CASE REPORT

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The Contribution of Forensic Geology and Other Trace Evidence Analysis to the Investigation of the Killing of Italian Prime Minister Aldo Moro

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ABSTRACT: In May 1978 the body of the kidnapped Italian Prime Minister, murdered by the Red Brigades, was found in a car parked in the center of Rome. This paper discusses the findings from the investigations conducted on the evidence found on Mr. Moro's clothes, shoes (beach sand, bitumen, vegetals and polyester fragments), and on the car. To get a comprehensive picture of the characteristics of the various pieces of evidence, use was made of a multiple-technique approach. The sand was identified as coming from the seashore close to Rome. A tract of shore with a limited number of roads leading to the beach was defined as compatible with the textural and compositional characteristics of the sand. The study of the vegetal *fragmenta* suggested that they had been picked up in a period of time close to the killing. Thermosetting polyester, of the type used in boat manufacturing was found under the fenders, in the tires and inside the car, as well as under Mr. Moro's shoes, supporting proximity of a beach. Pollen analysis showed that adhesion of volcanic soil to the car fenders antedated adhesion of the sand.

KEYWORDS: forensic science, forensic geology, sand, soil, bitumen, botany, car provenance

On March 16, 1978, at 9 a.m., the Prime Minister of Italy, Mr. Aldo Moro, was heading from his home, in the northern part of Rome, to the Parliament House, with bodyguards in his car and a second escorting car closely following. One km from his house the ambush took place: the first car collided with a Fiat 128 which had suddenly braked; approximately 90 bullets were fired from pistols and machine guns; the 5 bodyguards were killed, and Mr. Moro was kidnapped by a unit of the Red Brigades.

The abduction was followed by a very difficult period for Italy, marked by a major political turmoil on whether to deal or not to deal with the terrorists. The tension was periodically raised by the arrival of messages from the Red Brigades stating their demands, and by the numerous and dramatic letters from the imprisoned Mr. Moro, not only to his family, but also to the government and to the members of his party urging for negotiations. Despite the activity of all police forces, on 8 May 1978, a telephone call signaled that the last message of the Red Brigades was in a car parked in a street in the center of Rome, near the headquarters of the Italian Communist Party. On that tragic morning, the trunk of the car was opened and there was Mr. Moro's body, bent and reclined, shot a few hours before (Fig. 1).

During the autopsy, a small amount of sand was found in Mr. Moro's trouser cuffs. As forensic geologist cooperating with the Istituto di Medicina Legale e delle Assicurazioni (Institute of Forensic Medicine) of the Università degli Studi di Roma "La Sapienza," I was called in and appointed by the Court as a consultant. My assignment consisted of the following tasks: i) to analyze the evidence on Mr. Moro's clothes and shoes; ii) to inspect and analyze all evidence inside and outside the car where the corpse was found; iii) if possible, to indicate where the evidence came from and the period when it had been removed from its original environment.

From the samples provided by the police and based on the results of the inspection of the clothes, shoes and car, several assorted items were collected and then analyzed with multiple techniques and the cooperation of other specialists.

After 20 years, most of the kidnapping scenario has been reconstructed, the criminals were arrested and five lengthy court proceedings inflicted on them a series of penalties. By now, almost all the kidnappers have served their penalties, have been paroled or, under a semi-freedom law, work outside the prison. Thanks to the changed political climate and the end of terrorism in Italy, the results of this forensic investigation can now be disclosed. In this case of international prominence, the availability of adequate evidence allowed the investigators to fully exploit the potential of geological techniques for provenance studies.

Materials and Methods

A first batch of samples was collected from Mr. Moro's suit, trousers, and shoes. The suit was dark blue and in good state of conservation. In its left pocket there were small spikes. The trousers had cuffs, where a tiny amount of sand and a *capitulum* of a vegetal were found. The shoes were black leather moccasins with leather soles and rubber heels with various pieces of evidence adhering to them.

A second batch of evidence was collected from the car, which contained the folded corpse of Mr. Moro. The small-sized car was a red Renault 4, its trunk was only 100 cm wide, 85 cm deep, and

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FIG. 1—*In this historical photo, taken just after the car was found, Mr. Moro's reclined corpse is lying on a blanket inside the trunk. On the external part of the back door, note the lifted and torn sheet with the number plate, which was cut before opening of the trunk to whether a bomb had been planted in the car. (By courtesy of ANSA).*

TABLE 1—*A summary of the main assorted evidence which was collected from Mr. Moro's clothes, shoes and from the car.*

	Coat Pocket	Trousers Cuffs	Shoes	Car Floor	Car Fenders	Car Tires
Beach Sand		0.75 g	minor adhesions	mixed with other items	mixed with volcanic soil	in the grooves
Volcanic Soil			minor adhesions	mixed with other items	thick encrustation	
Bitumen			smears and pellets	smears and pellets	pellets	pellets
Road Asphalt					small aggregates	small aggregates
Vegetal *fragmenta*	few spikes	a capitulum of *Centaurea*		a varied assortment	minor fragments	
Building Material			tiny brick (?) fragments	a large assortment	small brick (?) fragments	small brick (?) fragments
Thermosetting polyesters					many fragments	many fragments
Paint			a tiny red flake	a varied assortment	several flakes	a few flakes
Fibers			just a few	a varied assortment	several	

with a height of 45 cm. On its floor, there was a varied assortment of evidence, which was sampled, together with the encrustation under the fenders and the material embedded in the tyres.

