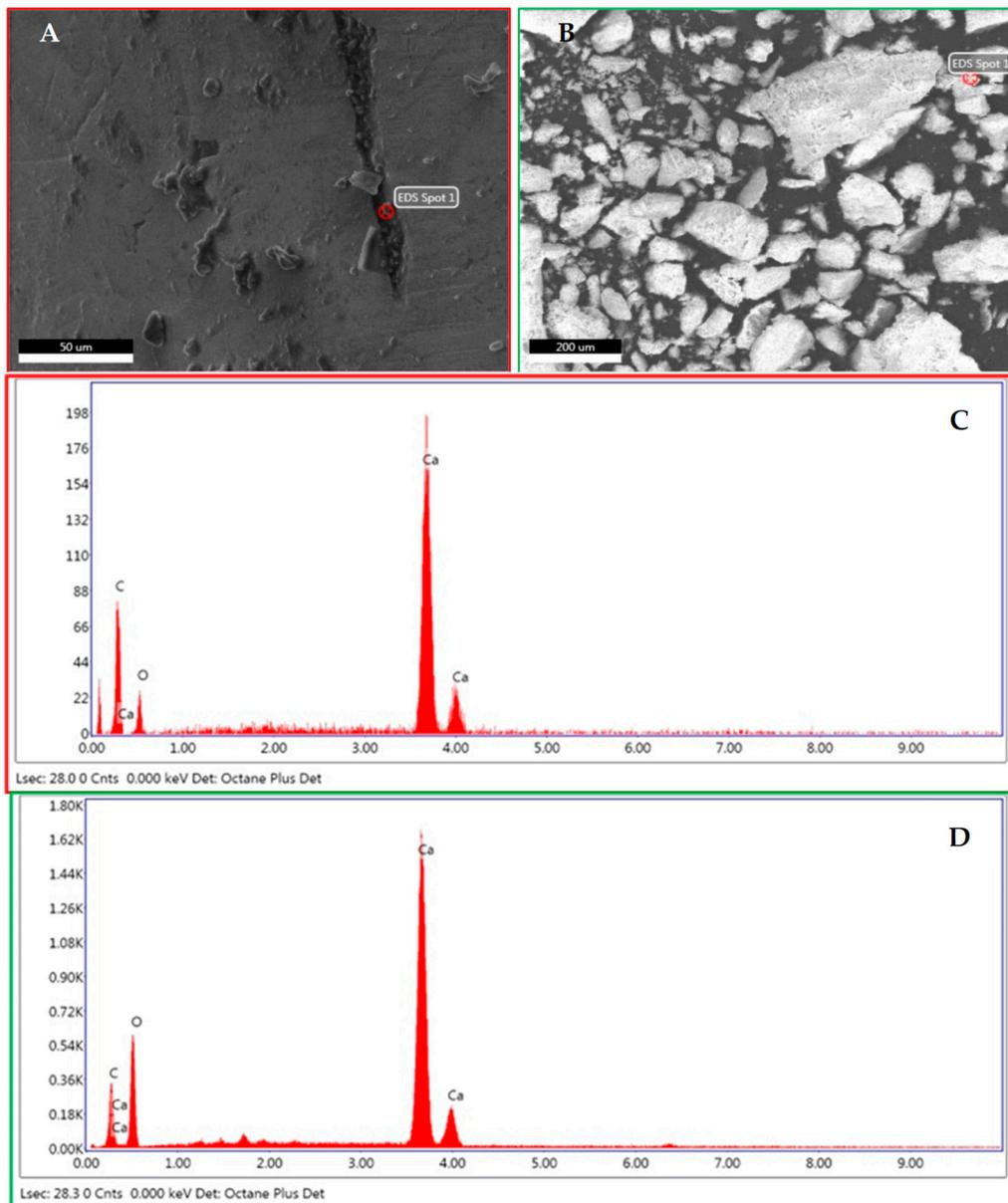
### 3.3.2. Match Point 1 (M1) (Table 3, Figure 6)

Inorganic micro traces (calcite) from MPF 1's ring.

These micro traces were comparable with the calcareous composition of the top of a ~ 1 m high perimeter wall delimiting the lateral gate of the highway (Figure 7). The transfer from the wall to the ring could realize when the MPF 1, in order to reach the raised ground on the back of the highway, passed on the wall touching it with the hands to lift him-herself from the roadway in order to continue to escape from the car accident site.

### 3.3.3. Exit (E1) (Table 3, Figure 6)

Two MPFs passed through a rudimental wood gate delimiting the area surrounding the highway tunnels.

