Using community science for detailed pollution research: A case-study approach in Indianapolis, IN, USA

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Abstract

Heavy metal contamination in urban environments, particularly lead (Pb) pollution, is a health hazard both to humans and ecological systems. Despite wide recognition of urban metal pollution in many cities, there is still relatively limited research regarding heavy metal distribution and transport at the household-scale between soils and indoor dusts-the most important scale for actual human interaction and exposure. Thus, using community-scientistgenerated samples in Indianapolis, IN (United States), we applied bulk chemistry, Pb isotopes, and scanning electron microscopy (SEM) to illustrate how detailed analytical techniques can aid in interpretation of Pb pollution distribution at the household-scale. Our techniques provide definitive evidence for Pb paint sourcing in some homes, while others may be polluted with Pb from past industrial/vehicular sources. SEM revealed anthropogenic particles suggestive of Pb paint and the widespread occurrence of Fe-rich metal anthropogenic spherules across all homes, indicative of pollutant transport processes. The variability of Pb pollution at the household scale evident in just four homes is a testament to the heterogeneity and complexity of urban pollution. Future urban pollution research efforts would do well to utilize these more detailed analytical methods on community sourced samples to gain better insight into where the Pb came from and how it currently exists in the environment. However, these methods should be applied after large-scale pollution screening techniques such as portable X-ray fluorescence (XRF), with more detailed analytical techniques focused on areas where bulk chemistry alone cannot pinpoint dominant pollution mechanisms and where community scientists can also give important metadata to support geochemical interpretations.

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2   *Indianapolis, IN, USA*

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9   **Abstract:**

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11 health hazard both to humans and ecological systems. Despite wide recognition of urban metal
12 pollution in many cities, there is still relatively limited research regarding heavy metal
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14 important scale for actual human interaction and exposure. Thus, using community-scientist-
15 generated samples in Indianapolis, IN (United States), we applied bulk chemistry, Pb isotopes,
16 and scanning electron microscopy (SEM) to illustrate how detailed analytical techniques can aid
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19 from past industrial/vehicular sources. SEM revealed anthropogenic particles suggestive of Pb
20 paint and the widespread occurrence of Fe-rich metal anthropogenic spherules across all homes,
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24 methods on community sourced samples to gain better insight into where the Pb came from and
25 how it currently exists in the environment. However, these methods should be applied after
26 large-scale pollution screening techniques such as portable X-ray fluorescence (XRF), with more
27 detailed analytical techniques focused on areas where bulk chemistry alone cannot pinpoint
28 dominant pollution mechanisms and where community scientists can also give important
29 metadata to support geochemical interpretations.

30 **Keywords:** Lead (Pb); heavy metals; urban pollution; Pb isotopes; SEM; community science

31

32 **1. Introduction**

33   Understanding heavy metal pollution in the urban environment is particularly important
34 for the health and well-being of both humans and ecological systems, as many heavy metals can
35 be toxic to organisms in excessive amounts. Of particular interest is Pb, as it can especially harm
36 children and their developing brains (e.g., Egendorf et al., 2020) and it is established that there is
37 no known safe level of Pb exposure in children (e.g., Betts, 2012). A challenge with identifying

38 and mitigating Pb exposure is that its distribution is heterogeneous in urban environments, both
39 at the household and city-wide scale (e.g., Filippelli et al., 2018; Obeng-Gyasi et al., 2021).

40   One approach to better understand Pb heterogeneity in the urban environment is through
41 large sampling datasets at high spatial resolution, collected by community scientists. Community
42 scientists are local community members that can improve scientific research endeavors, bridge
43 the gap between scientists and the general public, enhance the ability to collect samples not
44 easily obtained by researchers alone (i.e., indoor home samples), and provide a link to
45 understanding the critical issues facing communities. While community science thus far has
46 made great strides in improving science communication and mapping Pb exposure risks (e.g.,
47 Filippelli et al., 2018; Ringwald et al., 2021; Watson et al., 2022), there is untapped potential for
48 further research advancement via community science.