The evidence may be grouped in four main categories: i) beach sand; ii) volcanic soil; iii) vegetal and animal *fragmenta;* iv) asphalt; and v) anthropogenic material. The distribution of the main pieces of evidence is summarized in Table 1.

The following analytical techniques were employed.

Stereoscopic and petrographic microscopy. It was used for the initial identification of the morphology, surface characteristics, and details of the various items and for the separation of the single particles for photographic documentation and further analyses. Sand

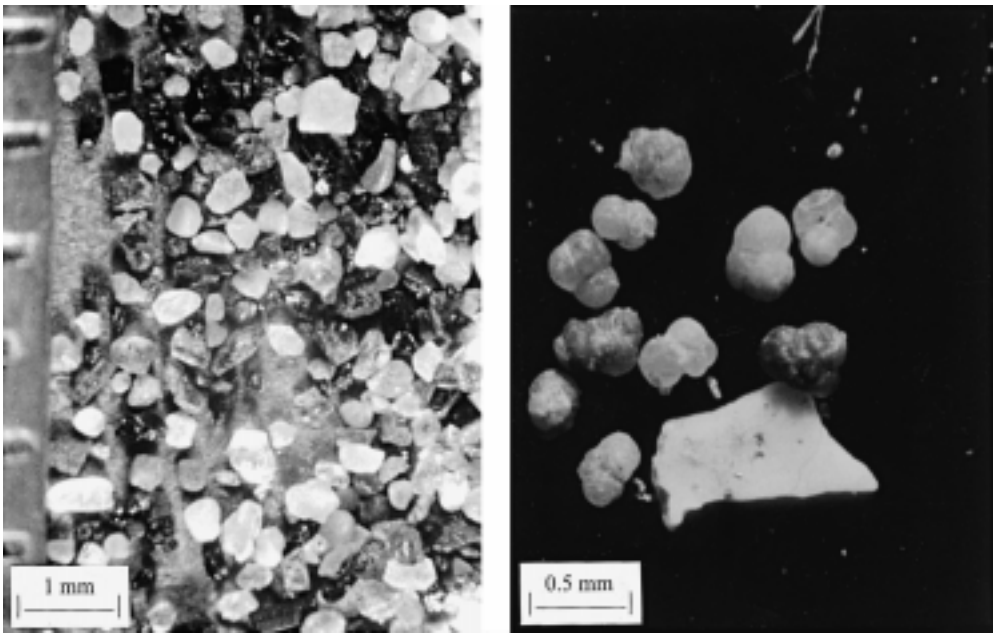


FIG. 2—*Left: the sand found in Mr. Moro's trouser cuffs, before sieving. Note the wide assortment of colors and shapes corresponding to several types of fragments of rocks and minerals with very similar size. Right: microfossils isolated from the sand of Mr. Moro's trouser cuffs, associated with a flat fragment of a Lamellibranchiata shell.*

and soil samples were mounted on a glass slide with epoxy resin and then milled down to a thickness of 30–40 μm. Thanks to these thin sections, studied under a polarizing microscope, rock samples, minerals and microfossils were identified. By using a point counter, the percentage of the sand samples components were also determined, with a view to making quantitative comparisons.

Grain size separation—Small steel sieves were employed for the separation of the sand samples into size fractions for classification and intersample comparisons. The same technique was used with the soil samples for a better assessment of the individual components. The heavy and light minerals (heavier and lighter than 2.85 g/cm^3, respectively) of sand samples were separated in order to facilitate their identification.

X-ray diffractometry—A Philips X-ray diffractometer was employed for analyzing the crystalline components of the fine fraction of the soil samples and for determining other crystalline phases.

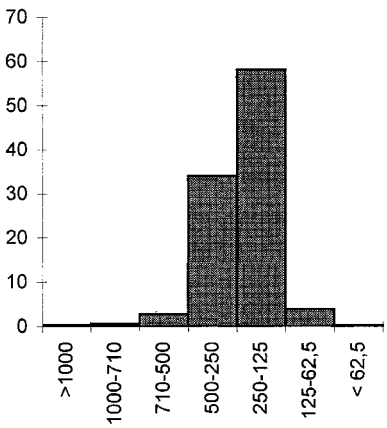
DSC—Differential Scanning Calorimetry measures the heat, which is involved upon a given reaction, i.e., heating (or cooling) according to a programmed temperature gradient. A Du Pont instrument was used to study the bitumen and polyester fragments found under Mr. Moro's shoes, inside and outside the car.

SEM and microprobe—A Cambridge Stereoscan scanning electron microscope equipped with ED X-ray detector was used to identify the chemical composition of minerals and of heterogeneous items found on the car floor. A JEOL XA 50A microprobe was employed for the chemical analysis of the sand grains, so as to better define their provenance.

Pollen analysis—It was carried out on the soils adhering to the car fenders, in order to trace back the period of adhesion. Soil samples were attacked with HCl 37% and HF 40%, boiled in NaOH 10% and washed with distilled water. Suspended in glycerine, they were analyzed at 500–700 magnification under the microscope.

TABLE 2—*Grain size distribution of the sand found in Mr. Moro's trouser cuffs. The histogram depicts its very good sorting, typical of beach sands.*

dimensions in micrometers	%
>1000	0,36
1000-710	0,62
710-500	2,74
500-250	34,02
250-125	58,15
125-62,5	3,9
< 62,5	0,21



Discussion of Results

Though obviously all evidence was analyzed, this paper is focused on what had relevance to the identification of the car provenance and itinerary and to the last whereabouts of Mr. Moro.

