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Brake Linings: A Source of Non-GSR Particles Containing Lead, Barium, and Antimony

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ABSTRACT: The observation of environmental particles similar in composition to gunshot residue (GSR) are not new to forensic experts and have been described in the scientific literature. In order to better define the origin of these particles, brake linings and their wear products were examined by SEM-EDX. The results obtained demonstrate that some types of brake linings contain lead, barium, and antimony and that they can represent a source of particles showing GSR-like elemental profiles. Most of these particles can be easily discriminated from primer discharge residue because of the high levels of iron or the presence of "prohibited" elements in the spectrum. However, particles with iron at minor or trace levels and lacking "prohibited" elements were also found. It is thus advisable to use caution when describing the composition of similar particles as "unique" to primer discharge residue. The strict application of a rigorous morphological criterion is also recommended.

KEYWORDS: forensic science, criminalistics, gunshot residue, environmental particles, scanning electron microscopy/energy-dispersive spectroscopy

The scientific basis for the techniques currently employed in the research and identification of gunshot residue (GSR) were laid down in studies dating back to the second half of the 1970s (1–4). Since these early years, awarness of the presence of occupational-environmental particles similar in composition to GSR, which may lead to misinterpretation, prompted the creation of a first classification system specifying the compositions to be considered *characteristic* (observed only in gunshot residue) and those *consistent* with, but not unique to, firearm discharge residue (2,3). This classification was modified in 1984 by Wallace and McQuillan (5). In their opinion, only particles of lead, barium, and antimony, or barium and antimony, may still be considered *unique*, bearing in mind that the use of the term *unique* is not limited to firearm discharge residue, but must be generally extended to discharge residue of any primer based on a mixture of lead, barium, and antimony compounds. Wallace and McQuillan also suggested a list of *indicative* (but not unique) compositions. Both unique and indicative particles must show at least one of the primary elements (lead, barium, and antimony) at a major level. Particles may also include aluminium, calcium, sulphur, and silicon at major, minor, or trace levels; chlorine, copper, iron, potassium, and zinc (solely in presence of copper and with zinc/copper ratio below 1) at minor or trace levels; or magnesium, sodium and phosphorus at trace level only. The presence of any other element usually indicates an origin other than primer discharge. In this classification, the terms "major," "minor," and "trace" refer to the relative height of the main peak of the element concerned, compared to the strongest peak in the spectrum: the element is "major" when its main peak height is above 1/3 the height of the strongest peak; "minor" when its main peak height is between 1/3 and 1/10 the height of the strongest peak; "trace" when its main peak height is below 1/10 the height of the strongest peak. The strongest peak in the spectrum must be "on scale." A simplified form of the classification proposed by Wallace and McQuillan was also adopted in the ASTM standard guide for gunshot residue analysis by scanning electron microscopy/energy-dispersive spectroscopy (6).

However, the most recent systematic study comparing GSR and occupational-environmental particles (7) suggested that particles composed of barium and antimony should be removed from the "unique" category and assigned to the "indicative" category. It is also confirmed that cartridge-operated industrial tools and fireworks can produce particles with a composition that is similar to GSR.

Since 1982 the Laboratory of Criminalistic Sciences of the University of Turin has specialized in the study of GSR. As a consequence, its staff is often asked for scientific advice in the advanced stages of criminal trials, when in-depth evaluation of the results of GSR analyses performed during preliminary investigations is needed by the court. This privileged position, entitling the Laboratory's scientists to review other experts' work, has resulted in the creation of a large case record including not only personal data, but also those from several Italian laboratories carrying out GSR investigation.

Figure 1*a–d* shows a selection of particles from this case record, which were identified as GSR by experts. Some laboratories (even recently) have been classifying "unique" particles as composed of: barium and antimony with iron at a major level (Fig. 1*a*); lead, barium and antimony with iron at a major level and with exogenous elements, like chromium and manganese, in traces (manganese in traces is present in the spectrum shown in Fig. 1*b*); lead, barium, and antimony with magnesium at a minor level (Fig. 1*c*). According to the classification of Wallace and McQuillan, and to personal experience, these particles should not be considered as "unique." Strictly speaking, because of their ubiquitous environmental distribution, they cannot even be described as "indicative": only when particles with the same features are found in the discharge residue from the firearm and/or ammunition used in the crime, may they be carefully taken into consideration. Italian laboratories, as a rule, consider "unique" particles as composed of barium and antimony, with iron at minor or trace levels (Fig. 1*d*). Although the signifi-

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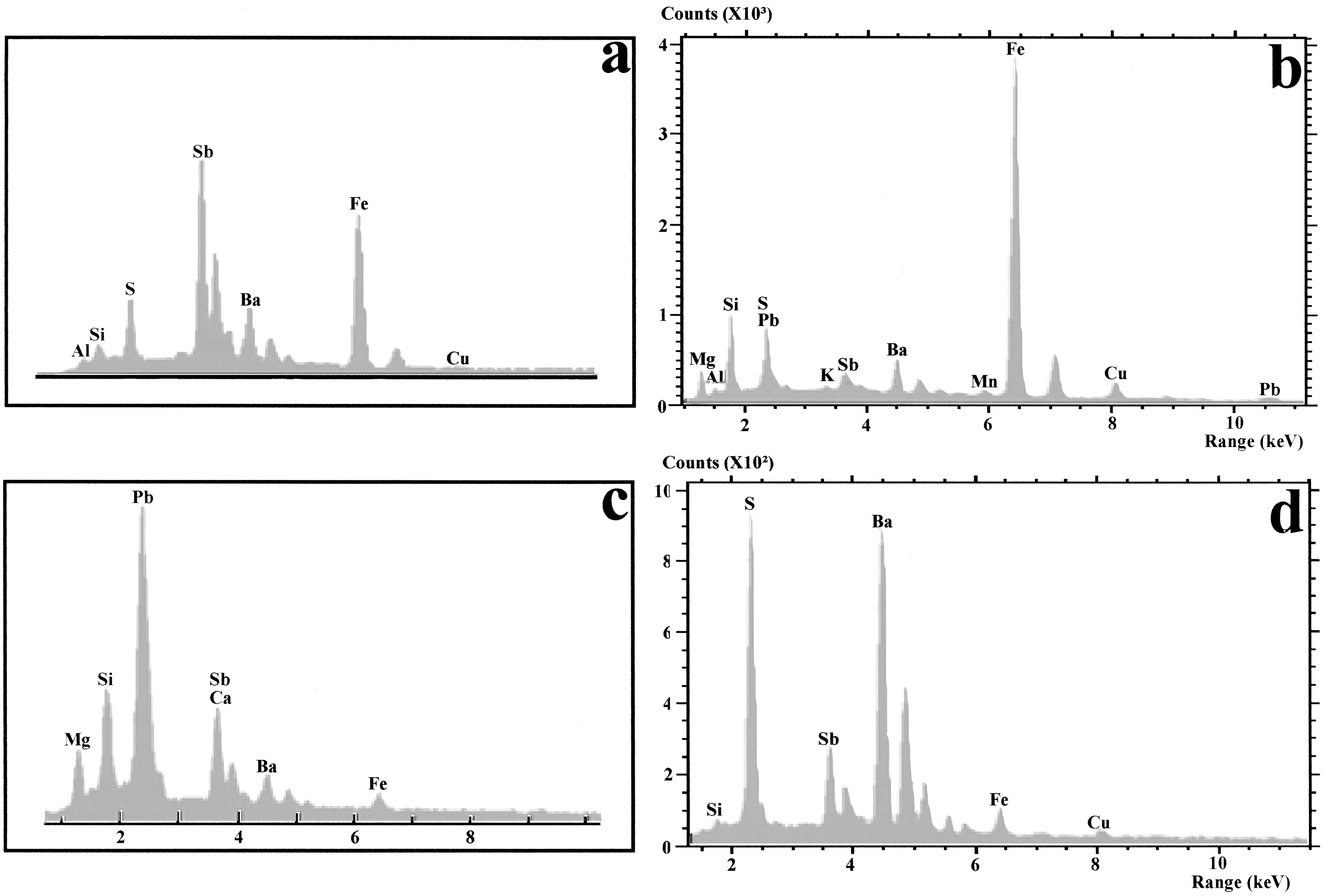