49   Although community science samples contain inherent variability with sampling
50 techniques, even with clear instructions, the large sample size of community science endeavors
51 often overcomes this limitation (Filippelli et al., 2018). However, a key question not addressed
52 thus far in community science-based research is whether smaller subsets of samples can be
53 utilized for more detailed geochemical techniques and analyses to understand pollution
54 distributions, despite potential variability in sampling methodology?

55   Lead stable isotopes have frequently been used for tracing pollution sources of Pb in the
56 environment as a more detailed geochemical technique (e.g., Adgate et al., 1998; Jaeger et al.,
57 1998; Sutherland et al., 2003; Wang et al., 2019), largely due to unique Pb isotopic ratios of
58 many Pb sources and minimal environmental and biological fractionation of Pb isotopes (e.g.,
59 Ayuso & Foley, 2020). Despite their applicability in pollution source apportionment studies,
60 complexities arise in urban settings when multiple pollution sources may be present.
61 Additionally, while original Pb ores may oftentimes contain unique Pb isotopic signatures, the
62 diverse range of Pb isotopic ratios in major urban sources such as paint and gasoline can lead to
63 overlap in source ratios (e.g., Resongles et al., 2021; Wang et al., 2021). This can complicate
64 interpretations of Pb pollution sources in environmental media such as soils and dusts, even
65 within a single indoor home, where multiple types of Pb paint, with vastly different isotopic
66 ratios, may persist (Jaeger et al., 1998). Thus, it is often important to not only rely on Pb isotopic
67 ratios when determining pollution sources in the urban environment, but to incorporate other
68 techniques such as bulk chemistry and scanning electron microscopy (SEM) as well. SEM in
69 particular can identify the nature of pollutant particulates (i.e., metal fragments, combustion
70 spherules, etc.) (e.g., Dietrich et al., 2019; Gaberšek & Gosar, 2021), which can help identify the
71 actual form of Pb pollution and thus help differentiate between potential sources when used with
72 other analytical techniques (e.g., Miler & Gosar, 2019).

73   Both SEM and Pb isotope techniques in tandem provide more detailed analytical
74 approaches that can help better parse out Pb pollution sourcing and source distribution compared
75 to bulk chemistry alone. Through four community scientist homes, we provide a case study of
76 how detailed analytical techniques can create a more holistic picture of Pb pollution sourcing and
77 transport in an urban environment. We focus on one typical Midwest US city with known
78 elevated Pb concentrations (Indianapolis, Indiana) as a case study because of the abundance of

79 bulk soil Pb data already collected in the area (Filippelli et al., 2018). We aim to characterize
80 household-scale soil and indoor dust samples to better quantify how Pb sources (i.e., paint and
81 gasoline) are dispersed, and to illustrate how our methodology can be utilized in subsets of large-
82 scale community science projects to address complex patterns uninterpretable based on bulk
83 chemistry alone.

84

85 **2. Materials and Methods**

86 *2.1 Sampling and Preparation*

87 Soil and dust samples were provided by local community members from four households
88 in Indianapolis (Fig. S1) as part of the Anthropocene Network (https://anthropocenes.org/lead),
89 which provides free household screening for Pb (water, dust, and soil sampling) and aims to
90 address issues of environmental equity in the age of the Anthropocene. The community science
91 relationship was enabled through partnerships with local faith leaders in churches and the
92 assurance of participant anonymity, which allowed for sample collection at homes that would
93 otherwise be inaccessible. Residents were instructed to collect bulk vacuum cleaner dust in a
94 sealed plastic bag, as well as soil (upper 0-5 cm) at their home's dripline (directly adjacent to
95 home), the middle of their yard, and directly adjacent to the street with any type of scoop
96 available at their home. Soil samples (~25 g. or more) were placed in separate plastic bags. Each
97 vacuum dust sample was a composite of the entire home, and each soil sample was an individual,
98 non-composite sample. We only selected sampling kits that had clearly labeled sample bags,
99 indicative that the participants followed sampling instructions. Households that were spread out
100 across Indianapolis was also taken into consideration to capture as much potential representation
101 of the city as possible. A small sample size was used because the purpose of this research was to
102 serve as a case study illustrating the ability to utilize community science samples for more
103 detailed analytical research outside bulk soil screening for Pb.