The Sand Samples

The composition of the sand from the clothes, the shoes, and the car was studied in detail. The results may be summarized as follows. The sand from the trousers cuffs (0.75 g) and from the blanket on which laid the corpse in the car (0.25 g) had the same characteristics. Completely loose, easily recognizable as beach sand from the Tyrrhenian coast of Latium, was identified due to its rich-

ness in volcanic elements, it was made up of several components, with colors ranging from dark black to bright white and an overall brownish color (Fig. 2).

The shape of the histogram and the parameters of the grain size analysis revealed that these sands were very well sorted, with over 92% of the grain diameters ranging between 500 and 125 μm (Table 2). As regards grain morphology, rounded to subrounded forms were dominant over angular ones. The absence of coarse and fine "*tails*" in the grain-size distribution are typical of a deposition environment where wind and water applied a high level of energy to the sediment after its deposition, inducing a good sorting. On a beach, such distribution occurs from the wind and water line to the dune alignment. The absence of fine tails indicated origin from a non-pedogenized area. Altogether, it was classified as medium-fine supratidal marine sand, where supratidal refers to provenance from an environment sheltered from the direct action of tides and waves. Combining microscopic observations with instrumental analyses assessed the composition of the sand. Three groups of components were identified: i) rock fragments and minerals (Table 3); ii) fossils and other organisms; iii) fibers and a tiny metallic lamina. The following main inferences were drawn from the varied assortment of rock fragments and minerals. i) The texture and microfossil content of the carbonate micrites indicated provenance from the Mesozoic formations of the Sabina area, in central northern Latium. Micrites are rare in the mountains of Southern Latium. ii) The metamorphic rock fragments, and their minerals (microcline, part of the quartz, albite, orthoclase and chlorite) derived from the alteration of Cretaceous-Oligocene flyschoid formations outcropping along the coast in northern Latium, featuring extensive sandstone units with such metamorphic content. iii) The volcanic fragments and their minerals (pyroxenes, amphibole, olivine, biotite and garnet) had textural and compositional characteristics which were easily ascribable to the alkaline-potassic Quaternary volcanics outcropping extensively in central-northern Latium. The pyroxene chemical composition obtained from SEM-EDX analysis showed high variability in their chemistry. The well-preserved habit of some of these volcanic minerals and the presence of adhesions of a glassy, fragile matrix indicated that at least part of them underwent a limited transport process and then deposition close to their point of origin.

TABLE 3—*The numerous types of fragments of rocks and mineral species identified in the beach sand found in the trouser cuffs and in the car. They derive from alteration of the different lithologies belonging to the geological formations that outcrop in the hinterland.*

Rock Fragments	Minerals
Sedimentary	Quartz
Carbonates	Albite
Micrites	Oligoclase
Microcrystalline	Orthoclase
Dolomitic	Sanidine
Marls	Clinopyroxene augite
Sandstones	Clinopyr. aegirinaugite
Chert	Amphibole hornblende
Metamorphic	Biotite
Quartzites	Muscovite
Phyllites	Chlorite
Schists	Calcite
Volcanic	Dolomite
Leucititic lavas	Apatite
Leucite tephritic lavas	Magnetite
Trachytic lavas	Titanite
Zeolitised tuffs	Garnet
Reddish scoriae	

The sand samples from the trouser cuff and from the blanket accommodated a varied assortment of marine organisms, recent and fossilized, both intact and fragmented (Fig. 2). Among them, a few fragments of shells of present-day Lamellibranchiata were macroscopically evident, with rounded edges and adhesion of parasites on their outer surface. Most organisms, instead, were planktonic (dominantly) and benthic microfossils, which were identified with the assistance of a palaeontologist and divided into two groups. The first group included a few forms of *Cassidulina laevigata carinata* SILVESTRI and *Ammonia beccari* LINNE' which had well-preserved outer surfaces and are common in the present-day local beach environment. The second, much larger group consisted of microfossils with their shells filled with calcite, often fragmented and with rounded and polished outer surfaces, indicating that they originated from a different environment and underwent a major transport process. Among these forms, rare benthic forms were identified, such as *Cibicides sp.* and *Lagena sp.*, and the following planktonic forms: *Globigerina pachyderma* (RHRENBERG), *G. regina* (Crescenti), *G. cf. aequilateralis* (BRADY), *G. bulloides* d'ORB., *Globigerinoides gr. trilobus* (REUSS), *G. trilobus immatures* (REUSS), *G. gr. conglobatus* (BRADY), *G. trilobus hispaericus, G. gr. obliquus* BOLLI, *G. gr. ruber, Globorotalia cf. scitula ventriosa* OGNIBEN, *G. mayeri* CUSH & ELLISOR, *Globoquadrina dehiscens* (CHAP, PARR & COLL.), *Orbulina suturalis* (BRONN).

The inferences from the palaeontological analysis contributed to frame the provenance of the sand. The fresh macro- and microfossils indicated that the sand was originally deposited in a very shallow marine environment, close to the coastline. The association with other fossils showed that it originated from processes of alteration of terrigenous Upper-Middle Miocene formations and transported by streams and rivers. Formations of this age outcrop in northern Latium not far from the coast and, farther north and east, along the Tiber and Aniene valleys.

