

# 1 Sampling and characterization of resuspended and respirable road 2 dust

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## 16 17 Abstract

18 Urban air quality is severely affected by traffic related particulate matter, including  
19 direct emissions from exhaust, brake pad, tire wear and road dust resuspended by  
20 vehicular motions. Deposited road dust can also be resuspended by wind force or  
21 other anthropogenic activities, and overall it may contribute up to 30 % to urban  
22 PM<sub>10</sub>. A mobile resuspended road dust PM<sub>10</sub> sampler was developed and  
23 constructed which simulates the effects of traffic or gusting winds on road surfaces  
24 and collects resuspended PM<sub>1-10</sub> samples in a cyclone separator and PM<sub>1</sub> samples  
25 on filters. The sampler was tested by collecting resuspended road dust at kerbside  
26 locations in Veszprém, Hungary. The collected PM<sub>1</sub> and PM<sub>1-10</sub> fractions were  
27 analysed by various analytical methods to show the potential of size-selective on-line  
28 sample collection combined with the chemical characterization of resuspended road  
29 dust. The main constituents of the resuspended road dust were crustal elements,  
30 and it was also possible to determine the mineral phase composition of PM<sub>1-10</sub> dust  
31 which is generally not feasible from samples collected on filter substrate. The  
32 application of the sampling and analysis methods may facilitate the evaluation of  
33 resuspended road dust sources in cities as well as help constrain a better source  
34 apportionment of urban PM<sub>10</sub>.

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## 36 Keywords

37 Particulate matter; Sampling; Characterization; Respiratory health

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## 39 1. Introduction

40 Air pollution in cities is a very complex issue, showing strong seasonality and  
41 dependence on meteorological factors, sometimes culminating in severe and  
42 dangerous smog episodes which require intervention by local authorities. The urban  
43 particulate matter with aerodynamic diameter less than  $10\ \mu\text{m}$  ( $\text{PM}_{10}$ ) is now  
44 identified as one of the most dangerous air pollutants on human health because its  
45 size range overlaps with the range of respirable particles. Prolonged exposure to  
46 respirable urban  $\text{PM}_{10}$  has been associated with adverse health effects and linked to  
47 an increased risk of respiratory illnesses (Pope, 1996).

48 Resuspension of road dust is now an established source of urban particulate matter.  
49 Fugitive dust from paved and unpaved roads and bare grounds as well as  
50 construction and demolition works was shown to be important contributors to both  
51  $\text{PM}_{10}$  and  $\text{PM}_{2.5}$  in urban aerosol (Chow and Watson, 2002). A source apportionment  
52 study based on elemental composition of particles using Al as a tracer for crustal  
53 matter estimated a total contribution of 10 % (m/m) in  $\text{PM}_{10}$  and 6 % in  $\text{PM}_{2.5}$  in Hong  
54 Kong (Ho et al., 2003). On the other hand, in Mexico City fugitive dust was estimated  
55 to account for as much as 54 % (m/m) of  $\text{PM}_{10}$  (Vega et al., 2001). Its contribution  
56 strongly depends on local conditions, including meteorology, road surface, traffic,  
57 etc.

58 In addition, dust particles preserve cumulative signatures of particles that had once  
59 been airborne and deposited from the atmosphere at the location of sampling. Its  
60 detailed analysis may provide qualitative and quantitative information on the  
61 significance of various local and regional aerosol sources. Fugitive dust sources are  
62 extremely difficult to measure and quantify in urban air due to their diffuse nature and  
63 strong dependence on sampling conditions (Cowherd and Grelinger, 1992; Watson  
64 and Chow, 2001).

65 Detailed source profile studies on this fraction of aerosol that can be used for  
66 receptor modeling is known (Ho et al., 2003; Vega et al., 2001; Amato et al., 2010).  
67 The mass size distribution of primary particles of fugitive dust is poorly characterized.  
68 Scanning electron microscopic examination of PM<sub>10</sub> particles in Shanghai showed  
69 that most of particles were originally released from construction sites, cement plants,  
70 vehicle exhaust, coal boilers and steel mills (Li et al., 2003). Such studies typically  
71 used the source type “paved road dust” as a collective term for all types of urban  
72 dust particles, including freshly emitted or resuspended particles, without regard to  
73 their ultimate origin (Schauer et al., 1996).