FIG. 1—*A selection of spectra from particles classified as "unique" by some Italian laboratories carrying out GSR analysis. Since only poor-quality copies of the original experts' reports were available, it was not possible to include in the figure suitable images showing the particles' morphology, which was not, however, typical of GSR. As spectra were obtained at different times and with widely varying instrumentation, a computer retouch was necessary in order to render the images graphically homogeneous. a) (sample from a windowsill, 1997): iron is present at a major level. b) (sample from garment, 1997): note iron at a major level and the presence of magnesium and manganese. c) (sample from the interior a machine shop, 1990): note the presence of magnesium and calcium. d) (sample from garment, 1997): sulphur is the strongest peak in the spectrum.*

cance of these particles has been debated in recent literature (7,8), they actually fall within those indicated by Wallace and McQuillan as "unique" for primer discharge. However, personal experience suggests that these particles often have an environmental origin, being easily found in urban areas rich in metallic particulate, such as those exposed to road traffic.

Friction material used in the production of car brake linings may contain lead sulphide, antimony sulphide, and barium sulphate in different combinations (9–12). Industrial smoothing and grinding of brake lining surfaces releases microscopic residues. Similar particles may also spread through traffic, as a consequence of brake lining wear. It must be remembered that, while braking, the temperature inside the metallic disk brake exceeds 600°C, reaching over 1500°C in friction spots on the disk surface (Dr. Kostantin Vikoulov of ITT Automotive Italy S.p.A., Barge, Italy, personal communication). Heat combines with mechanical action to pulverize and blend the different components of the lining. It is thus reasonable to expect that, through manufacture and wear, brake linings may produce particles containing the most significant elements for the purpose of GSR identification. This hypothesis was confirmed by a preliminary study (13).

The results of a systematic analysis of particles originating from brake linings are shown. The data will be of help to discriminate between environmental particles and primer discharge residue.

Methods

The following samples were analyzed:

1. Debris (blackish dust) from the front rims of a set of 40 cars, representing 40 different models. Debris was collected with clean disposable tissues. Fifty samples in all were taken from the tissues by transfer to 13 mm diameter stubs coated with double-sided adhesive carbon tabs (Agar Scientific, Stansted, UK);
2. Fragments derived from the crushing of new brake linings (Textar, Leverkusen, Germany; Unipart, Cowley, UK), transferred to 13 mm diameter stubs coated with double-sided adhesive carbon tabs. One sample for each brand of brake-lining was taken;
3. Debris collected with 13 mm diameter stubs coated with double-sided adhesive carbon tabs, from the surface of new brake linings (Textar, Leverkusen, Germany; Unipart, Cowley, UK) (two stubs were taken, one for each brand) and from the hands of the person who carried out the sampling (two stubs, one for each sampling);
4. Debris obtained from new brake linings (Unipart, Cowley, UK) experimentally worn by means of a rotary tool equipped with a grinding stone (Dremel, Racine, Wisconsin) and transferred to 13 mm diameter stubs coated with double-sided adhesive carbon tabs. Two stubs were prepared.

All the stubs were carbon-coated using a Polaron PS100 sputter coater (Agar Scientific, Stansted, UK), then analyzed using a Stereoscan 120 scanning electron microscope (Cambridge Instruments, Cambridge, UK) with a Link ISIS 300 dispersive X-ray analyzer (EDX) equipped with the Cameo™ program for X-ray color imaging (Oxford Instruments, High Wycombe, UK) (14). A working distance of 24 mm, an accelerating voltage of 20 kV and an X-Ray detector take-off angle of 30° were used in all analyses.

Only barium and antimony, or lead, barium, and antimony particles, with diameter below 20μm, were examined.

Results

Environmental Samples from Cars

In the introductory phase of the study, the presence of primary elements (lead, barium, antimony) was investigated in debris from the front rims of 40 cars. The analysis was performed by means of SEM-EDX equipped with BSE at 700X (Fig. 2). Results are shown in Table 1.