More beach sand was found on the leather soles and on the rubber heels of Mr. Moro's shoes. Fine grains of fragments of volcanic rocks and minerals, and carbonates were identified in discontinuous, thin adhesions mixed within a bitumen spot. These fragments had strong morphological and compositional analogies with most of those observed in the trousers and blanket sand, albeit with a less complete assortment of species.

Several hundreds of grams of mixed material deriving from more than one source were scattered on the car floor and, among them, there were several fragments of rocks, minerals and microfossils with characteristics similar to those noted in the sand from the trousers cuffs. However, in no part of the car could pure sand be sampled; the admixture with other components prevented any significant comparison and inference on its provenance.

In summary, the sand analyses revealed that: i) samples from the blanket, trouser cuffs and shoes had very similar characteristics; ii) the grain size was typical of a beach environment close to the wind and water line of the Tyrrhenian coast near Rome; iii) the samples contained a dominant amount of volcanic material associated with sedimentary and metamorphic components, and their area of origin was determined. Therefore a reference sand sample and the environment of deposition were identified.

The composition of beach sand depends on type of inland geological formations, distribution of streams and rivers and sea current direction and intensity. In the literature, there were (and still are) only scarce data on the sand composition along the coast near Rome, of no use for provenance studies. Therefore, a systematic inspection of all accesses to the beach was carried out, sampling the

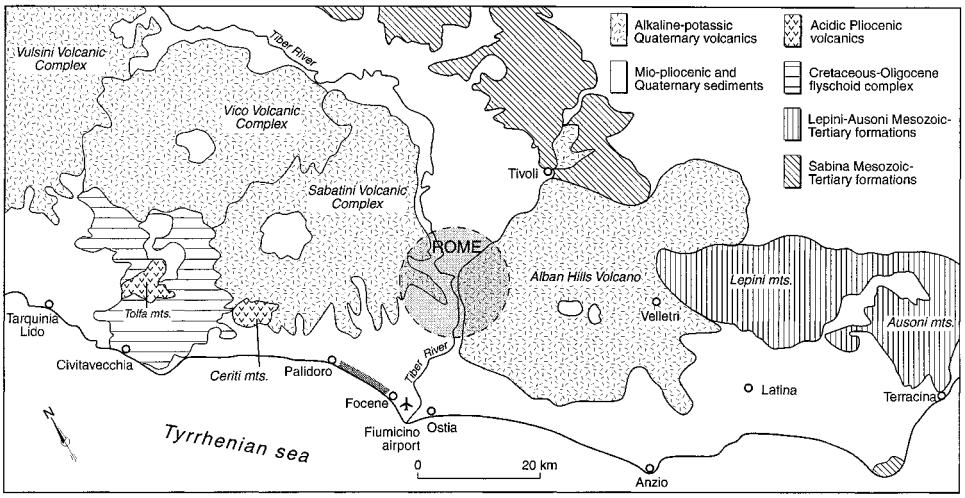


FIG. 3—*A schematic geological map of the periTyrrhenian central-northern Latium, with the coastline from which beach-sand samples were collected. Major outcrops of Quaternary volcanics are associated with sediments belonging to geological formations of various ages. The marked stretch of the coast north of Fiumicino airport, between Focene and Palidoro, is where the local beach had a composition compatible with that of the sand found in Mr. Moro's trouser cuffs.*

local sands, with the following constraints: i) the investigated shore was approximately 150 km long: from Terracina, a locality south of Rome (where Mr. Moro had a beach house that he used on weekends) to Tarquinia, the northern limit of influence of the inland volcanic systems on beach composition; ii) the sampling was carried out only where a road gave access to the beach and to an environment compatible with terrorist activity; this condition drastically reduced the number of final sampling sites to 92; iii) one-to-three samples per site were collected, 20 to 100 m from the wind and water line, checking that their grain size was compatible with the reference samples; iv) the type of vegetation existing in the sampling sites was also checked.[2]

The parameters considered in the comparison with the sand found on the corpse of Mr. Moro were the following: i) content and type of light and heavy (specific weight > 2.85 g/cm^3) minerals; ii) content and type of carbonate and volcanic rock fragments; iii) morphology and grain-size. An initial screening was done with the stereoscopic microscope, eliminating the samples, which were clearly different from the reference sand. From the remaining 70 samples, thin sections were prepared and then semi-quantitative composition was assessed by using the polarizing microscope and, on selected samples, the point counter.

Based on this analysis, provenance of the reference sand from the beach south of the Tiber mouth (and thus the assumption that the sand on Mr. Moro's trousers and shoes might derive from his beach house in Terracina) was ruled out (Fig. 3). The composition of the northernmost beaches was substantially different from the one of the reference sample. Closer to Rome, north of the Tiber outlets, the area whose sand composition showed marked analogies with the reference sand was restricted between Focene Nord and Marina di Palidoro, i.e., a length of approximately 11 km. An area of such length might seem scarcely useful to locate a kidnappers' den. However, it must be considered that on this tract there were only few roads which gave access to the beach. Moreover, many of them lead to logistically-impossible places for a terrorist hideout. There were only few reasonable access roads leading to an area useful for terrorists. And in the area, but not only there, there were widespread plants of *Centaurea aspera* in the same stage of evolution as the *capitulum* found in the Mr. Moro's trouser cuffs (see paragraph on vegetals).