74 Sampling of resuspended urban particulate matter has usually been performed by  
75 simply sweeping and sieving deposited road dust (Wei et al., 2009; Han et al., 2007;  
76 Manno et al., 2006; Ho et al., 2003). In a few studies the collected bulk samples  
77 were resuspended in the laboratory and the size-distribution of the particles was  
78 determined (Zhao et al., 2006; Chow et al., 2004). These procedures and sample  
79 treatments were affected by the loss of fine particles owing to the difficulties of  
80 collecting all deposited material and to the electrostatic adhesion of particles to brush  
81 hairs and sieve meshes. A recent study has shown that aerosol particles can be  
82 quantitatively resuspended from road dust using a specific sampling device (Amato  
83 et al., 2009). The objective of this study is to develop and test a mobile sampler that  
84 simulates the effect of strong winds and heavy traffic and on-line collects the  
85 resuspended PM<sub>10</sub> particles. Furthermore the potential of various analytical methods  
86 are evaluated in the use of the samples for source profiling of resuspended road dust  
87 in source apportionment of urban PM<sub>10</sub>.

88

## 89 2. Material and methods

90

### 91 2.1 Resuspension and sampling unit

92 This work involved the development and construction of a mobile resuspended road  
93 dust PM<sub>10</sub> sampler which induces resuspension and collects particles on-line directly  
94 from road surfaces (see Fig. 1). A rectangular stainless-steel hood (length: 600 mm,  
95 width: 400 mm, height: 170 mm) was fixed to the front of a laboratory cart 0.5 m  
96 above the road surface. A leaf blower (Makita UB1101, 600W) was connected to the

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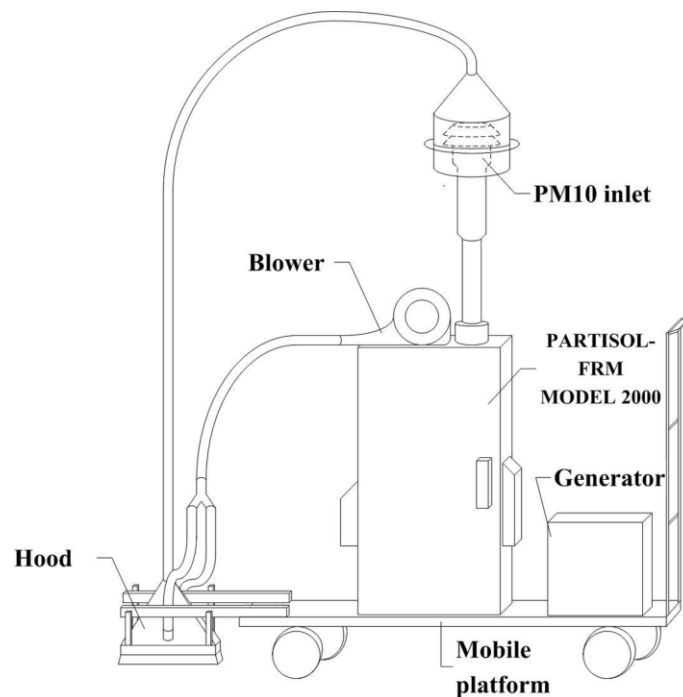


Fig. 1. The mobile resuspended PM<sub>10</sub> sampling unit.

118 A PARTISOL-FRM MODEL 2000 sampler (operating at the flow rate of  $16.7 \text{ l min}^{-1}$ )  
119 was mounted on a mobile sampling cart. This sampler collected resuspended  $\text{PM}_{1-10}$   
120 samples in a cyclone separator and  $\text{PM}_{10}$  samples on filters. The sampling unit was  
121 powered with a portable electrical power generator (Honda EU10i), also mounted on  
122 the platform. The mobile sampling unit has been successfully deployed on the site of  
123 the catastrophic red mud spillage near Ajka- Kolontár, Hungary (Gelencsér et al.,  
124 2011).