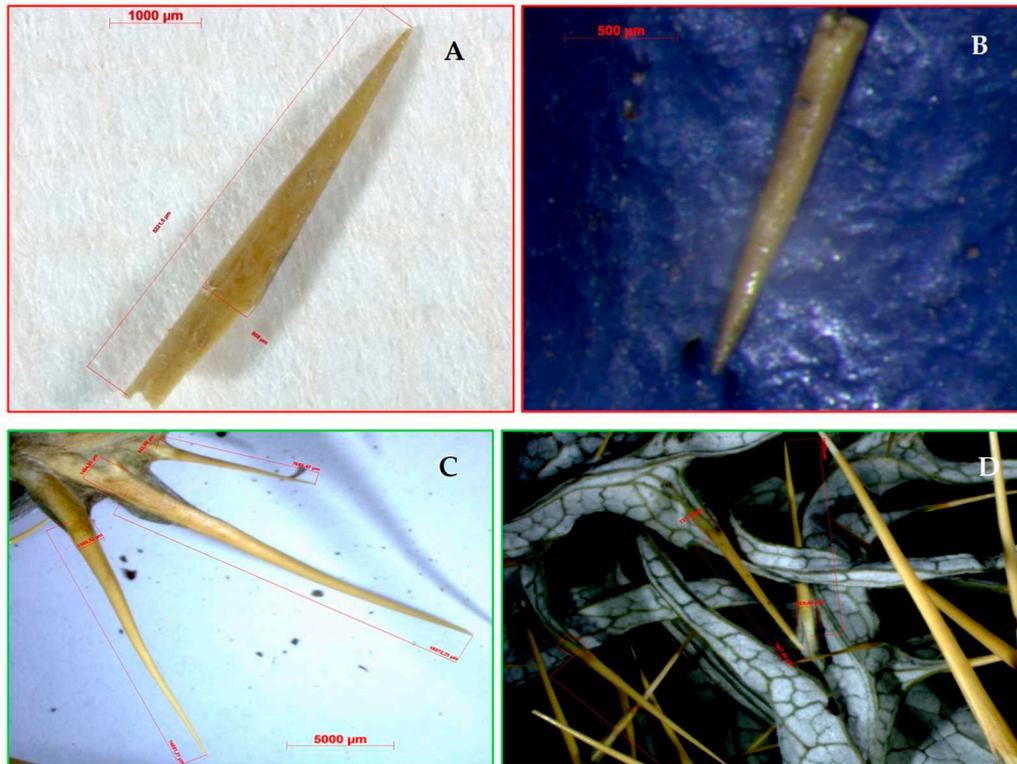


**Figure 7.** A) SEM micrograph of calcite traces in a groove on the gold ring of MPF 1. B - SEM micrograph of calcium carbonate fragments scraped from the upper part of the wall. C) X-ray microanalysis (SEM-EDS) compatible with calcium carbonate from the traces (spot 1 in Figure 7A). D) X-ray microanalysis (SEM-EDS) compatible with calcium carbonate from the fragments (spot 12 in Figure 7B) (M1 in Figure 6). Source: Author.

#### 3.3.4. Match Linear Belt 2 (M2) (Table 3, Figure 6)

Organic traces (thorns of *Cynara cardunculus*) from MPF 1's sock and MPF 2's shoes.

This evidence was comparable with some thorny plants growing on an uncultivated field in the meadow area with anthropic pressure from pasture (Figure 8). The transfer from the plants to the shoes could realize when the subject walked on these thorny plants distributed in the linear belt reported in Figure 6.

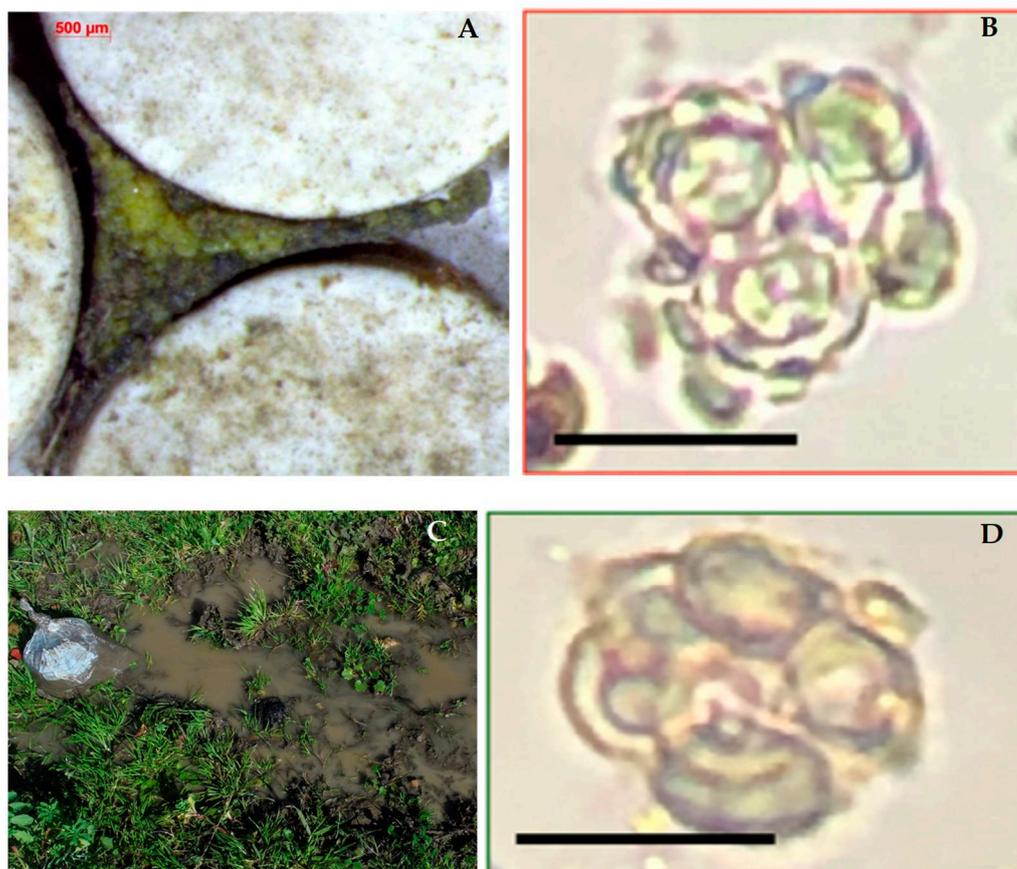


**Figure 8.** Microphotographs taken under stereobinocular microscope and reflected light of *Cynara cardunculus*. A) Thorn from the sock of MPF1. B) Thorn extracted from the sole of the shoe of MPF 2. The hole in the sole is observable near the pointed termination. C) Thorns collected from a plant in the event site. D) Thorns and leaves collected from a plant in the event site (M2 in Figure 6). Plants determined by Fabio Mondello. Source: Author.