104 All Pb results in the Anthropocene Network were communicated back to anonymous
105 participants with tips on how to mitigate Pb exposure. Because of the emphasis on anonymity,
106 there is sparse metadata for this community science partnership, but other community science
107 endeavors have focused more on participant metadata information (e.g., Dietrich et al., 2022),
108 which can help in interpretation of geochemical results and determining efficient pollutant
109 remediation strategies.

110 Dust samples were sieved at 250 µm and were dry due to the nature of sampling, and thus
111 needed no desiccation. Soil samples were air dried, sieved at 2 mm, then powdered and
112 homogenized utilizing an agate mortar and pestle prior to acid digestion. Samples were weighed
113 (~300-400 mg) into Savillex screw-cap vessels and digested utilizing a multi-stage, three-acid
114 digestion procedure (HF, HNO_3, and HCl), following methods by Rader et al. (2021). Samples
115 were then suspended in 2mL of distilled 8M HNO_3 for column chromatography. A small aliquot
116 of this solution was extracted and diluted for concentration analysis prior to chromatographic
117 separation. This is defined as total soil Pb for the purposes of this study.

118   Samples were purified for Pb isotope analysis via column chromatography utilizing
119   Eichrom Sr Spec resin, slightly modified from that described by Deniel & Pin (2001) and
120   Thibodeau et al. (2007). After purification, samples were diluted accordingly after a
121   concentration check and spiked with NIST 997 thallium (Tl) standard to achieve a Pb/Tl ratio of
122   ~4.

123

124   *2.2 Instrument Analyses*

125   The metal Pb [along with cadmium (Cd), Tl, and antimony (Sb)—which are reported
126   because of their sparseness in the U.S. urban soil/dust literature] was quantified via an Agilent
127   7700 Inductively Coupled Plasma Mass Spectrometer (ICP-MS), operating in no gas mode. The
128   Pb isotopes ^{204}Pb, ^{206}Pb, ^{207}Pb, and ^{208}Pb were detected with a Nu Plasma II Multicollector
129   Inductively Coupled Plasma Mass Spectrometer (MC-ICP-MS), with the Pb isotope ratios
130   208/206, 207/206, 208/207, 206/204, 207/204, and 208/204 reported after being normalized to
131   Galer & Abouchami (1998). All ICP analyses were completed at Indiana University-
132   Bloomington in the Department of Earth and Atmospheric Sciences' Metal Isotopes Laboratory.
133   More details are provided in Text S1.

134   Dust and soil samples were prepared for SEM and energy dispersive X-ray spectroscopy
135   (EDS) analysis on aluminum samples stubs using carbon sticky tab substrates. EDS lines used to
136   identify Pb specifically include the L_α = 10.541 keV (nominally M_α = 2.342 keV, M_β = 2.444
137   keV). All SEM-EDS analyses were conducted at Indiana University-Purdue University
138   Indianapolis, using a Zeiss EVO-10 SEM and Bruker XFlash6, 60 mm^2 EDS detector.
139   Backscatter electron (BSE) images and EDS data were collected at a setting of 20 kV in variable
140   pressure mode.

141

142   *2.3 Quality Control*

143   Lead total concentration was deemed acceptable based on a mean recovery of 89.4% $\pm$
144   11.0% (n = 5) for NIST SRM 2702 (Table S1) and runs of USGS standard AGV-2a and NIST
145   2702 were both in agreement with previously published Pb isotopic compositions (see Text S2
146   and Table S2). More details on quality control are provided in Text S2.

147

148   **3. Results and Discussion**

149   *3.1 General Soil and Dust Pb Enrichment and Relationships*

150   Regardless of sample type or location, nearly all samples are enriched relative to the 75th
151   percentile of background soil samples [upper 5 cm of soil, air dried <2 mm fraction crushed to
152   <150 μm prior to a near-total four-acid (hydrochloric, nitric, hydrofluoric, and perchloric)
153   digestion at a temperature between 125 and 150 ℃] from throughout Indiana for Pb (Fig. S2;
154   Table S3) (Smith et al., 2013). The 75th percentile value for background soil in Indiana is 25.6

155 mg/kg for Pb. Lead concentrations are ≥80 mg/kg in nearly all dust and soil samples (Fig. 1B;
156 Table S3). The general anthropogenic enrichment of Pb (at concentrations in the hundreds to
157 thousands of mg/kg) has been well documented in Indianapolis in urban soils (Filippelli et al.,
158 2018).