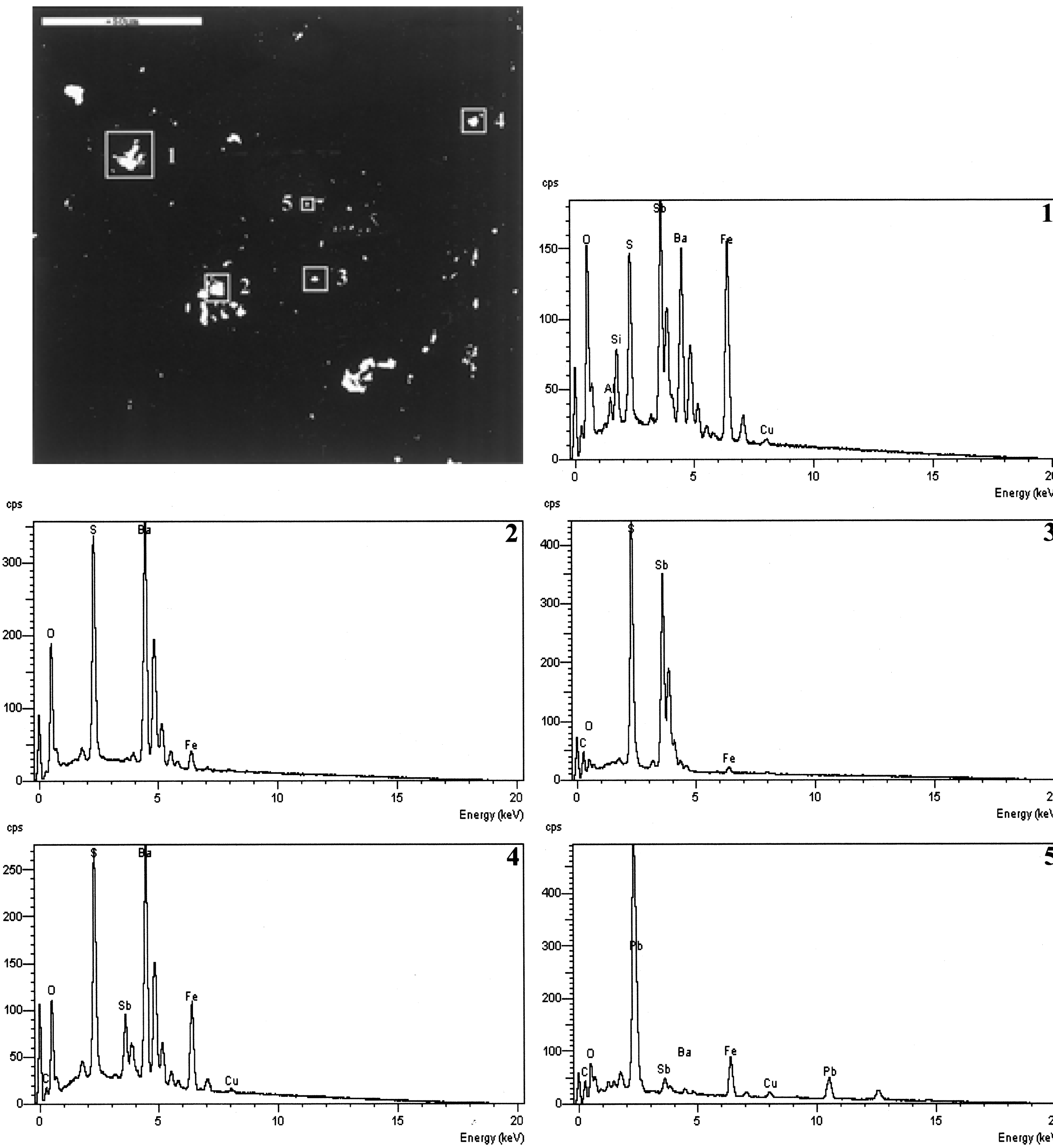

FIG. 2—*Sample from the front rim of a car (Volkswagen) (backscattered, 712X). Particles (from 1 to 5 with relevant spectra) containing primary elements, alone or combined, are shown.*

TABLE 1—*Presence of primary elements in samples from car front rims.*

Make (No. of Cars Sampled)	Number of Stubs	Ba	Sb	Pb
Italian (7)	1	+ +	−	−
	1	+	−	−
	1	+ +	+ +	−
	3	+ +	+	−
	3	+ +	−	+ +
	1	+ +	+	+ +
British (7)	1	+ +	+	−
	1	+ +	−	+ +
	1	+ +	−	+
	1	−	+ +	−
	5*	+ +	+ +	+ +
German (18)	3	+ +	−	−
	1	+ +	+ +	−
	1	+	+ +	−
	2	−	+ +	−
	2	−	+ +	+ +
	1	−	+ +	+
	1	−	+	+ +
	1	−	+	+
	3	−	−	+ +
	1	+ +	+	+ +
	1	+	+	+ +
	6†	+ +	+ +	+ +
French (4)	1	+ +	+ +	−
	1	+	+ +	−
	1	−	+ +	+ +
	1	−	+	+
Japanese (2)	2	+ +	−	+ +
Swedish (2)	1	−	+ +	−
	1	−	+ +	+ +

NOTE: −: absent; +: sporadically present in the sampling field (700X); + +: constantly present in the sampling field (700X).
* Rover.
† VolksWagen.

The study was then restricted to car models showing the constant and contemporaneous presence of barium, lead, and antimony, that is one car model of German make (Volkswagen, two stubs from two different cars were taken) and one car model of British make (Rover, two stubs from two different cars were taken). The composition of the 98 particles found on these stubs is shown in Tables 2 and 3.

Results concerning the most relevant elements can be summarized as follows.

- *Primary elements.* In most of the particles (66%) barium and antimony without lead were present; the remaining particles contained lead, barium, and antimony. Barium and antimony were at major, minor, or trace levels. An exact evaluation of the lead level was often difficult because of overlap with the sulphur peak.
- *Iron.* Iron was always present. It was found at major (72%), minor (22%), or trace (6%) levels.
- *Copper, Zinc.* Copper was always found, at major (20%), minor (38%), or trace (42%) levels. When zinc was also present, the copper/zinc ratio was always >1.
- *Magnesium.* 47% of the particles showed the presence of magnesium at major (20%), minor (10%), or trace (17%) levels.
- *Other elements.* Sodium, tin, chromium, manganese, zirconium, and strontium were found sporadically.

Direct Examination of Fragmented New Brake Linings

The study of the surface of friction materials shows (Fig. 3) distinct clusters mainly composed either of barium and sulphur or antimony and sulphur; other clusters containing lead are seen, though smaller and rarer.

TABLE 2—*"Unclean" particles in samples from car front rims.*

Number of Particles	Major	Minor/Trace
33	Fe	Sb, Ba
3	Fe, Ba, Sb	
7	Fe, Ba	Sb
2	Fe, Sb	Ba
2	Cu, Fe, Mg	Sb, Ba
2	Cu, Mg, Sb, Fe, Zn	Ba
1	Sb, Ba, Fe, Cu	
1	Cu, Sb, Fe	Ba
1	Fe, Cu	Sn/Sb, Ba
1	Mg, Sb	Ba
1	Ba	Sb, Na*
1	Ba	Sb, Sr
1	Fe	Pb, Sb, Ba
1	Pb, Fe	Sb, Ba
2	Pb, Fe, Cu, Mg	Sb, Ba
4	Pb, Fe, Cu, Mg, Sb	Ba
1	Fe, Pb, Mg, Ba	Sb
1	Pb, Mg, Fe, Sb	Ba
3	Pb, Fe	Sb, Ba
4	Fe, Pb, Cu	Sb Ba
1	Pb, Fe, Cu, Sb	Ba
1	Pb, Mg, Cu	Sb Ba
1	Pb, Mg, Cu, Sb	Ba
4	Pb, Mg	Sb, Ba
1	Pb, Mg, Sb	Ba
1	Pb	Mg†, Sb Ba

NOTE: Only Ba—Sb and Pb—Ba—Sb particles, with the most significant elements found in their spectra, are shown. In addition to these, particles with the following compositions were also detected: Pb; Pb—Ba; Pb—Sb; Sb (without S); Sb (with S); Cu—Zn; Pb—Cu—Zn. For the definition of "unclean" particles, see "Synthesis of the Results."
* Na minor.
† Mg minor.

TABLE 3—*"Clean" particles in samples from car front rims.*

Major	Minor	Trace
S, Ba	Si, Sb, Fe	Mg, Cu
S, Ba	Fe, Sb, Si	Al, Cu, Mg
Ba, S, Si	Fe, Sb, Al	Cu
S, Ba	Fe, Si	Sb, Al, Cu
S, Ba	Sb, Si, Fe, Cu	Al, Zn
Al, Sb, S, Ba		Fe, Cu, Zn, Si
Sb, Al, S	Cu, Ba, Fe	Si, Zn
Ba, S	Si, Fe	Al, Ca/Sb, Cu
S, Ba		Sb, Fe, Si, Al, Cu
S, Ba		Al, Si, Sb, Fe, Cu
Pb, Si	Fe, Cu, Ca/Sb, Ba	Al, Mg
Pb, Si	Fe, Cu, Ca/Sb, Ba	Al, Mg
Pb, Si	Fe, Cu, Ca/Sb, Ba	Al, Mg
Pb, Si	Ba, Fe	Sb, Cu, Zn, Al, Mg
Pb	Fe	Sb, Al, Mg, Ba, Cu
Pb		Fe, Sb, Ba, Cu
Pb	Sb, Si	Al, Ba, Fe, Cu

NOTE: The complete elemental composition of "clean" particles (see "Synthesis of the Results" for definition) is shown.