Volcanic Soil

A mixture of a fine halloysite-rich clay matrix, glassy scoriae and volcanic minerals, with an overall red-brown color, identifiable as volcanic soil, lay in minor quantities under the shoes, as encrustation under the fenders and in fine adhesions on the external body of the car. Such soil type is very common in central-northern Latium, where there are over 6000 sq km of volcanic outcrops. Its analysis was of no help for provenance inferences. However, two factors suggest that the volcanic soil adhered to the car and shoes before the beach sand: i) under the shoes it could be observed that the volcanic soil was overlain by the beach sand; ii) pollen analysis (see next paragraph) revealed that the soil encrustation under the fenders did not contain traces of Spring blooms and therefore antedated Mr. Moro's kidnapping (16 March 1978).

Vegetal Fragmenta

Botany may be an important ancillary discipline in the study of soils and its value should never be underestimated. In the case in point, it gave a significant contribution to the definition of provenance and to the dating of the time of adhesion to the car. The botanist Prof. Valerio Giacomini of the Università degli Studi di Roma "La Sapienza" was entrusted by the investigating Magistrate with the task of cooperating in the analysis of the vegetal *fragmenta.* A further contribution to their determination was given by G. Montelucci, an extraordinary amateur botanist who accumulated a unique knowledge on the flora of Latium by recording its

[2] Acknowledgment for this sampling should also be given to my wife Patrizia. In that period of full activity of the Red Brigades, my name was kept secret for security reasons, but the sand found on the corpse of Mr. Moro was major news in the newspapers of the time. Therefore, I did the sampling while trying not to be noticed, with my wife getting out of the car casually, picking up parts of plants, and romantically looking at the sea. Then, sitting with her on the beach at the chosen site, I discreetly checked the type of sand and then filled a plastic bag with it.

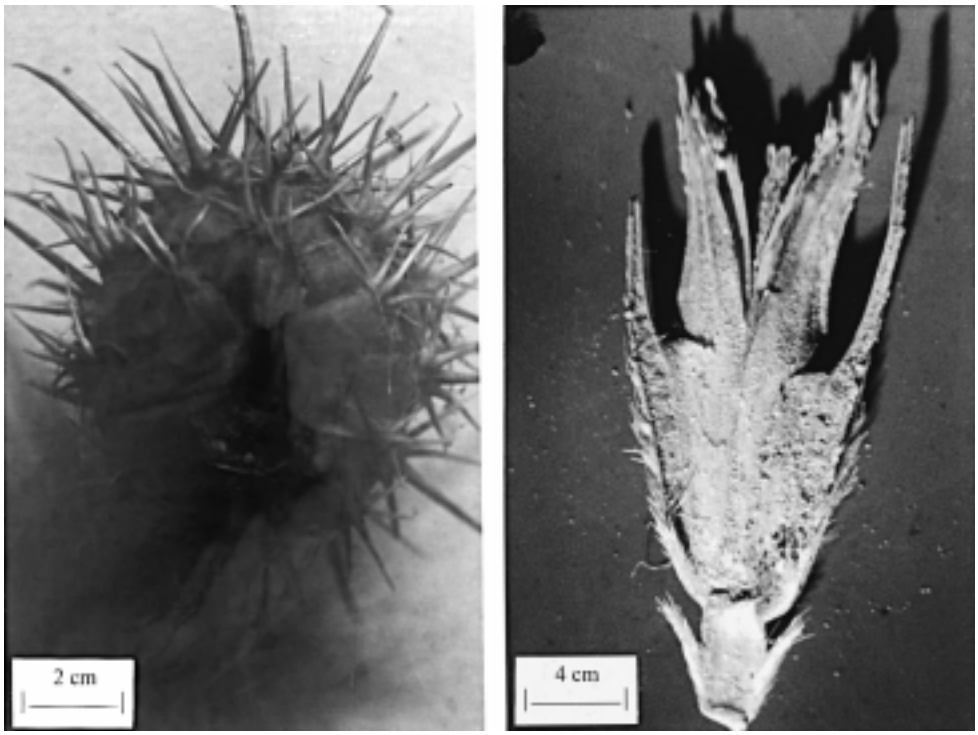


FIG. 4—*Left: the immature* Centaurea aspera *capitulum found in Mr. Moro's trouser cuffs. Right: A spike of* Triticum villosum *found in a pocket of Mr. Moro's coat.*

evolution in hundreds of notebooks, every day for many years, during his movements both in Rome and in its surroundings.

Initially, the attention was focused on the vegetal *fragmenta* on Mr. Moro's clothes. In the left pocket of his coat there were a few 20–24 mm long fresh spikes identified as *Triticum villosum (Dasypirum Villosum)* (Fig. 4). This is a thermophile species, widely diffused in the periTyrrhenian Latium, rapidly disappearing towards northern Tuscany, while it is common in southern Italy. Its stage of development indicated that it might have grown only since the end of April. Identical spikes were on the blanket over which the corpse laid in the car. In the same left pocket of his coat, there were also a few specimens of *Hordeum murinum*, a species with very wide distribution and therefore of scarce significance.