125

## 126 2.2 Sample transfer and gravimetric determination

127 The  $\text{PM}_{10}$  fraction was collected on 47 mm diameter Whatman quartz filter, and  
128 before and after sampling filters were weighted with a microbalance (Sartorius,  $10 \mu\text{g}$   
129 sensitivity). The  $\text{PM}_{1-10}$  fraction was deposited in the sharp-cut cyclone-separator of  
130 the PARTISOL sampler. The collected dust samples were transferred with a PTFE-  
131 coated spatula into pre-weighted clean vials. Then the vials were weighted again  
132 with a microbalance. The total mass of the  $\text{PM}_{1-10}$  fraction was determined by  
133 difference. It should be noted that though sample collection from the surface is not  
134 quantitative, mass concentration data above the surface during the sampling can be  
135 derived for comparative purposes. The resuspended road dust samples were tagged  
136 and stored in the freezer until analysis. The collected  $\text{PM}_{1-10}$  fractions were analysed  
137 by various analytical methods to establish chemical composition, to identify major  
138 source types and to assess the potential contribution of major sources to deposited  
139 dust.

140

## 141 2.3 Chemical analyses

142 The direct determination of phase composition of particulate matter has not generally  
143 been available in ambient aerosol studies due to limited sample size and the  
144 presence of a filter matrix. However, quantification of phase composition would be an  
145 invaluable supplement to source apportionment studies of specific aerosol types  
146 such as resuspended road dust. The X-ray diffraction (XRD) analyses were carried  
147 out with a Philips PW 3710 type diffractometer equipped with a PW 3020 vertical  
148 goniometer and curved graphite diffracted beam monochromator. The radiation  
149 applied was  $\text{CuK}\alpha$  from a broad focus Cu tube, operating at 50 kV and 40 mA. The

150 samples were measured in continuous scan mode with  $0.02^\circ \text{ sec}^{-1}$  scanning speed.  
151 Each small powder sample (approximately 7 mg) was deposited on a glass plate  
152 from a slurry of the sample in isopropyl alcohol (Bish and Post, 1989). The  
153 quantitative determination was carried out with Rietveld analysis which is a full-  
154 pattern fitting method. In this method the measured diffraction profile and the  
155 calculated profile are compared, and the difference is minimized. Crystal structure  
156 data, such as atom positions are necessary to the standard Rietveld refinement. In  
157 addition the scale factors calculated for the mixture of phases are proportional to  
158 weight fractions.

159 Due to the limited amounts of resuspended road dust samples particle morphologies  
160 were studied and elemental composition (of elements with  $Z > 5$ ) were determined by  
161 environmental scanning electron microscopy (ESEM, Philips XL30) with an attached  
162 EDAX energy-dispersive X-ray spectrometer (EDS). ESEM was operated at 20 kV  
163 accelerating voltage in low-vacuum environmental mode due to the non-conductive  
164 character of the samples.  $\text{PM}_{1-10}$  powder samples were sprinkled on cylindrical Al  
165 stubs covered by double coated conductive carbon tape. Determination of mean  
166 elemental composition (except C) was performed on 3 different areas ( $200 \times 200$   
167  $\mu\text{m}$ ) of each prepared sample. Secondary electron (SE) images of hundreds of  
168 particles in each  $\text{PM}_{1-10}$  fraction were taken to characterize of particle sizes and  
169 morphologies.

170 The total carbon (TC) concentration of  $\text{PM}_{1-10}$  samples were analysed by high-  
171 temperature catalytic oxidation, using Zellweger Astro TOC 2100 total carbon  
172 analyzer with NDIR detector. The TC was determined by catalytic burning at  $680^\circ \text{C}$   
173 in oxygen followed by non-dispersive infrared detection of the evolved  $\text{CO}_2$ .  
174 Approximately 0.5 mg of bulk dust samples were oxidized in the combustion boat.  
175 Calibration of the instrument was performed with reagent-grade potassium hydrogen  
176 phthalate (VWR International) dissolved in high-purity water (MilliQ).

177 The water-soluble inorganic ions ( $\text{Na}^+$ ,  $\text{NH}_4^+$ ,  $\text{K}^+$ ,  $\text{Mg}^{2+}$ ,  $\text{Ca}^{2+}$ ,  $\text{Cl}^-$ ,  $\text{NO}_3^-$  and  $\text{SO}_4^{2-}$ )  
178 were measured by Dionex DX300 gradient chromatographic system that consists of  
179 a CHA-6 high pressure chromatographic module, Dionex EDM eluent degas module  
180 and gradient pump equipped with a conductivity detector CDM-II. Separations were  
181 carried out by a Dionex IonPac AS12A column for anions and a Dionex IonPac

182 CS12A column for cations. The conductivity of the eluent was suppressed by a  
183 Dionex CSRS 300 4 mm suppressor. Approximately 1 mg samples were extracted  
184 with 1 ml high-purity water. The detection limit of each ion was 10 ppb.