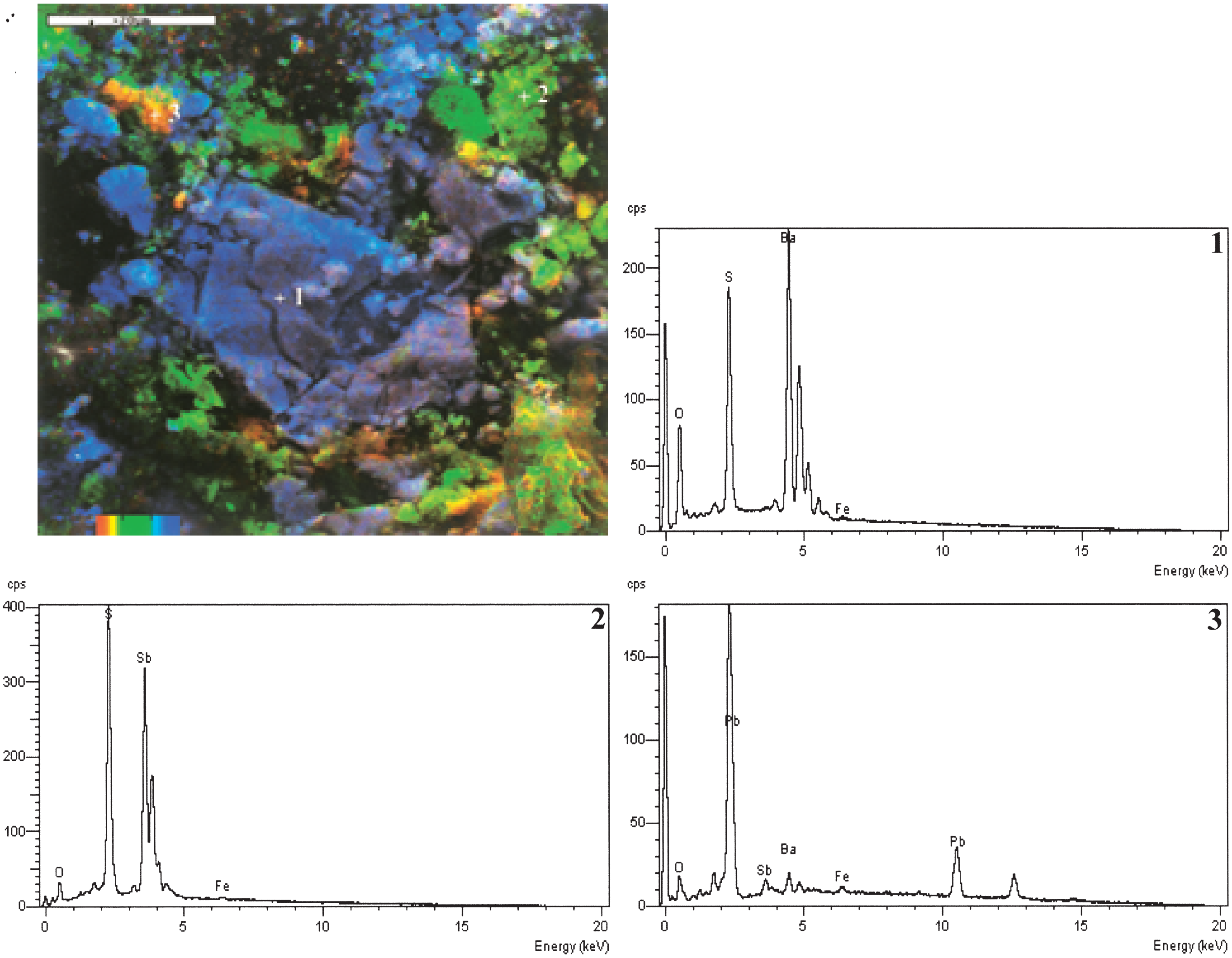

FIG. 3—*Surface of experimentally crushed brake linings of British make (Unipart). Secondary electron image (1600X) with true color X-ray vision using the Cameo™ program. With a visual response offset to 2.1–5 KeV, barium is seen as blue (Spectrum 1), antimony as green (Spectrum 2) and lead as red (Spectrum 3).*

Debris from the Surface of New Brake Linings, Hands of the Person Taking the Sample, and Experimentally Worn New Brake Linings

73 particles were identified. They are shown in Tables 4 and 5. Results concerning the most relevant elements can be summarized as follows.

- *Primary elements.* Ba-Sb particles (67%) prevailed over Pb-Ba-Sb (33%). Barium and antimony were found at major, minor, or trace levels. An exact evaluation of the lead level was often difficult because of overlap with the sulphur peak.
- *Iron.* Iron was present at a major level in 22% of the particles, in 8% at a minor level, and in 54% at a trace level. 16% of the particles did not contain iron.
- *Copper, Zinc.* Copper was found in 96% of the particles, usually at a trace level. Only in two particles (3%) was copper at a major level. When zinc was also present, the copper/zinc ratio was always >1.
- *Magnesium.* Magnesium was seen in 64% of the particles, mostly at a trace level.
- *Other elements*. Sodium, chromium, manganese, and zirconium were found sporadically.

Synthesis of the Results: "Clean" and "Unclean" Particles

For each category of samples both "clean" and "unclean" particles were found. "Clean" particles are defined as those with a composition similar to GSR (unique, according to the classification of Wallace and McQuillan): they are mainly made up of primary elements—at least one of them at a major level—while no other element (chlorine, iron, copper, zinc, sodium, magnesium, and phosphorus) was present in high proportions nor were extraneous elements present (Figs. 4–6). All remaining particles were defined as "unclean" (Figs. 7,8). The distribution of "clean" particles found in the examined samples is shown in Fig. 9.

Discussion

The results show that wear of car brake linings may produce particles containing lead, barium, and antimony. In order to compare these particles with primer discharge residues, as classified by Wallace and McQuillan, they were divided into two categories.