### 3.3.5. Match Point 3 (M3) (Table 3, Figure 6)

Organic traces (*algae*) from MPF 1's shoes.

These were comparable with *algae* present on freshwaters of a muddy puddle (Figure 9). The transfer from the puddle to the shoes' soles could realize when the subject walked on this specific puddle.

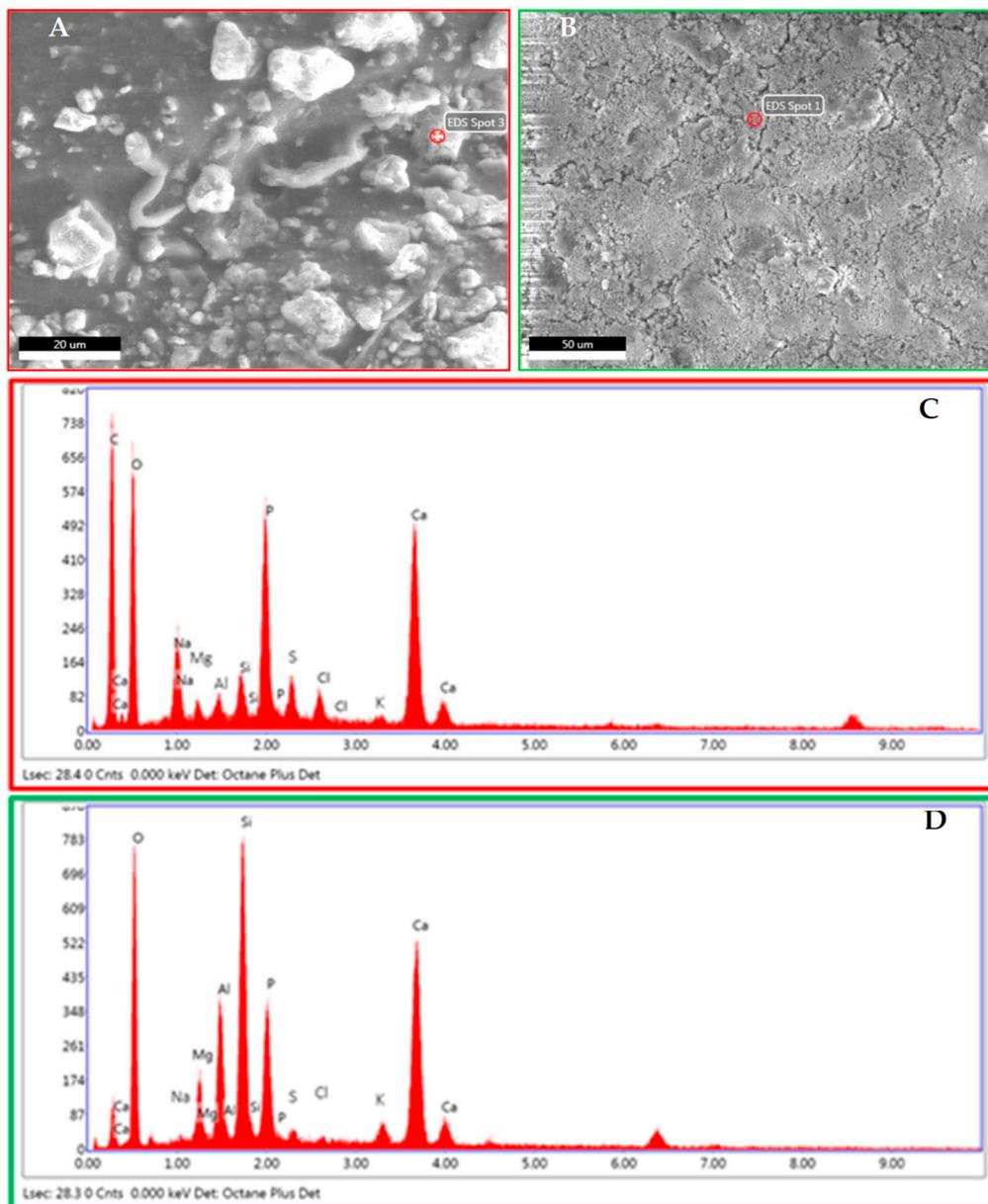


**Figure 9.** A) *Algae* and soil aggregate imbedded in the space among adjacent circular cleats on the sole of the shoes observed under stereobinocular microscope with reflected light. B) *Chlorellales* or *Chlamydomonadales* (*Chlorophyta*) from the aggregate of Figure 9A observed under microscope. C) Puddle with freshwaters in the scene of events. D) *Chlorellales* or *Chlamydomonadales* (*Chlorophyta*) from the puddle with freshwaters of Figure 9C (M3 in Figure 6). Scale bar:100 µm. *Algae* determined by Marina Morabito. Source: Author.

### 3.3.6. Match Point 4 (M4) (Table 3, Figure 6)

Inorganic micro traces of P-rich clays from MPFs' shoes.

These were comparable with a wet soil present on the above reported muddy puddle (Figure 10). The transfer from the P-rich clayish wet soil to the victim could realize when the MPF 1 and 2's shoes walked on the wet area.