In the trouser cuffs, mixed with beach sand, there was a 15 × 14 mm thorned, immature *capitulum* of *Centaurea aspera* (Fig. 4). The blooming of this species in periTyrrhenian Latium occurs rather late, normally in late May-early June. The specimen in the cuffs had not yet bloomed and its formation was assumed to have occurred 15 days at the most before the trouser cuffs had captured it. This plant has a littoral habitat and is diffused along the Tyrrhenian coast as far as northern Tuscany. Under the microscope, the *capitulum* of *Centaurea aspera* had a few mineral grains deeply embedded within its spikes. Their analysis showed that they were calcite, carbonate rocks and pyroxene, and that their morphology and elemental composition matched the ones of the grains of beach sand with which they were associated in the cuffs.

On the car floor, there was a varied assortment of pieces of small branches, bark and of other dried woody fragments of scarce significance, such as dried leaves and parts of laurel (*Laurus nobilis*), of alfalfa (*Medicago hispida*), of box (*Buxus sempervirens*), of *Triticum villosum, Triticum sativum, Milium* and others. More interesting was the presence of seven spikes of *Triticum villosum* on the trunk floor, with the same characteristics as those found on Mr. Moro's clothes. On one of the spikes there was a spot of bitumen, meaning that it had adhered to the spike after the end of April, therefore very close to the date when the corpse was found (8 May).

Under the car fenders, there was an encrustation of volcanic soil with only minor quantities of beach sand. In order to establish whether the volcanic soil had adhered to the fenders before or after the beach sand, a pollen analysis was carried out by Prof. Follieri of the Università degli Studi di Roma "La Sapienza" on the superficial layers of the encrustation on the right-back and the left-front fender. In both samples, the pollen content was the same and small, with no traces of the abundant spring blooming. Most of the identified pollens were of Cypress and Hazel tree and produced in winter. Associated with these recent pollens there were also fossil Pliocenic pollens from Pines and other Coniferae (*Cedrus, Cryptomeria*) with *Chenopodiaceae, Compositae* and Fern spores. They were supposed to have originated from the degradation of clayey formations outcropping at the periphery of the volcanoes of Latium. The conclusion of the pollen analysis was that the volcanic soil had adhered to the fenders in winter, thus prior to adhesion of the beach sand.

Asphalt

A black, plastic, shiny, sticky material was present under Mr. Moro's shoes, inside the car, under the fenders and in the tire grooves. Under the shoes there were tiny nuclei mixed with sand in the front part of the sole and a larger (22 × 3 mm) adhesion on the side of the right shoe (Fig. 5). Two were the possible origins: asphalt from the road surface of bitumen from a beach.

A small fraction of the bitumen from the shoe and other samples from the tires and the inside of the car were isolated and analyzed.

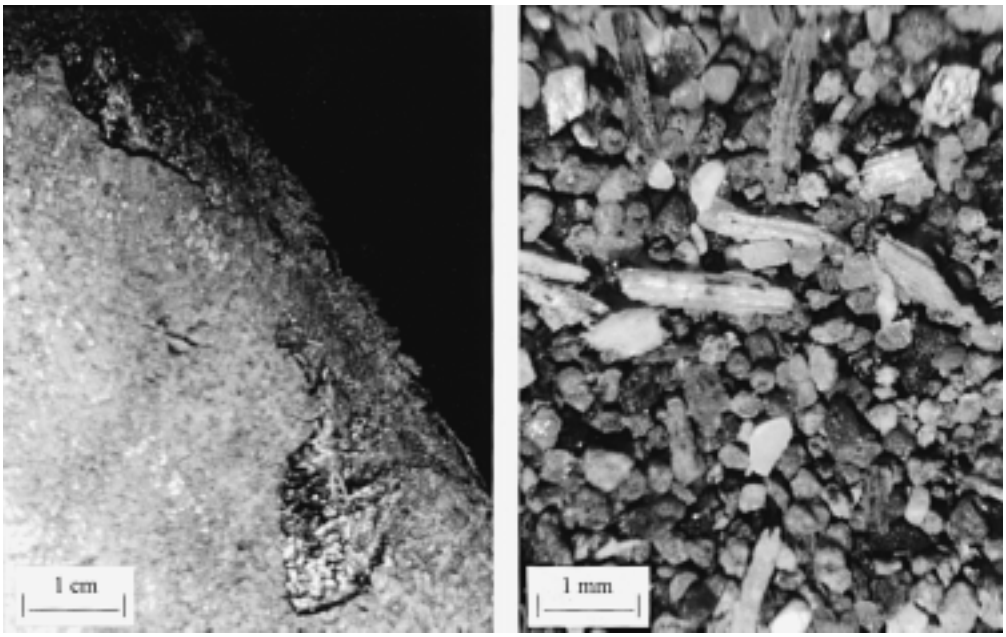


FIG. 5—*Left: an enlargement of one side of Mr. Moro's right-shoe sole with a blackish encrustation of plastic, bright bitumen, associated with beach sand and minor amounts of volcanic soil. Right: a mixture of beach sand, volcanic soil and other items from under the car fenders. The white, elongated, fibrous fragments are of a thermosetting polyester of the type used also in the manufacturing of boats. Such fragments were present also in the tire grooves.*

TABLE 4—*Heat rates at different temperatures, calculated from the DSC curves of the bitumen from the shoes and of refinery bitumen.*

	50°C	100°C	140°C	180°C	200°C	240°C	270°C
Bitumen from the Shoes	0.341	0.363	0.380	0.381	0.388	0.398	0.408
Refinery Bitumen	0.388	0.385	0.391	0.394	0.395	0.398	0.408

It was observed that after three weeks at room temperature their plasticity and brightness was markedly reduced. The analyzed samples were very similar, with the same solubility of paraffin hydrocarbons (n-pentane), typical of refinery bitumens. However, they contained a lesser quantity of asphaltenes than industrial bitumens. The specific heats calculated from their differential scanning calorimetry (DSC) curves are very similar to those typical of bitumen from a Middle East crude oil obtained in a refinery. The difference was that the curve of the bitumens from the shoe and from the car had a weak endothermic effect between 140 and 170°C, induced by the presence of light fractions not normally present in bitumens produced in a refinery.