"Unclean" Particles

In most of the particles originating from wear of car brake linings that contain barium and antimony or lead, barium, and anti-

TABLE 4—*"Unclean" particles in samples from new brake linings.*

No. of Particles	Major	Minor/Trace
5*	Fe	Ba, Sb
5†	Fe, Sb	Ba
3	Fe, Ba	Sb
1‡	Fe, Zr	Ba, Sb
1	Cu	Sb Ba
1	Mg	Sb, Ba
1	Ba, Mg, Sb, Zr	
3	Ba	Sb, Mg§
3		Sb, Ba‖
1	Pb/S, Fe, Sb, Mg, Cu	Ba
1	Pb/S, Mg, Ba, Sb, Fe	
1	Pb/S, Mg	Ba, Sb
1	Pb/S, Ba	Sb, Mg§
1	Pb/S, Sb	Ba, Zr
1	Pb/S	Sb, Na¶, Ba
1	Pb	Sb, Ba, Cr

NOTE: For the definition of "unclean" particles, see "Synthesis of the Results".
* Two particles out of five were found on the hands of the person taking the sample.
† Two particles out of five were found on the hands of the person taking the sample.
‡ Found on the hands of the person taking the sample.
§ Mg minor.
‖ Sb— Ba trace only
¶ Na minor.

mony, iron was present at a major level. Similar particles were found in samples collected from new brake linings, though in markedly smaller amounts. This observation was expected since, when a car brakes, debris forms as a consequence of friction between the metallic disc brake and brake lining surfaces. Samples from both car front rims and new brake linings showed particles composed of primary elements in association with copper at a major level and/or magnesium at major/minor levels. Particles containing sodium at a minor level, chromium or manganese at trace levels, tin, zirconium, and strontium were sporadically found.

These results are in agreement with the classification proposed by Wallace and McQuillan, who precisely state that in primer discharge residue iron and copper are allowed at minor or trace levels only and magnesium and sodium at trace levels only; chromium, manganese, and other elements normally suggest that particles do not originate from gunshot.

Magnesium deserves particular attention. It was present, at different levels, in more than half of the particles examined. Moreover, it was often found in spectra already to be considered inconsistent, because of the presence of allowed elements at anomalous levels or of "prohibited" elements. Sometimes merely the presence of magnesium, either at major or minor levels, enables a particle to be considered as inconsistent.

The composition of this category of particles has been judged by previous authors as inconsistent with primers discharge residue (2–5). Moreover, the characterization of car brake linings as the source of these particles justifies their widespread presence in the environment, a fact that is well-known to GSR experts.

"Clean" Particles

The analysis of samples from both car front rims and new brake linings showed the presence of "clean" particles composed of Ba-Sb and Pb-Ba-Sb, compositions classified as unique by Wallace and McQuillan. These particles are very similar in size to GSR. "Clean" particles were more often found in samples from new brake linings, while environmental samples from cars frequently showed the presence of iron at a major level.

Regarding *Ba-Sb particles*, the results of this study are in agreement with data from the most recent literature, which exclude this particle type from the category defined as "unique." In particles derived from wear of friction materials, the relative ratio of primary elements, as in primer discharge residues, varies widely, though particles where barium prevails predominate. However sulphur at a major level is a constant finding in these samples. Therefore, whether Ba-Sb particles from casework belong in the category of primer discharge residues should always be considered questionable in the presence of sulphur at a major level.

Sulphur is often present in *Pb-Ba-Sb particles*; in this case, lead and sulphur major peaks (Mα1 2.3475 keV and Kα1 2.3075 keV, respectively) represent the strongest peak in the spectrum, while antimony and barium are usually found at major or minor levels.

TABLE 5—*"Clean" particles in samples from new brake linings.*

Major	Minor	Trace
S, Sb	Si, Ba	Mg, Al, Fe, Cu
S, Ba	Sb	Cu, Si, Al, Mg, Fe
S, Sb, Ba		Na, Fe, Cu
*S, Ba	Sb	Cu, Na
*S, Sb		Si, Al, Ba, Fe, Cu, Na
S, Ba	Si, Al, Sb	Fe, Cu, Na
S, Ba	Sb	Fe, Al, Na, Cu
S, Ba	Sb	Si, Fe, Na, Mg, Cu
S, Ba		Sb, Fe, Cu
S, Ba	Sb	Si, Fe, Cu
S, Ba	Sb	Cu
*S, Ba		Sb, Fe, Cu
*Sb, S	Ba	Cu, Zn, Fe
*Sb, S, Al	Cu	Ba, Fe
*S, Ba		Si, Sb, Fe, Cu
S, Ba	Sb	Si, P, Mg, Cu, Al
S, Ba	Sb	Fe, Cu, Si, Mg, Al
S, Ba		Sb, Si, Mg, Al, Fe, Cu
S, Ba	Fe, Si, Ca/Sb	Al, Mg, Cu
Ba, S	Fe, Sb	Si, Cu, Al, Mg
S, Ba	Si	Al, Sb, Na, Cu
S, Sb	Ba	Na, Cu
S, Ba	Sb, Si	Mg, Na, Al, Fe, Cu
S, Ba	Fe	Sb, Cu
S, Ba	Fe	Si, Sb, Cu
S, Ba, Sb		Si, Fe, Cu
Pb/S, Sb, Ba		Al, Mg, Fe, Cu
Pb/S	Sb, Ba	Si, Mg, Fe, Cu
Pb		Ba, Al, Mg, Fe, Cu, Sb
*Pb/S	Sb, Ba	Cu
Pb		Sb, Ba, Fe, Cu, Zn
Pb		Ba, Cu, Sb
Pb/S	Sb, Cu, Ba, Fe	Si, Mg, Al
Pb/S	Sb, Ba, Fe	Si, Al, Mg, Cu
Pb/S		Si, Sb, Ba, Fe, Al, Mg
Pb		Ba, Sb, Al, Mg, Cu
Pb	Sb	Ba, Mg, Fe, Cu
Pb		Cu, Sb, Ba, Mg, Al, Fe
Pb/S, Ba, Sb		Cu, Na
Pb	Ba, Sb	Na, Mg, Fe, Cu, Al
Pb		Si, Al, Ba, Sb, Fe, Cu
Pb		Sb, Ba, Cu
Pb		Sb, Ba, Cu

NOTE: The complete elemental composition of "clean" particles (see "Synthesis of the Results" for definition) is shown.
* Particle found on the hands of the person taking the sample.