185 A series of 16 polycyclic aromatic hydrocarbons (PAHs) regulated by the US  
186 Environmental Protection Agency (US-EPA) were analysed. PAHs were determined  
187 by liquid chromatography with Jasco PU-980 pump, Jasco LG-980-02 gradient unit  
188 and Waters 470 scanning fluorescence detector. Separations were carried out by a  
189 LiChrospher PAH 5 µm column with RP18 silica gel charge, and its temperature was  
190 held at 35 °C with a Waters thermostat. Approximately 6 mg dust samples were  
191 extracted with 1 ml of dichloromethane:methanol (80:20) solvent mixture. Extraction  
192 was performed in an ultrasonic bath for 20 minutes. The extracts were filtered by  
193 0.22 µm filters. The injection volume was 20 µl. The calibration was performed with  
194 TCL polynuclear aromatic hydrocarbons mix (SUPELCO) dissolved in  
195 acetonitrile:methanol (9:1) solvent. The standard solution containing the 16 EPA  
196 priority pollutant PAHs: naphthalene (Nap), acenaphthylene (Acy), acenaphthene  
197 (Ace), fluorine (Fl), phenanthrene (Phe), anthracene (Ant), fluoranthene (Fla), pyrene  
198 (Pyr), benz[a]anthracene (BaA), chrysene (Chry), benzo[b]fluoranthene (BbF),  
199 benzo[k]fluoranthene (BkF), benzo[a]pyrene (BaP), ideno[1,2,3-cd]pyrene (IndP),  
200 dibenz[a,h]anthracene (dBaAnt) and benzo[g,h,i]perylene (BghiPer). 15 PAHs  
201 (exception is acenaphthylene) were detected with fluorescence detector.

202 The TC and PAHs concentrations of PM<sub>1</sub> fractions on quartz fiber filters were also  
203 determined with the above methods. TC concentrations were analyzed from filter  
204 spots of 10 mm in diameter which were cut with a special puncher and were oxidized  
205 directly in the combustion boat. PAHs concentrations were measured from the  
206 remaining filter samples. Other measurements were not carried out due to the limited  
207 sample size and the presence of the filter matrix.

208

### 209 3. Testing

210

#### 211 3.1 Sampling

212 The sampling unit was tested by collecting resuspended particulate matter at three  
213 kerbside locations in Veszprém, Hungary. Veszprém lies approximately 110

214 kilometers far from the capital of Hungary, Budapest. The city is lying in the embrace  
215 of Lake Balaton and the Bakony Hills, on both sides of the Séd creek. Veszprém has  
216 about 60 thousands inhabitants, its climate is continental. The daily average  
217 temperature is 20 °C in summer and -1 °C in winter.

218 Each sampling involved collection of resuspended road dust from a sampling area of  
219 about 840 m<sup>2</sup>. The samples were collected on the sidewalks ~ 2 m from the roads for  
220 a period of 2 hours each. The sampling was carried out on three consecutive days  
221 between 22 and 24 September 2010. The sampling locations were characterized  
222 with high traffic of passenger cars and busses, but heavy-duty trucks were not  
223 allowed. The speed limit is 50 km hr<sup>-1</sup>.

224 The meteorological and air quality parameters before and during sampling days were  
225 recorded by the local meteorological station of Veszprém and by the Hungarian Air  
226 Quality Monitoring Network. During this period the daily mean temperature varied  
227 between 12 and 18 °C. The sampling took place three days after a rainy period  
228 between 16 and 19 September, under generally dry conditions. On the days of  
229 sampling the daily mean PM<sub>10</sub> concentrations were 28.4, 29.2 µg m<sup>-3</sup> and absent  
230 data on 24 September, and the NO<sub>x</sub> concentrations were 62.6, 60.7 and 43.1 µg m<sup>-3</sup>.