The conclusion of these analyses was that the bitumen encrustation and aggregates were not the product of a refining process, but might derive from a spontaneous selections of an original mixture of hydrocarbons as it occurs in crude oil spills over the sea surface. Nuclei of bitumen were then sampled on the beaches near Rome, where the activity of an offshore oil-tanker terminal contributed (and still contributes) to spread out such pollutants. Their analysis revealed that the characteristics were very similar to those of the encrustations under the shoes and inside and outside the car and that the bitumen did not derive from a road surface, but from a beach (Table 4).

Bitumen was evidently diffused in the area where the car passed and was parked. Centimeter- or millimeter-sized nuclei of bitumen were found on the car floor, both in the trunk and between the seats; bitumen was adhering to several items sampled on the floor, such as mineral grains, fibers, vegetals, a piece of electric wire; bitumen spots were on the clutch pedal; bitumen adhesions were rare under the fenders, but scattered inside the tire grooves. Two clues suggested that the bitumen adhered to the shoes and car a short time before Mr. Moro's assassination: the nuclei and the adhesion had high plasticity and softness, which do not last long, as observed upon exposure to room temperature in the lab; there were bitumen smears over a fresh *Triticum villosum* spike which, in the 1978 climate, might have developed only after the second half of April (the corpse was found on 8 May).

A different type of black encrustation of hydrocarbon-based material was noticed on the tires and under the fenders. Its characteristics, as evidenced by DSC, were different from the bitumen samples and similar to those of asphalt bits from the road surface.

Anthropogenic Material

The car had been used for the transport of building material and on its floor there was an assorted collection of very different items such as gravel, electric wire, metal and plastic fragments, nails, paint crusts, glass, brick fragments, buttons, seeds, artificial fibers, an animal plume, cigarette butts. Under the fenders and in the tires grooves, there were also artificial fibers, animal hairs, minute plastic, paint, metal, glass ceramic, and brick fragments. Part of these items was also embedded in the thread of the tires. Their analysis did not give specific clues to this investigation. At that time, a DNA analysis of the cigarette butts was not feasible.

However, two clues were given by this material: i) several of these items had smears and spots of bitumen, presumably carried into the car by the shoes of its occupants, again stressing the diffusion of bitumen in the area where the car had passed; ii) under Mr. Moro's shoes, there were tiny reddish aggregates which might be brick fragments and one fragment of red paint with morphological and chromatic characteristics similar to those of the items which were present on the car floor.

Of much more interest was the finding, under the fenders and embedded in the tires, especially in the back ones, of several 1–2 mm white fibrous fragments (Fig. 5). Analyzed by Differential Scanning Calorimetry (DSC), they were identified as thermosetting polyester, of the same type in use for the manufacturing of boat shells. This fact validated the assumption that the car had recently passed on a surface where activities connected also with a beach environment took place.

Conclusions

From the analysis of the assorted evidence collected both on the corpse of Mr. Moro and on the car used for its transport, the following conclusions were reached. i) The textural and compositional characteristics of the sand samples found on the trousers and under the shoes of Mr. Moro, inside the car and embedded in the tire grooves were very similar to and typical of the beach sand from the Tyrrhenian coast of Latium. ii) The closeness of the sand-sampling site to the shore was substantiated by the presence, under the shoes, on the tires and inside the car, of nuclei and smears of bitumen as derived from oil evaporation on the sea surface and diffused on the Tyrrhenian beaches. The fresh state of the smears testified their recent adhesion to the evidence. The presence of fragments of thermosetting polyesters, like those used for the construction of boat shells, embedded in the tires and under the fenders, might indicate proximity of a naval yard. iii) Thanks to the vegetal *fragmenta* on the corpse and in the car, the time of pick up of the sand was determined to be very close to the day when the corpse was found. Pollen analysis indicated that volcanic soil encrustations had adhered to the fenders prior to the sand. iv) A comparison of the sand from the corpse and the car with a series of samples collected along the beaches of Latium narrowed the investigations to a tract of shore where the car and the shoes had passed. v) The presence of volcanic soil on the shoe soles (whose adhesion antedated the one of the beach sand) suggested that the shoes had passed on a volcanic terrain before passing on the sand.

A few weeks after the killing, the preliminary results of this investigation were handed over to the Court. Inspections and searches were carried out by police forces on the indicated suspected tract of the beach, but no terrorist hangout was found. Only years after, the investigators found the apartment in the south-eastern suburbs of Rome where the captors indicated Mr. Moro had been imprisoned. Their confession indicated that he had been shot in the garage of that building and then driven downtown. They also claimed that the sand and the vegetal *fragmenta* had been planted on Mr. Moro's trousers and coat in order to mislead the investigators.