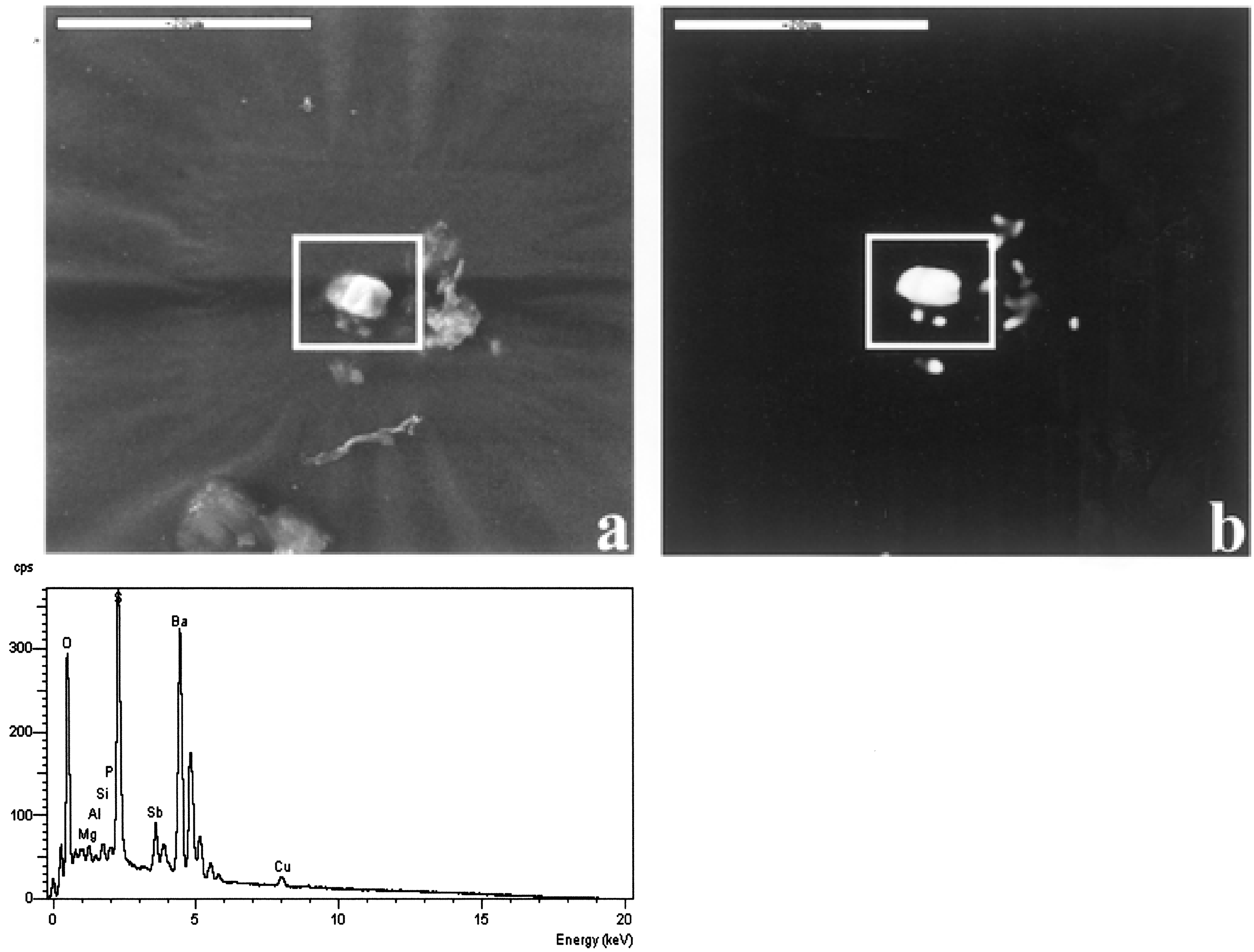

FIG. 4—*"Clean" Ba-Sb particle (2350X; a: secondary electron image; b: backscattered image). Sample from debris obtained by producing experimental wear on new brake linings of British make (Unipart). Sulphur is the strongest peak in the spectrum. Phosphorus, magnesium and copper are present at trace levels.*

When sulphur is not detectable, the strongest peak in the spectrum is the lead major peak, while antimony and barium are generally at minor or trace levels.

Among these "clean" particles magnesium was frequentely found, obviously at a trace level. According to personal experience, magnesium at this level, although allowed by Wallace and McQuillan in their classification, is rather rare in primer discharge residues. Consequently magnesium, even at a trace level, should be considered as a questionable element and particles containing magnesium classified as inconsistent with primer discharge, unless magnesium is present in the discharge residue from the gun or ammunition used in the crime.

The observation that clean Pb-Ba-Sb particles can occur independentely of primer discharge inevitably prevents from being classified as "unique" even this particle type, considered up to now the most classic. In this study, the only compositions that were not seen in particles originating from the wear of friction materials are:

clean Ba-Sb particles with no sulphur, or sulphur at minor or trace levels;

clean Pb-Ba-Sb particles with barium and/or antimony levels higher than the lead level.

Consequently, these compositions could still be considered "unique." Neverthless, previous experience suggests that the classification "unique" should be abandoned in favor of the more prudent "consistent." The word "unique", if taken literally, often generates in the uncritical reader a belief of certainity inherent in the results of the investigation, actually not confirmed by present knowledge of the composition of environmental particles. Data on this subject remain too fragmentary and incomplete to safely adopt a strict classification: serious mistakes deriving from unconsidered use of evidence may be avoided by resisting this temptation.

In the end it is necessary to stress, in agreement with Garofano et al., that in order to discriminate between primer discharge residue and environmental particles, morphology must be reevaluated. Actually, it is possible to find environmental particles identical in composition and size to primer discharge residues, but never of typical shape. Therefore, during data evaluation, morphological criteria must always be considered. Caution is mandatory, when dealing with a subject as vast and complex as that of environmental particles. At present, the only reliable particles must be considered those with "ideal" morphology, that is to say spherical or globular, with surface either perfectly smooth, pitted with craters, or