159   Although the dust samples were sieved to a finer particle fraction and finer sized particles
160 tend to contain higher concentrations of heavy metals (e.g., Herngren et al., 2006; Tansel &
161 Rafiuddin, 2016), bulk geochemistry results indicate that dust is not consistently higher in metal
162 concentration than the soil samples, even within the same house location (Fig. 1B; Fig. S2). This
163 may indicate that the dominant anthropogenic source for these elements in both media is coarser
164 material, and the interior loading reflects both indoor dust and finer particle invasion from
165 outside. This emphasizes recent work by Gillings et al. (2022) that demonstrates how
166 relationships between indoor and outdoor sources are not always predictable, and inferences on
167 one based on the other should be taken with caution.

168   It is noted that we examined the bulk grain size (<2 mm) composition of outdoor soil
169 samples, and that grain size may affect metal concentrations and partitioning of Pb sources.
170 However, we emphasize that bulk grain size is the most representative way to encapsulate all
171 possible Pb exposure within a household environment. While finer sized particles may be a
172 greater inhalation and transport risk, larger sized particles may degrade over time and still supply
173 a reservoir of Pb pollution.

174

3.2 Bulk Pb Concentration and Pb Isotope Heterogeneity

176   Three homes displayed clear heterogeneity in bulk metal concentrations of Pb depending
177 on sample location at the home, with only House 1 showing more consistent metal trends for Pb
178 (Fig. 1B; other metals displayed in Fig. S3). This heterogeneity extends to Pb isotopic ratios
179 (Table S4) such as $^{206}Pb/^{204}Pb$, although House 2 displayed fairly consistent $^{206}Pb/^{204}Pb$ isotopic
180 ratios (Fig. 1A), with slightly more variance in $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios (Fig. S4). This
181 matches previous research in urban centers that documented extensive heterogeneity at the
182 household-scale for both bulk metal concentrations such as Pb (e.g., Filippelli et al., 2018;
183 Obeng-Gyasi et al., 2021; Wade et al., 2021) and for Pb isotopic composition (Wang et al.,
184 2021). Due to our small sample size and no consistent trends between Pb isotopes or bulk metal
185 soil concentrations based on sample location, we cannot make any broad generalizations on
186 spatial relationships between dripline, yard, and streetside soils such as larger studies in
187 Indianapolis, IN (Filippelli et al., 2018), Durham, NC (Wade et al., 2021) and Greensboro, NC
188 (Obeng-Gyasi et al., 2021) have done. However, when using bulk Pb concentrations, Pb isotope
189 ratios, and SEM collectively at a house-by-house basis, clearer interpretations of Pb pollution
190 can be made.

191

3.3 Pb Pollution Sources and Pb Distribution by Household—Synthesis of Analytical Methods

193 *House 1:*

194   The $^{206}Pb/^{204}Pb$ isotopic ratio changes significantly depending on the sample location and
195   between the indoor dust and outdoor soil, increasing towards the street, with the dust sample
196   containing the lowest $^{206}Pb/^{204}Pb$ isotopic ratio (Fig. 1A). This is not clearly reflected in bulk Pb
197   concentration though, which remains fairly consistent throughout the property, between 70 and
198   130 mg/kg (Fig. 1B; Table S3). Based on Pb isotopes alone, one would interpret a greater
199   proportion of geogenic background glacial till (indicative of surficial Wisconsin glaciation
200   sediments in the area) contribution closer to the street (Fig. S5). However, this is unlikely,
201   because Pb concentrations did not decrease toward the street (Fig. 1B), which would be expected
202   based on much lower Pb concentrations in geogenic background till (Barnes et al., 2020;
203   Kousehlar & Widom, 2020). Thus, the Pb changes in isotopic composition must have come from
204   an additional source of Pb such as leaded paint or leaded gasoline. Microscopy revealed only a
205   few instances of possible Pb paint particles, but routinely revealed evidence of high temperature
206   anthropogenic process Fe-rich spherules at all soil locations (Fig. 2). Thus, while Pb paint likely
207   contributed to bulk Pb inside the home (Fig. 2), the scarcity of distinguishable paint particles via
208   SEM in the soils and prevalence of anthropogenic spherules suggests the possibility of
209   vehicular/industrial Pb sourcing, such as from residual microscopic particulate leaded gasoline or
210   other vehicle Pb-wear (i.e., wheel weights) too small to detect via SEM.