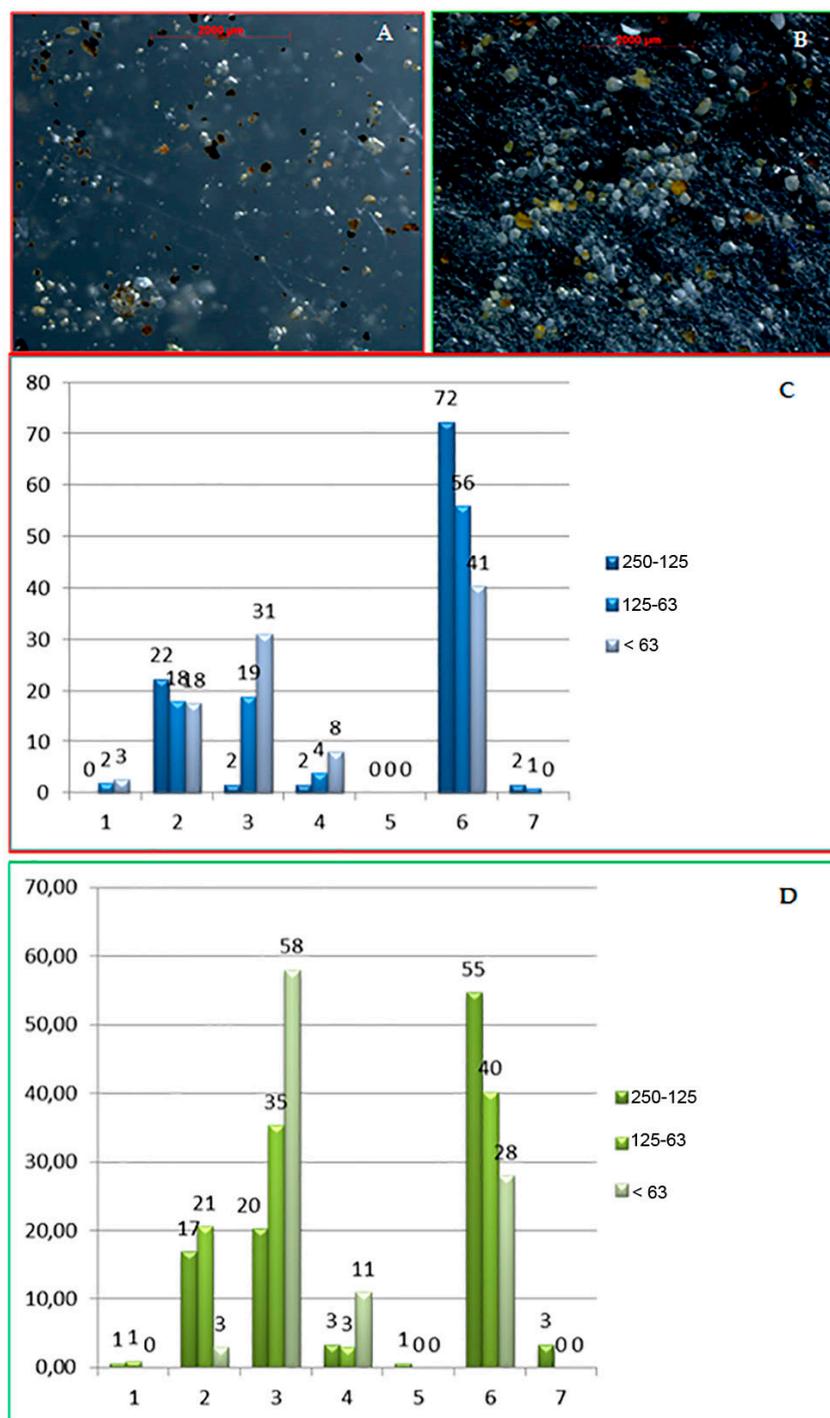


**Figure 10.** A) SEM micrograph image of P-rich clayey minerals from the MPF 1's shoes (unknown sample). B) SEM micrograph image of P-rich clayey soil from a puddle in the event scene. C-D) X-ray microanalyses (SEM-EDS) related to P-rich clayey minerals (spot 3 in Figure 10A) (C) and soil (Figure 10B) (D) (M4 - spot 1 in Figure 6). Source: Author.

### 3.3.7. Match Point 5 (M5) (Table 3, Figure 6)

Inorganic traces from MPF 2's shoes.

This particle assemblage was comparable with the sandy and silty soil present in a specific site of an uncultivated field in the meadow area with anthropic pressure from pasture (Figure 11). The transfer of the soil to the shoes could realize when the victim walked on this site.



**Figure 11.** A) Sandy grains from the MPF 2's shoes (unknown sample) under stereomicroscope. B) Sandy grains from a soil sample (unknown sample) from the event scene under stereomicroscope. C-D) Comparative analyses (sieve size is expressed in  $\mu\text{m}$ ). Histograms of the 7 grain types related to the percentages of the sandy grains from the MPF 2's shoes (in Figure 11A) (C) and the soil (Figure 11B) (D) (M5 in Figure 6). Source: Author.