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### 232 3.2 Mass proportion of resuspended road dust

233 Even if the collection of resuspended PM<sub>10</sub> is not quantitative, a surface load of  
234 resuspended PM<sub>10</sub> can be estimated from the measured data by taking into account  
235 the flow rate of the blower and that of the PM<sub>10</sub> sampler. The estimated surface load  
236 of PM<sub>10</sub> was found to be 3.4–4.9 mg m<sup>-2</sup> at the three sites. This value compares well  
237 with surface loads estimated from measured emissions caused by passing vehicles  
238 (0.3–3 mg m<sup>-2</sup>) (Etyemezian et al., 2003). The absolute mass concentrations of the  
239 PM<sub>1-10</sub> and PM<sub>1</sub> fractions inside the sampling hood were determined by weighted  
240 masses on filters and in vials. The mass concentration of the PM<sub>1-10</sub> was 15.4–19.6  
241 mg m<sup>-3</sup> and of the PM<sub>1</sub> fraction was 0.2–2.7 mg m<sup>-3</sup>.

242

243 Table 1. Sampling locations and the absolute mass concentrations of the collected  
244 PM<sub>1-10</sub> and PM<sub>1</sub> fractions, and the surface loads of resuspended PM<sub>10</sub>.



Code	Location	GPS	Date	Absolute mass concentrations				Surface loads of PM <sub>10</sub> [mg m <sup>-2</sup> ]
				PM <sub>1-10</sub> [mg]	PM <sub>1</sub> [mg]	PM <sub>1-10</sub> [mg m <sup>-3</sup> ]	PM <sub>1</sub> [mg m <sup>-3</sup> ]	
1	Egyetem Str.	47°05'13"/17°54'30"	22 Sept.	36.35	5.12	18.2	2.56	4.54
2	Cholnoky Str.	47°05'25"/17°55'27"	23 Sept.	39.19	5.36	19.6	2.68	4.88
3	Jutasi Str.	47°06'20"/17°54'42"	24 Sept.	30.75	0.46	15.4	0.23	3.42

245

246 The PM<sub>1</sub> fraction constituted on average 9.3 % of the PM<sub>10</sub> fraction in the  
 247 resuspended road dust which compares well with the mass ratio of fine (PM<sub>2.5</sub>) to  
 248 total (PM<sub>10</sub>) particles found in soil and paved road dust (10 –30 %) (Ho et al., 2003).  
 249 In addition the particulate matter with aerodynamic diameter less than 1 µm (PM<sub>1</sub>)  
 250 was sampled directly and was much less subject to losses during sampling.

251

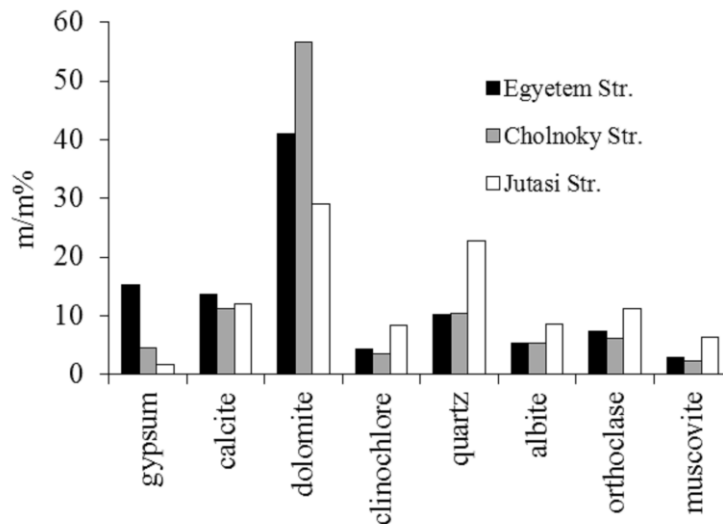
### 252 3.3 Phase composition

253 In addition to source profiling based on elemental composition the direct  
 254 determination of mineral phase composition is also feasible from resuspended bulk  
 255 PM<sub>1-10</sub> road dust samples. Similarly to the quantification of oxygen, this is also not  
 256 available on dust samples collected on filter substrates. The mineral phase  
 257 composition could, on one hand, be used to cross-check mass balance calculations  
 258 based on elemental compositions. But more importantly, it can be used in the source  
 259 identification of resuspended road dust itself, as thermally altered phases can be  
 260 directly identified and quantified by this method. Moreover, by comparing mineral  
 261 phase compositions of resuspended native soils in the areas, building materials  
 262 resuspended road dust it may also be possible to estimate the relative contribution of  
 263 demolition and construction works to the resuspended road dust concentrations in  
 264 cities.