211   *House 2:*

212   There is greater bulk Pb variability in samples than $^{206}Pb/^{204}Pb$ ratios on the property
213   (Fig. 1). This includes a dripline soil sample that was 4 mg/kg Pb, and resembled mulching
214   material. Thus, although the house samples are grouped closely on bivariate Pb isotope plots
215   (Fig. S5), Pb sourcing is potentially different between the 4 mg/kg Pb dripline sample and other,
216   more elevated Pb streetside & yard samples. Yard and streetside Pb was much higher than inside
217   the home (Fig. 1B), with SEM imaging revealing no Pb-rich particles inside the home, but
218   several apparent paint Pb-rich particles at the streetside and within the yard, similar to apparent
219   paint particles in Dietrich et al. (2022) (Fig. 2). The prevalence of Pb-rich particles at these
220   locations supports the higher bulk Pb concentrations and suggests that Pb paint abundance
221   outside the home is greater than inside the home, even though Pb isotopic ratios are similar. This
222   may be because of peeling exterior Pb paint that has been reworked in the outdoor environment
223   and covered at the dripline by recent mulch material. There still appears to be an exchange of
224   material across all household samples, as Fe spherules were also found at this household at all
225   locations, even the mulched dripline. However, the spherules at the dripline were less Fe-rich
226   (Fig. S11) than other spherules, suggesting they may have degraded more over time with
227   minerals (i.e., clays, apatite) adhering or precipitating on the spherule structure, or because they
228   were formed under different conditions or processes.

229   *House 3:*

230   Bulk Pb concentrations increase toward the street in soils and are the lowest in dust (Fig.
231   1B; Table S3). $^{206}Pb/^{204}Pb$ ratios increase from the dust to the dripline to the yard, but drastically
232   decrease at the streetside (Fig. 1A). SEM did not reveal any Pb paint particles at any location at
233   the home, or any Pb-rich particles of any nature. This suggests reworked, reprecipitated Pb is
234   prevalent in this home environment, likely from historic leaded gasoline because of the increase

6

in Pb concentration towards the street (Fig. 2). Because all samples contain anthropogenic metal spherules, this illustrates the potential for distribution and transport of microscopic aerosol Pb to the home dripline and indoor environment from a distance—either industrial or vehicularly sourced. The widespread dispersion of vehicular Pb from historic leaded gasoline has been observed in atmospheric aerosols in London, U.K. (Resongles et al., 2021), suggesting the potential for the same type of dispersal here. Additionally, the Pb isotopic ratios for streetside soil at this home contain the least ^{206}Pb, ^{207}Pb, and ^{208}Pb relative to ^{204}Pb, which closely aligns with the Pb isotopic range of leaded gasoline (Fig. S5), and House 3 was near a road with the highest modern daily traffic volume compared to any other house in this study (Table S5)—historic traffic volume was likely also high given the urban location.

House 4:

Bulk Pb concentration is highly variable depending on sample location, at the highest (> 800 mg/kg) in the dust and dripline soil before decreasing significantly in the yard soil, then increasing in the streetside soil (Fig. 1B). The ^{206}Pb/^{204}Pb isotopic ratio also changes, increasing from the dust to the dripline soil, then decreasing again for yard and streetside soil (Fig. 1A). Based on microscopy, the dust and dripline soils commonly contain Pb-rich particles resembling paint chips (Fig. 2), and the differences in Pb isotope ratios may be because of different layers or types of paint in the interior versus exterior of the home. Microscopy did not reveal any obvious Pb paint chips in the streetside or yard soils, but did reveal numerous high temperature anthropogenic process Fe-rich spherules, which were evident in both the streetside and dripline soil (Fig. 2). Although there may be mixing of microscopic Pb-rich particles from past vehicular exhaust or other industrial sources at the dripline, that soil is likely more dominated by Pb paint relative to streetside soils, where no Pb paint particles could be easily identified. Thus, because the bulk Pb concentration was still elevated well above background soils (Smith et al., 2013) at the streetside and no Pb paint could be readily identified, residual leaded gasoline, vehicle wear, or other industrial processes was likely the main source of Pb there.