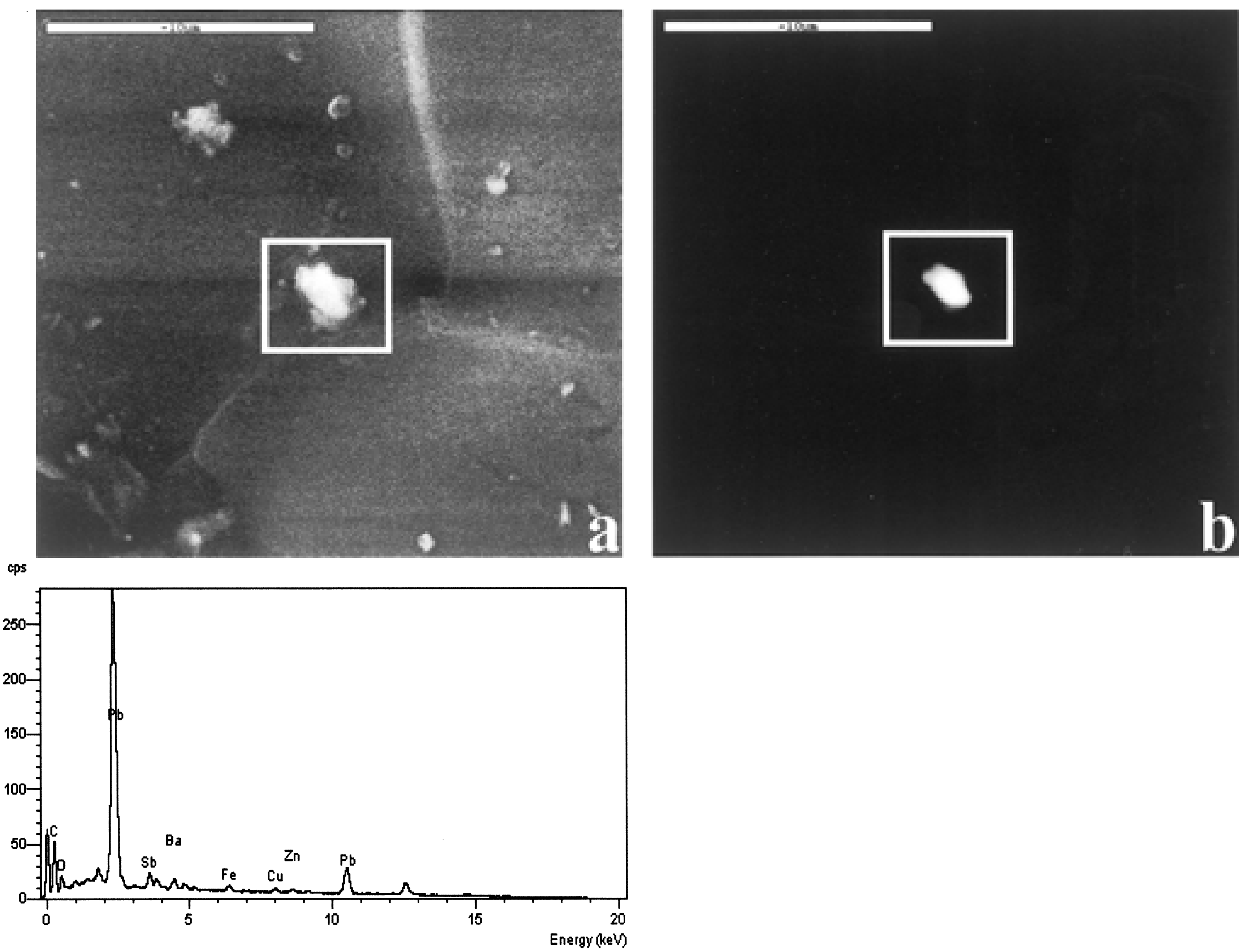

FIG. 5—*"Clean" Pb-Ba-Sb particle (4840X; a: secondary electron image; b: backscattered image). Sample taken from the surface of a new brake lining (Textar). Barium and antimony are seen at trace levels.*

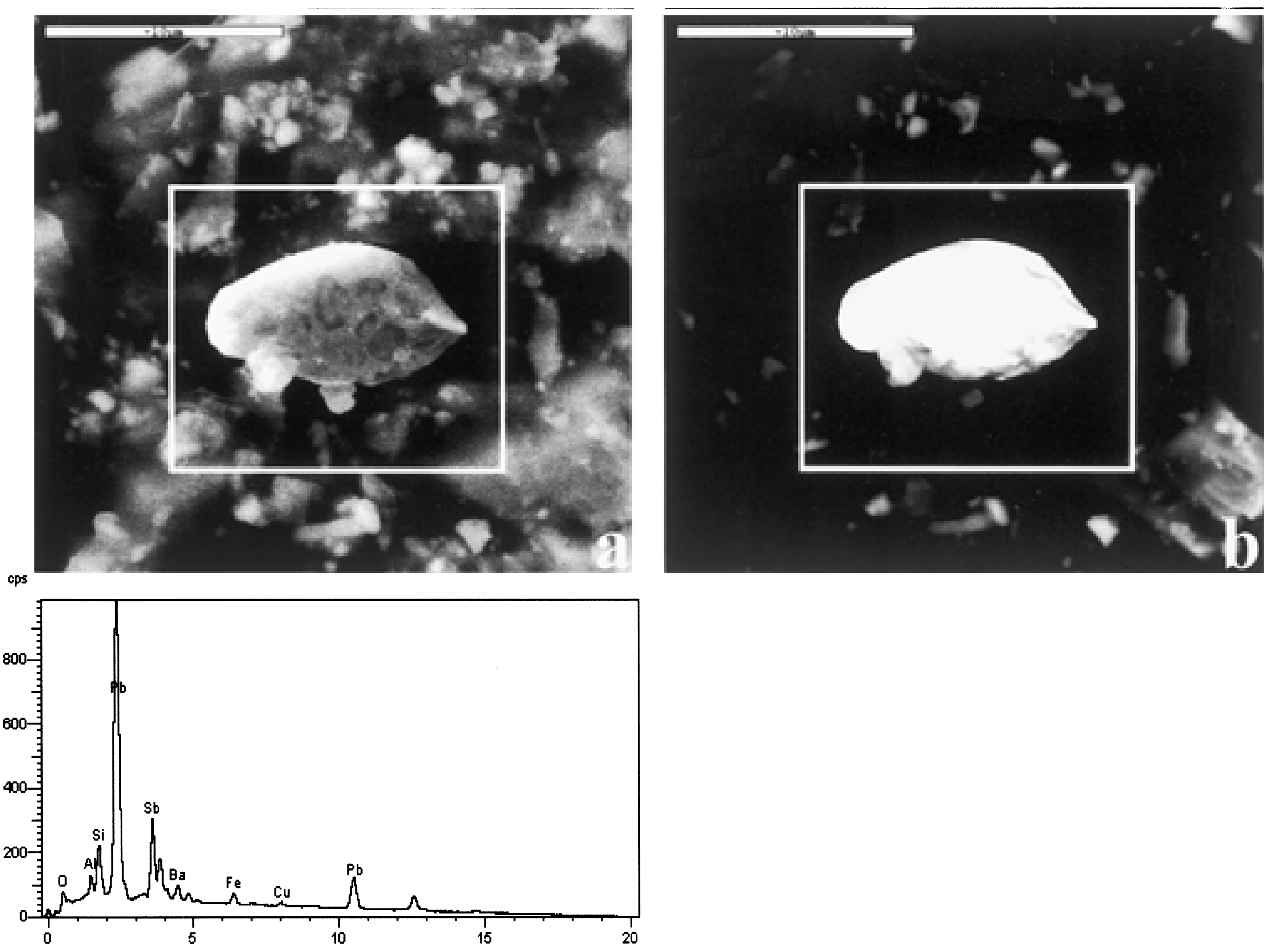

FIG. 6—*"Clean" Pb-Ba-Sb particle (4310X; a: secondary electron image; b: backscattered image). Sample taken from the front rim of a car (Volkswagen).*