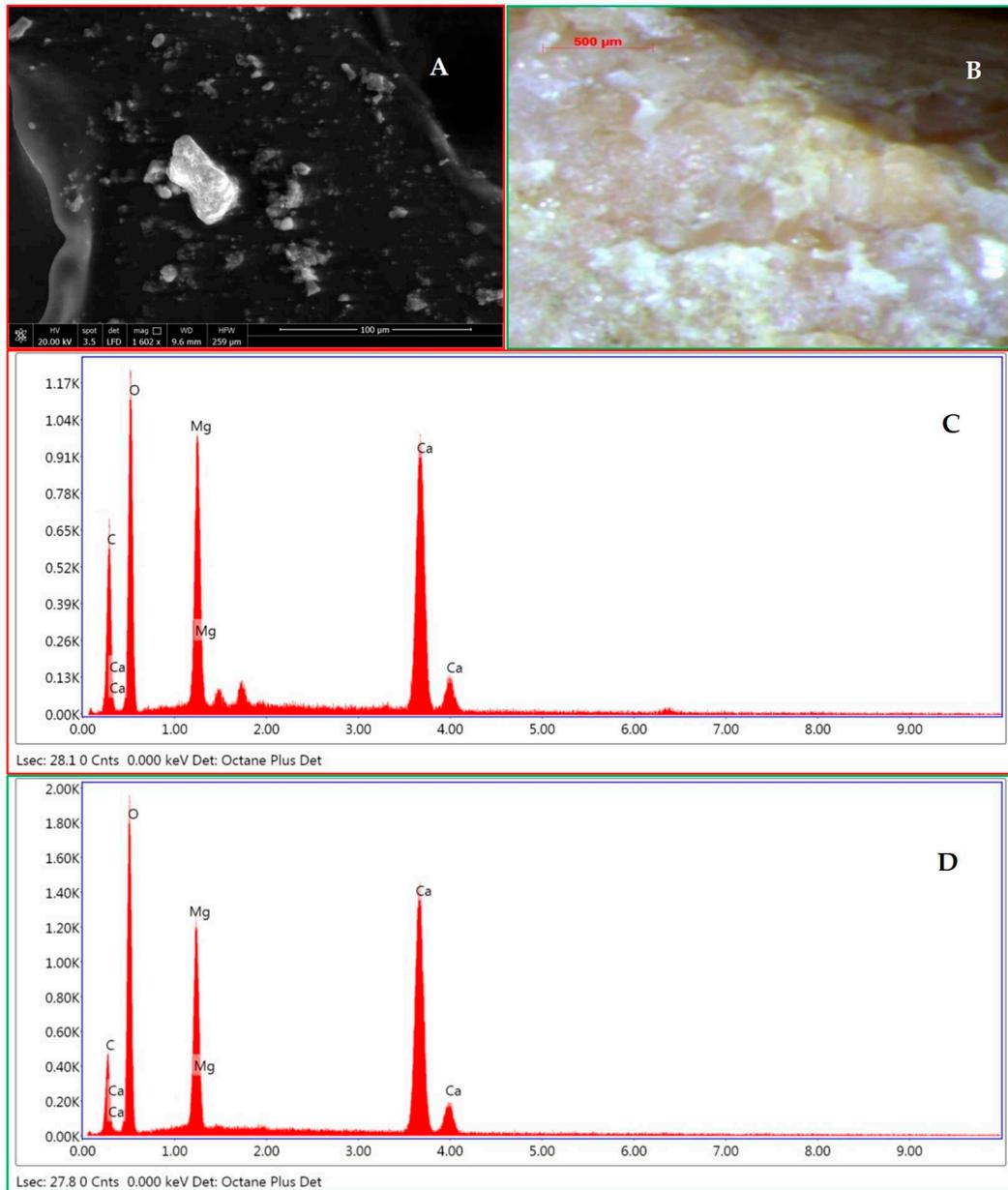
### 3.3.8. Exit Point (E2) (Table 3, Figure 6)

The two MPFs passed through a rudimental wood gate delimiting an uncultivated field in the meadow area with anthropic pressure from pasture.

### 3.3.9. Match Point 6 (M6) (Table 3, Figure 6)

Inorganic traces (dolomite) from MPF 2's shoes.

These were comparable with clasts of pinkish dolostones artificially reported on a dirt road present on an uncultivated field, near a wood rudimentary gate (Figure 12). The transfer to the shoes could realize when the victim walked on this road.



**Figure 12.** A) SEM micrograph image of dolomitic clast from the MPF 2's shoes (unknown sample. B) Microphotograph under stereomicroscope of clast of pinkish dolostone (known sample) from a dirty road in the event scene. C-D) X-ray microanalyses (SEM-EDS) of dolomite minerals from the MPF 2's shoes (C) and dolostone from the event scene (D) (M6 in Figure 6). Source: Author.