265 In the resuspended bulk PM<sub>1-10</sub> road dust samples the major mineral phases  
 266 identified were dolomite [CaMg(CO<sub>3</sub>)<sub>2</sub>], calcite [CaCO<sub>3</sub>], clinoclone  
 267 [(Mg,Fe)<sub>6</sub>(Si,Al)<sub>4</sub>O<sub>10</sub>(OH)<sub>8</sub>], quartz [SiO<sub>2</sub>], muscovite [KAl<sub>2</sub>Si<sub>3</sub>AlO<sub>10</sub>(OH)<sub>2</sub>], albite

268 [NaAlSi<sub>3</sub>O<sub>8</sub>], orthoclase [KAlSi<sub>3</sub>O<sub>8</sub>] and gypsum [CaSO<sub>4</sub>·2H<sub>2</sub>O], in the mass ratios  
269 shown in Fig. 2.

270



271

272 Fig. 2. The mineral phase composition of resuspended road dust (m/m%).

273

274 The main mineral phase in the resuspended road dust is dolomite which forms the  
275 rock bed in the entire region around Veszprém. There are dolomite mines in  
276 operation upwind the town of Veszprém and all the unpaved roads in the region are  
277 covered with ground dolomite. It is therefore not surprising that the predominant  
278 mineral phase in the resuspended road dust is dolomite. Calcite, quartz and gypsum  
279 are much less related to the phase composition of local soils, they mostly come from  
280 industry, and building activities such as construction and demolition works. The other  
281 mineral phases (clinochlore, albite, orthoclase and muscovite) in lower amounts  
282 indicate the crustal origin, originate from the regional soils or abrasion of surfaces.

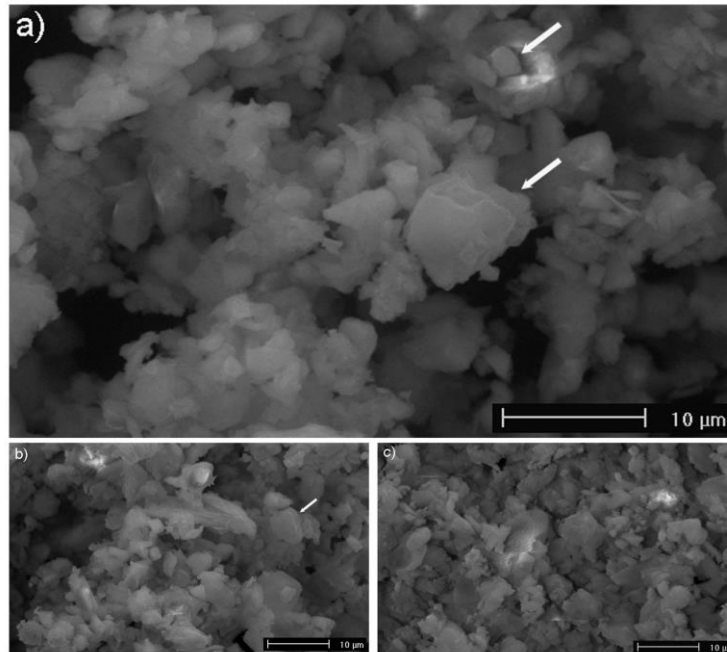
283

### 284 3.4 Morphologies of individual particles

285 The morphologies of individual particles in the PM<sub>1-10</sub> fraction are similar in each  
286 sample as observed in the SEM. Most of the particles have irregular shape, their  
287 geometric sizes vary between 1 and 5 μm. The smallest particles form fluffy  
288 aggregates and, the larger ones also appear as loose aggregates. There are some  
289 individual grains which have nearly euhedral crystal shape. Although the original  
290 crystal shape has been eroded by the weathering process as it is manifested in the

291 rounded edges and growth terraces some crystals have rhombohedral shape. This  
292 shape is typical for carbonate minerals which form the main mineral phase of the  
293 resuspended PM<sub>1-10</sub> based on the XRD measurements.