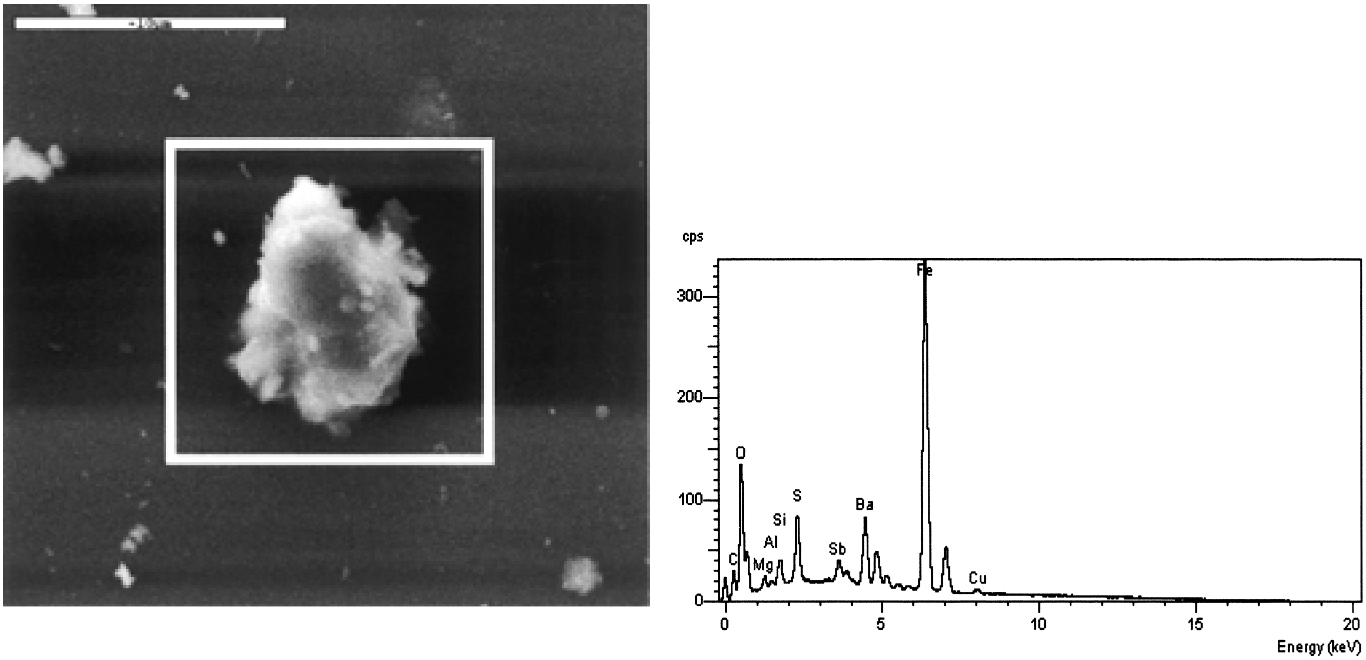

FIG. 7—*"Unclean" Ba-Sb particle (4560X; secondary electron image). Sample taken from the front rim of a car (Volkswagen). Iron is the strongest peak; magnesium is present at a trace level.*

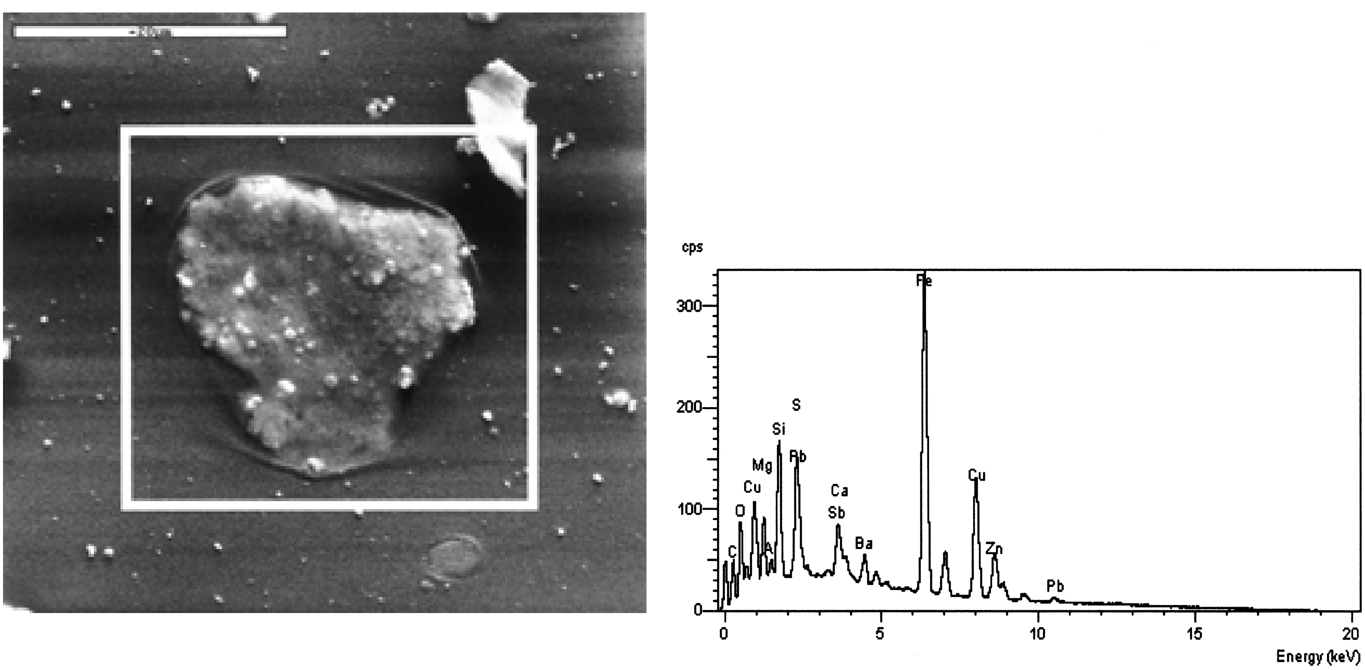

FIG. 8—*"Unclean" Pb-Ba-Sb particle (2300X; secondary electron image). Sample taken from the front rim of a car (Rover). Iron and copper are found at major levels, magnesium at a minor level; note the presence of sulphur and calcium.*

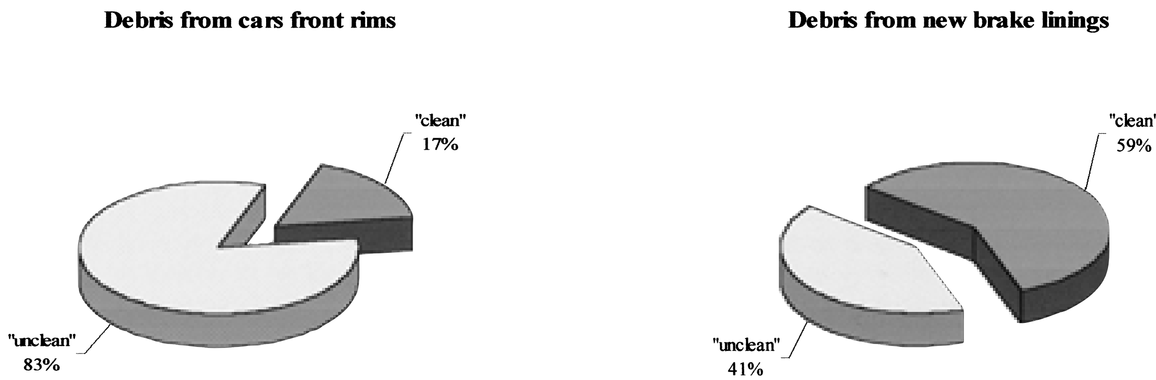

FIG. 9—*Distribution of "clean" and "unclean" particles in the different categories of samples under study.*

coated with roundish and smooth nodules, but never—even in part—rough or dusty. It is also important to remember that residues from cartridge-operated industrial tools, blank cartridges, and fireworks may show similar characteristics. For classification purposes, it would be advisable to abolish the equivocal and misleading term "GSR" and rather use general expressions like "*primer discharge residue*," as previously suggested by Wallace and McQuillan, or better *"residues of the detonation of a mixture of lead, barium and antimony compounds*." Finally, before judging a sample as positive, the type of ammunition fired in the investigated crime must always be taken into consideration: only by comparison between the sample and the ammunition's particles is it possible to attain a decisive answer. When the firearm or ammunition is not known, extreme caution must be used before drawing any conclusion.

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