### 3.3.10. Entry Point (E3) (Table 3, Figure 6)

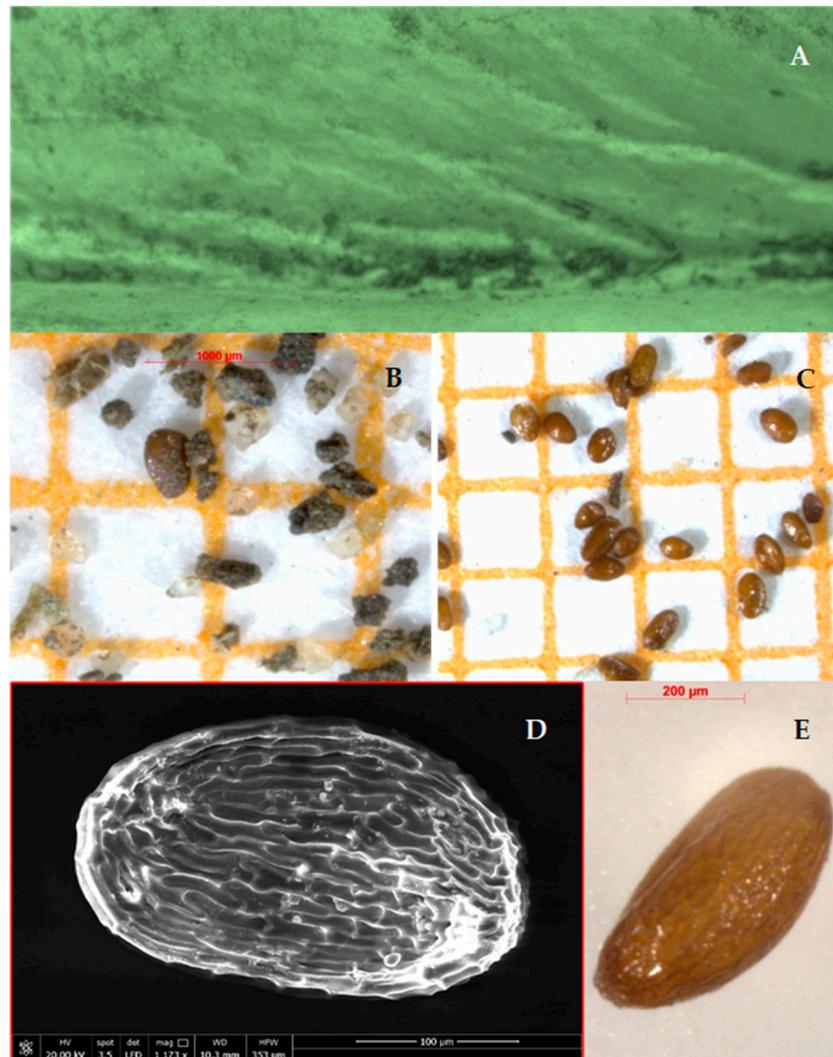
The two MPFs passed through a passage in the barbed wire delimiting the Sughera wood with *Erica arborea* plants, entering in this cover and isolated area.

### 3.3.11. Match Linear Belt 7 (M7) (Table 3, Figure 6)

Organic traces (*Erica arborea* seeds) from MPF 1's shoes (Figure 13) and socks.

The freshness state of the *Erica arborea* seeds in the MPF 1's shoes (Figure 13A) were comparable with seeds present in the soil present in the wood with Sughera (*Quercus suber* L.) associated with

*Erica arborea* shrubs above cited (Figure 13). The transfer to the internal parts of shoes and socks could realize when the victim walked on this area, along the identified linear belt, infilling the shoe internal parts with *Erica arborea* seed-rich soil and seeds fallen by the shrubs due to the impact of the body with *Erica arborea* shrubs.