This might have occurred, but it must be recalled that sand was also stuck under the shoes together with beach bitumen, sand was under the fenders and the tire grooves, associated with bitumen and thermosetting polyesters, bitumen was disseminated on many items on the car floor. One could state that there is no proof that Mr. Moro was ever brought on a beach and that the sand and vegetal *fragmenta* in the trousers cuffs had been planted. But the car, its occupants, and Mr. Moro's shoes did trample on the sand of the indicated tract of beach, where there were diffused bitumen and thermosetting polyesters. And the clues from the vegetal *fragmenta* indicated that this action occurred in a period very close to when Mr. Moro's corpse was found. Moreover, the distribution of the sand and the bitumen under the shoes strongly suggested that the adhesion occurred when the shoes were worn by somebody, either Mr. Moro or one of his kidnappers.

Other clues would favor the existence of a base close to the seaside. The van used to abduct Mr. Moro from the place of the kidnapping was seen by a witness on the Via Aurelia, one of the main road leading to the seaside. A first analysis of the bullets found in the Renault 4, close to Mr. Moro's corpse, revealed oxidation phenomena with characteristics similar to those occurring through the action of the sea environment.

During the 55 days of captivity, the evidence collected by Police Forces also led to searches for the Moro's prison in buildings along the seaside, but at no avail. However, aside the aseptic interpretation of the scientific data, in this case there are two significant and antithetic factors to be considered. a) The average intellectual level of the members of the Red Brigades components was quite high, many of them were from universities and they were fanatics with a strong political motivation. Therefore, it is not surprising that in many actions they showed great care in planning and details. A planting of the sand and vegetal *fragmenta* on his body and shoes it is not unconceivable. However, as forensic geologist with 25 years of experience, I would have some problems in planning such a complex mislead, involving wearing Moro's shoes and collecting and distributing such an assortment of items as found on his body and on the car. b) On the other hand, all over the world when a major political personality is assassinated, no investigation has ever allowed the public to exactly know what happened, and President John Kennedy and Martin Luther King's assassinations are two cases in point. The Moro's case well fits into this category and still nowadays, although officially the arrested killers "confessed," there are many empty slots in the reconstruction of the ambush, the imprisonment, and the killing. A few examples: it is still unknown who were the two people on a Honda motorbike who shot at the ambush and were seen by witnesses; of the 91 bullets shot at the ambush site, none wounded Mr. Moro and 46 were from the same weapon (which has never been recovered), though among the "official" killers, none was a particularly good shooter; the van used for the kidnapping has never been found. Furthermore, many doubts were expressed on the assumption that Mr. Moro was held for 55 days, examined and moved to and from the 250×120 cm cell in an apartment which the terrorists indicated as his only prison. It should be pointed out that the autopsy revealed a body in good physical conditions and that the many letters he wrote during his captivity showed a normal handwriting, not that of a person writing in a cramped position, with no proper table. There are strong suspicions that there is a group of members or supporters of the Red Brigades which was never discovered or betrayed by the arrested terrorists.

These and other facts had been amply debated by the media in the last two decades and there are still many who believe that too much is still to be clarified and verified on the major political killing of the post-war Italian history. Among the many books and documents on the subject, which may be found on Internet, it should be mentioned Mr. Moro's brother recent book (1) which analytically summarizes the many omissions in the confessions of the terrorists and inconsistencies in the official reconstruction of this dark page of the Italian life.

The study described in this paper, and the subsequent experience of the author as forensic geologist in Italy, stimulate some com-

ments on the present-day approach to the forensic analysis of soils. In comparison with drugs, fingerprints, bullets, body fluids, there is a limited number of cases/year where the necessity of analyzing soils crops up. Therefore, only large central organizations can justify full-time geologists. To help peripheral labs to deal with occasional analyes of soil, several articles appeared in the literature dealing with standardized practices to be used also for soil comparisons. In a recent paper by Junger (2) there is good review of the various approaches to the problem, where "practitioners have moved from direct examination, statistical measurements and chemical assaying, to modern instrumentation methods and analytical component analysis." Much of the effort deals with the identification and quantitative evaluation of the minerals present in the sand fraction of the soils. But it should be underlined that this practice gives a very partial view of the soil composition. In most sand fractions of the soil, there are not only minerals but fragments of rocks, and they may be accurately identified in thin section only, a "weapon" which can be fully used only by a trained geologist. The overall picture of the geologic environment from where the components of the soil derive may be obtained only by a geologist who can interpret the geologic maps. And the experience of a geologist may also be decisive for the choice of the on-site sampling criteria.

I do hope that the petrographic techniques utilized in this investigation, and the background needed to properly exploit their results, may help to understand the potential of geologists' work in forensic science, especially when integrated with the collaboration of other disciplines.

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Though many recall the name of the politicians and magistrates killed in Italy during terrorism, very few pay an adequate tribute of remembrance to the over 100 members of the Carabinieri and police forces who were killed during the terrorism. In this case, I would like to publicly pay homage to the memory of Mr. Moro's bodyguards Raffaele Iozzino, Oreste Leonardi, Domenico Ricci, Giulio Rivera, Francesco Zizzi, who died serving their country, and let their families know that they are not alone in their sorrow.

References

1. Moro AC. Storia di un delitto annunciato. Le ombre del caso Moro (History of a predicted crime. The shadows of the Moro's case) Rome: Editori Riuniti, 1998.
2. Junger EP. Assessing the unique characteristics of close-proximity soil samples: how useful is soil evidence? J Forensic Sci 1996;41–27.

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