294



295

296 Fig. 3. SEM images of the PM<sub>1-10</sub> fraction of resuspended road dust. (a) sample 1,  
297 (b) sample 2, (c) sample 3. The particles form loose aggregates. White arrows  
298 indicate euohedral crystals with rounded edges.

299

### 300 3.5 Chemical composition

301 Due to the limited sample amount the elemental composition of resuspended PM<sub>1-10</sub>  
302 was determined by EDS and TC analyses. The mass concentrations of the identified  
303 elements are given in units of mg g<sup>-1</sup> (in Table 2). The main constituents of the  
304 PM<sub>1-10</sub> fraction were O, Si, Ca, C, Al, Mg, Fe, S, K and Na. Crustal elements such as  
305 Si, Al, Ca, Fe have been identified in other studies (Vega et al., 2001; Zhao et al.,  
306 2006) as important constituents of the resuspended dust, but collection and analyses  
307 of bulk dust samples offers the possibility of measuring concentrations of oxygen  
308 which is generally not feasible in the analyses of filter samples. Direct measurement  
309 of mass concentration of oxygen can be a useful complement of mass balance  
310 calculations necessary for source apportionment studies. Furthermore, the sensitivity  
311 of the method and the lack of filter matrix allow the determination of less abundant

312 elements. For example, in the resuspended PM<sub>1-10</sub> samples P, Cl and Ti were also  
313 quantified. Titanium is known to result from resuspension of soil and road pavement  
314 erosion (Amato et al., 2009; Guo et al., 2009). The contribution of phosphorous in  
315 the resuspended PM<sub>1-10</sub> was significant compared to its mass proportion in the  
316 PM<sub>2-10</sub> fraction of urban aerosol (0.08 m/m%) (Salma et al., 2002). It might be  
317 possible that phosphorous originate from microbiological activities taking place in the  
318 deposited dust and thus might serve as a tracer for resuspended dust. Such  
319 hypotheses, however, require further targeted studies and are beyond the scope of  
320 the present study. It should be pointed out that the suggested methods of sample  
321 collection and analyses open the possibility of better source profiling of resuspended  
322 road dust component for urban PM<sub>10</sub> studies.

323 The average TC concentration of PM<sub>1</sub> fraction was 114.4 mg g<sup>-1</sup> (standard deviation  
324 14.68 mg g<sup>-1</sup>) which may be influenced by soot particles from vehicular emission.

325 As part of routine aerosol analyses water-soluble inorganic ions can also be  
326 determined in the bulk PM<sub>1-10</sub> resuspended road dust samples. This feature is also  
327 available for PM<sub>10</sub> samples collected on filter substrate. Note that the analyses of the  
328 bulk samples yields concentrations in units of mg g<sup>-1</sup> which allows source profiles to  
329 be established. It is generally not expected that water-soluble ions would be  
330 predominant components of resuspended road dust. The concentrations of the  
331 water-soluble inorganic ions in PM<sub>1-10</sub> fractions are shown in Table 2.

332 Similarly, as part of the routine aerosol analyses, PAHs can also be determined in  
333 the resuspended bulk PM<sub>1-10</sub> and PM<sub>1</sub> fractions on filter. The concentrations of PAHs  
334 are given in units of µg g<sup>-1</sup> (in Table 2). The average mass concentration in the PM<sub>1-10</sub>  
335 fraction was 2.38 µg g<sup>-1</sup> (standard deviation 1.02 µg g<sup>-1</sup>), and in the PM<sub>1</sub> fraction  
336 was 16.83 µg g<sup>-1</sup> (standard deviation 16.34 µg g<sup>-1</sup>). It may be expected that as a  
337 result of cumulative deposition and the proximity of tailpipe emission sources, PAHs  
338 that are characteristic of vehicular emission (Diesel or gasoline) will be enriched in  
339 the PM<sub>1-10</sub> fraction of road dust relative to that in the coarse fraction of urban  
340 particulate matter. This may increase the health risk associated with the inhalation of  
341 resuspended road dust, but may also provide a tool for fingerprinting resuspended  
342 road dust in the coarse fraction of urban PM<sub>10</sub>.