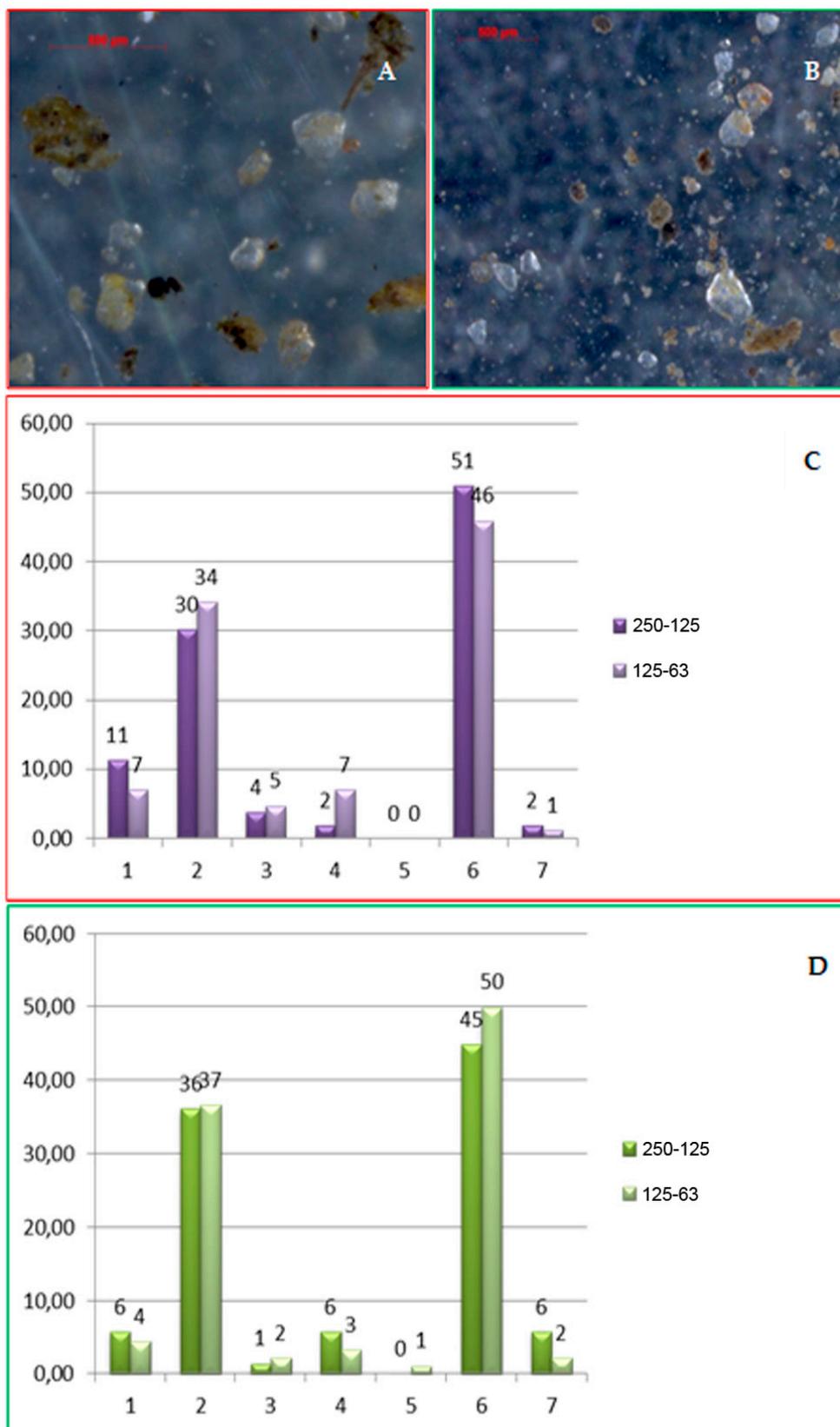


**Figure 13.** A) Dirty internal side of the upper part of the MPF 1's shoes showing geological evidence with a very abundant vegetal component made up of *Erica arborea* seeds (unknown sample), transferred to the shoes during the walking of MPF 1 in the Sughera woody area with *Erica arborea*. B) *Erica arborea* seeds and humus from the victim 1's shoes (unknown sample), under stereomicroscope. C) *Erica arborea* seeds separated from a soil sample (known sample) from the Sughera woody area with *Erica arborea*, under stereomicroscope. D) SEM micrograph of an *Erica arborea* seed (Figure 13C). E) Seed of *Erica arborea*, under stereomicroscope (Figure 13D). (M7 in Figure 6). *Erica arborea* determined by Fabio Mondello and Angelo Troia. Source: Author.

### 3.3.12. Match Point 8 (M8) (Table 3, Figure 6)

Inorganic traces from MPF 1's shoes.

This particle assemblage was comparable with the sandy and silty soil present in the area of the wood with Sughera (*Quercus suber* L.) and *Erica arborea* shrubs (Figure 14). The transfer of the soil to the shoes could realize when the MPF1 passed on this area.



**Figure 14.** A) Sandy grains from the MPF 1's shoes (unknown sample) under stereomicroscope. B) Sandy grains from a soil sample (unknown sample) from the event scene under stereomicroscope. C- D) Comparative analyses (sieve size is expressed in  $\mu\text{m}$ ). Histograms of the 7 grain types related to the percentages of the sandy grains from the MPF 1's shoes (in Figure 14A) (C) and the soil (Figure 14B) (D) (M8 in Figure 6). Source: Author.

### 3.3.13. Finding Site (F2) (Table 3, Figure 6)

The skeletonized human remains of victim 2 were found distributed in an articulated area of the dense Mediterranean maquis.

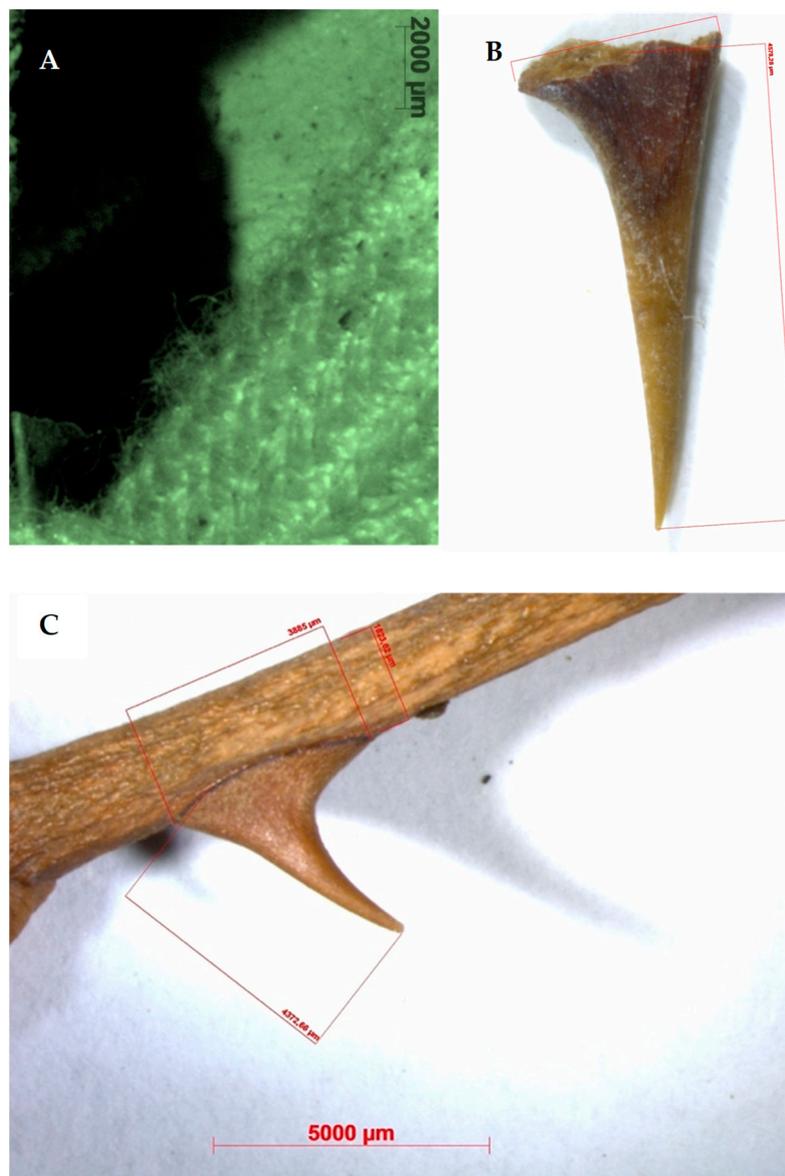
### 3.3.14. Exit (E4) (Table 3, Figure 6)

The MPF 1 passed through a passage in the barbed wire delimiting the Sughera wood with *Erica arborea* plants, abandoning this area.