3.3.1 Summary and Comparison of Household Pb Sourcing

The primary Pb sources in all homes were likely Pb-based paint or the remnants of leaded gasoline, supportive of previous literature in urban environments within the U.S. (e.g., Dietrich et al., 2022; Wang et al., 2021). However, each home had different patterns of Pb pollution sources (Table 1) and Pb concentrations (Fig. 1B). This did not seem to be dependent on larger-scale Pb relationships in Indianapolis, such as those at the zip code level (Filippelli et al., 2018). For example, homes 1, 2, and 4 resided in zip codes where reported median Pb concentrations in yard soils ranged from 183-263 mg/kg (Filippelli et al., 2018). However, the Pb concentrations in these homes were widely variable (4-2100 mg/kg; Table S3), and the likely Pb sources changed between paint and vehicular/industrial (i.e., leaded gasoline) both between homes and between sampling location within the homes. Thus, even our small number of households examined in this study exemplifies the fact that generalizations of Pb pollution at larger spatial scales should be made with caution, and multiple other external factors can affect Pb distributions at fine scales such as the history of the home and proximity to major roadways.

275

3.4 Similarities in Pb Pollution Between Households

276

277   Influences on metal concentrations in dusts and soils at the household-scale include not
278 only potential pollution sources, but how dust and soil get reworked and distributed throughout
279 the environment. In general, although there was much Pb pollution heterogeneity between
280 households (Fig. 1), a commonality was the presence of Fe-rich high temperature anthropogenic
281 process spherules at every home within multiple samples (Fig. 2). This entailed homes where
282 distance from road to home was between 7-14 meters, nearby daily traffic volume was highly
283 variable, and where there were multiple possible industrial sources (Table S5). These spherules
284 are commonly seen in industrial urban areas (e.g., Dietrich et al., 2019; Gaberšek & Gosar, 2021)
285 and are likely anthropogenic. This not only suggests that there is exchange of pollutant particles
286 to the dripline of the home, supporting the hypothesis that the side of the home can act as a
287 barrier for particulates to fall following roadside resuspension (e.g., Filippelli et al., 2018;
288 Laidlaw & Filippelli, 2008), but also supports previous studies where there was exchange of
289 outdoor pollution to the indoors (e.g., Adgate et al., 1998; Kelepertzis et al., 2020). Thus,
290 transport of pollutants in soils/dust at the household-scale is likely an additional factor affecting
291 Pb heterogeneity.

292   Future research should therefore consider the ability of metal pollution transport and
293 reworking across neighboring homes and properties. Recent research in other urban settings (i.e.,
294 London) has also pointed out the continued reworking and widespread distribution of historic Pb
295 pollutant particles throughout the environment in the form of atmospheric aerosols (Resongles et
296 al., 2021).

297

3.5 Limitations of Only Pb Isotopes for Pollution Sourcing

298

299   Using Pb isotopes or bulk chemistry alone can be problematic for determining pollutant
300 sourcing, because even within the same home, Pb isotopic composition of paints can vary
301 drastically (Jaeger et al., 1998), and the Pb isotopic ratios for leaded gasoline were widely
302 variable within the U.S. because of changing ore sources over time (e.g., Dietrich et al., 2021).
303 For example, nearly all dust and soil samples plot within 1σ variability of leaded gasoline and
304 lead paint source endmembers depending on the Pb isotope ratios used (Fig. S5). Thus, although
305 previous interpretations in urban settings within the U.S. have concluded Pb paint sources likely
306 dominating soils close to older homes (i.e., built prior to 1978) and leaded gasoline significantly
307 contributing to soils near roadways (e.g., Wade et al., 2021; Wang et al., 2021), we utilized SEM
308 imaging and EDS spectra to aid in interpretation of our variation in bulk Pb and Pb isotopic
309 ratios at the household-scale. This multi-analytical approach is often necessary in complex urban
310 settings where simple binary pollution mixing models of Pb sources will not work—particularly
311 with the increasing overlap of stable Pb isotope signatures of multiple anthropogenic sources
312 (e.g., Resongles et al., 2021).