343

344

345 Table 2. Chemical composition of PM<sub>1-10</sub> and PM<sub>1</sub> fractions of resuspended road  
 346 dust

	PM <sub>1-10</sub>			PM <sub>1</sub>				
	Egyetem Str.	Cholnoky Str.	Jutasi Str.	Egyetem Str.	Cholnoky Str.	Jutasi Str.		
mg g <sup>-1</sup>	C	83.9	74.3	94.1	122	124	97.5	
	O	402	409	377				
	Na	13.3	12.7	12.2				
	Mg	53.1	68.1	38.2				
	Al	62.1	59.8	82.1				
	Si	138	134	189				
	P	7.42	6.48	6.94				
	S	19.1	10.0	9.30				
	Cl	3.76	3.33	4.02				
	K	16.6	15.4	21.5				
	Ca	163	173	115				
	Ti	4.09	3.46	5.13				
	Fe	34.0	31.4	45.6				
	Na <sup>+</sup>	0.05	0.23	0.18				
	NH <sub>4</sub> <sup>+</sup>	<LOD	<LOD	<LOD				
	K <sup>+</sup>	1.06	0.64	0.95				
	Mg <sup>2+</sup>	0.84	0.84	0.77				
	Ca <sup>2+</sup>	18.1	11.9	12.2				
	μg g <sup>-1</sup>	Cl <sup>-</sup>	0.31	0.70	0.31			
		NO <sub>3</sub> <sup>-</sup>	0.06	0.06	0.32			
SO <sub>4</sub> <sup>2-</sup>		30.7	8.03	3.13				
Nap		0.29	<LOQ	<LOQ	0.00	0.04	<LOQ	
Ace		<LOQ	<LOQ	<LOQ	1.40	<LOD	<LOQ	
Fl		0.10	0.08	0.11	0.07	0.07	0.24	
Phe		1.07	0.47	0.92	1.44	1.31	4.74	
Ant		0.02	0.04	0.02	0.25	0.06	0.63	
Fla		0.48	0.25	0.24	1.51	0.86	1.66	
Pyr		0.51	<LOD	<LOQ	1.69	1.34	7.22	
BaA		0.05	<LOQ	<LOQ	<LOD	0.06	<LOD	
Chry		0.27	0.09	0.24	0.78	0.38	3.09	
BbF		0.23	0.12	0.20	0.40	0.34	0.37	
BkF		0.08	0.04	0.06	0.29	0.11	0.88	
BaP		0.09	0.08	0.10	0.36	0.25	1.28	
dBaAnt		<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	
BghiPer		0.17	0.21	0.20	0.45	0.39	0.80	
IndP		0.12	0.08	0.10	0.37	0.24	0.73	
ΣPAHs	3.48	1.46	2.20	9.40	5.53	35.57		

LOD: Limit of Detection  
 LOQ: Limit of Quantification

#### 348 4. CONCLUSIONS

349 A novel method for direct sampling of resuspended and respirable urban particulate  
350 matter has been developed and tested successfully. Although the collection method  
351 is not designed to be quantitative, it simulates the possible effects of environmental  
352 factors on road dust resuspension. Therefore it is capable of producing a  
353 representative aliquot of resuspended PM<sub>10</sub> in two size bins (PM<sub>1-10</sub> and PM<sub>1</sub>). The  
354 use of sharp-cut cyclone separator allows the collection of bulk particulate matter in  
355 the PM<sub>1-10</sub> fraction. The availability of bulk PM<sub>1-10</sub> facilitates the application of low-  
356 cost analytical methods to determine the elemental, chemical and phase composition  
357 of resuspended particulate matter, as it has been demonstrated in this study.

358 Contrary to other indirect methods of resuspended road dust characterization, such  
359 as brushing, sieving or laboratory resuspension of collected bulk particulate matter,  
360 the methodology presented may offer unbiased collection and characterization of  
361 resuspended PM<sub>10</sub>. The determination of the chemical and phase composition of the  
362 samples offers the possibility of more reliable source apportionment of resuspended  
363 urban PM<sub>10</sub> that poses a potential health risk for the population. Furthermore,  
364 chemical source profiling of this poorly characterized fugitive source type is also  
365 possible by this methodology. Chemical source profiles are indispensable for reliable  
366 source apportionment studies of urban PM<sub>10</sub> that serve as input to air quality  
367 management in cities. In addition, planned developments in automobile industry  
368 aiming at reducing non-exhaust (fugitive) emissions from vehicles may also benefit  
369 from the application of the proposed methodology.

370

#### 371 VITAE

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385

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391

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