### 3.3.15. Match Point 9 (M9) (Table 3, Figure 6)

Organic traces (*Rosa sempervirens* thorns) from MPF 1's shoes, socks, and clothing.

These traces were comparable with the thorns of the climbing *Rosa sempervirens* plants growing on the infrastructure in proximity of the finding site of the corpse (Figure 15). The transfer to the victim belongings could realize when the subject climbed on this structure (M9 in Figure 6).



**Figure 15.** A) Thorn of *Rosa sempervirens* L. catch in the lace of the MPF 1's shoes (in the bottom left). B) Thorn of *Rosa sempervirens* L. (Figure 15A), under stereomicroscope. C) Twig with a thorn of *Rosa sempervirens* L. collected from the climbing plant grown up on the infrastructure present in the scene of events (M9 in Figure 6). Plants determined by Fabio Mondello. Source: Author.

### 3.3.16. Finding Site (F1) (Table 3, Figure 6)

The manner of death of the MPF 1 for precipitation was ascertained by the medico legal investigations. The prone position of the MPF 1's body, its distance from the infrastructure, as well as its relationships with the plants present on the ground univocally supported this reconstruction. In particular, the injuries on the posterior and lateral sides of the limbs could be dependent on a dynamic impact due to the body's precipitation on the plants growing on the ground.

## 4. Discussion and Conclusions

The wide *spectrum* of mineralogical, morphological, morphoscopic, textural, and botanical determinations accomplished for the present criminal case work allowed to ascertain a general high degree of compatibility among samples collected on the MPFs and on the scene of events, and the exclusion of possible previous traces related to their staying with the same footwears in other sites in the days immediately before the tragic event.

These comparative analyses provided fundamental info-investigative data of paramount importance for establishing the active *pre-mortem* presence of the MPFs on the scene, dealing with a criminal case where other methods were not very useful and inapplicable. Nobody saw the MPFs walking in the countryside, MPFs had not any mobiles, GPS, or technological devices, no tele cameras were in the scene.

The most significant positive matches, based on the finding of peculiar and rare particles and assemblages, allowed reconstructing a very detailed walking carried out by the two MPFs on the event site. As a matter of facts, the finding of a ten of different points and linear belts of positive match, from 1 (near the car accident site) to 9 (site of the finding of victim 1), allowed to reconstruct and tracking the route walked by the two MPFs in the hours immediately preceding their death (Table 3, Figure 6).

These inferences were very useful for the judicial system. A few criminological and criminalistic inferences based on the investigations, carried out in laboratory and on field, allowed to hypothesize that:

1. Both MPFs actively interacted with the natural and anthropogenic microenvironments recognized in the scene of events (Figure 6).
2. Both MPFs actively walked in the scene of events along a specific route stretched in areas with different degrees of vegetation density and difficulty to pass through (Figure 6).
3. MPF 2 walked for a shorter path than that of MGF 1; this path was reconstructed up to the dirty path with detritus of dolostones (M6); it may be hypothesized that MPF 2 was carried out in the MPF 1's arms in the Sughera woody area with *Erica arborea*, from the surrounding of M6 site up to M8 site, i.e. in an area very next to the site of finding of victim 2 (F2 in Figure 6).
4. MPF 1 walked for a longer path than that of MPF 2 up to the site of finding of the body (F1 in Figure 6).
5. MPF 1 actively climbed on the infrastructure (M9 in Figure 6). This action supported evaluations made by the coroner on injuries due to precipitation from a high infrastructure.

In conclusion, the peculiar and rare grains, minerals, composition, textures together the peculiar and rare assemblages analysed in the unknown and known specimens from victims and event scene permitted to identify a "fingerprint" of most of the examined specimens. Most of these fingerprints were obtained by means of image analysis and the manual counting of grain characteristics. This procedure, also if it was extremely time consuming and relevant only in cases after the MPF's finding, it was of uttermost importance in strengthen the reconstructions here proposed. In such way, investigators revealed to be able to provide very strong geological and botanical evidence for supporting criminal investigations.

The here presented method for tracking the route walked by MPFs could fall back in the strategies to contrast the Al-Qaeda terrorism. When a terrorist is captured in the countryside, it may be useful or necessary to track backwards the route walked by him/her to search for a terrorist den or a site of investigative interest (burial of firearms, explosives, etc.).

Notwithstanding these encouraging and promising results and the great potentiality of this method, in Italy Forensic Geology still represents a minor discipline of the Forensic Sciences [104]. In the Italian police criminal laboratories, the analysis of geological and botanical traces actually rarely occurs, differently from the realities of other countries (Federal Bureau of Investigation -FBI- Laboratory of Trace Evidence, Quantico, USA [51,105]; Institute of Criminalistics -ICP- Prague, Czech Republic [106,107]; Australia [50]).

On the basis of the above, for the next generations of forensic experts in geology and botany, it should be desirable that the academics and researchers:

1. Further implement scientific and didactic initiatives on Forensic Geology and Botany [108–113].
2. Promote initiatives for introducing the master's degree in geology in the police applications for assuming Geologists/Forensic Examiners for the police forensic bureau (*Carabinieri*, Police).
3. Develop forensic protocols envisaging all possible technical procedures / operations to accurately apply on the crime or event scene to preserve evidence made of inorganic and organic materials and strengthen greater interaction and collaboration between forensic geologists, botanists, and experts in legal medicine directly on the crime scene, to arrange all the activities aimed at preserving these traces as far as possible, even during necropsy operations.

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