313

314 **4. Implications**

315   Urban environments contain complex, heterogenous distributions of heavy metals in soils
316 and dusts, particularly Pb. This is especially evident in a large, post-industrial city such as
317 Indianapolis, IN where historic Pb sources such as leaded paint and leaded gasoline contaminate
318 soils and dusts in varying ways, as shown with differences between our study's household
319 samples. Community science can provide a large sampling set to gather Pb data from, which can
320 effectively help map Pb hotspots, general trends, and inform people of risks in their home (e.g.,
321 Filippelli et al., 2018; Watson et al., 2022). However, there are often nuances associated with
322 pollution interpretations based on bulk chemistry alone, and more detailed analytical methods
323 can help better understand Pb heterogeneity.

324   Here, we demonstrated how detailed methodology such as SEM and Pb isotopes can give
325 a clearer picture of Pb pollution source distribution on a property. This approach can be utilized
326 for even larger subsets of community science samples to better understand pollution variability
327 in bulk chemistry following initial screening through techniques such as X-ray fluorescence
328 (XRF). While there is inherent uncertainty in sampling with community scientists, as long as
329 general instructions are followed, enough information may be gathered to obtained informative
330 and actionable insight into pollution sources distributions. For example, whether Pb pollution
331 from the home reaches the street, or whether Pb pollution from the street reaches the home. This
332 information can therefore aid in home pollution remediation and prevention by determining
333 whether there is significant transport and exchange of Pb pollution sources.

334   Additionally, working more with community members as real partners in research can be
335 helpful for both gaining useful information to interpret Pb pollution results and helping the
336 community members to place these results in their household context. This is a different
337 approach that "parachute science" and has more lasting effects in changing behavior (Hayhow et
338 al., 2021). For example, we recommend surveying community members first about their
339 concerns and gathering important metadata during the course of the study, such as the age of
340 their home, whether there has been recent renovation, worries of a particular Pb source nearby,
341 etc.

342   Future studies in urban centers throughout the world would do well to capitalize on
343 community science and the multi-analytical techniques such as those used here and in other
344 recent urban metal pollution studies (e.g., Gaberšek & Gosar, 2021; Kelepertzis et al., 2021) to
345 more fully understand the nuance associated with urban metal pollution distributions. This can be
346 important in determining whether a pollutant source is coming from a property or elsewhere, the
347 nature of the pollutant particles (i.e., are there Pb particles that are small enough to be an
348 inhalation risk), and whether there is transfer of material from inside to outside a home. All these
349 details are helpful from both a health risk and remediation perspective.

350   These techniques should be particularly used more within the U.S. because of the
351 abundance of urban centers with varying legacies of pollution, the demographic and climate
352 diversity, and the growing popularity of community science research providing an abundance of
353 samples to study (e.g., Filippelli et al., 2018; Ringwald et al., 2021). These community science

354 endeavors offer a cost-effective way to systematically choose subsets of samples for more
355 detailed multi-analytical approaches that provide important and scalable insight into Pb
356 pollution. Lastly, these community science efforts expand the possible options for sample
357 accessibility to researchers, such as to household indoor dust samples.

358

359 **Acknowledgements**

368

369 **Manuscript Tables:**

370

371 **Table 1**: Summary of the likely primary Pb pollution sources by house and sampling location.

House	Indoor Dust	Dripline	Yard	Streetside
1	Paint	Vehicular or industrial	Vehicular or industrial	Vehicular or industrial
2	Potentially Paint	None	Paint	Paint
3	Vehicular or industrial	Vehicular or industrial	Vehicular or industrial	Vehicular or industrial
4	Paint	Paint	Potentially Paint/Vehicular	Vehicular or industrial

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Manuscript Figures:
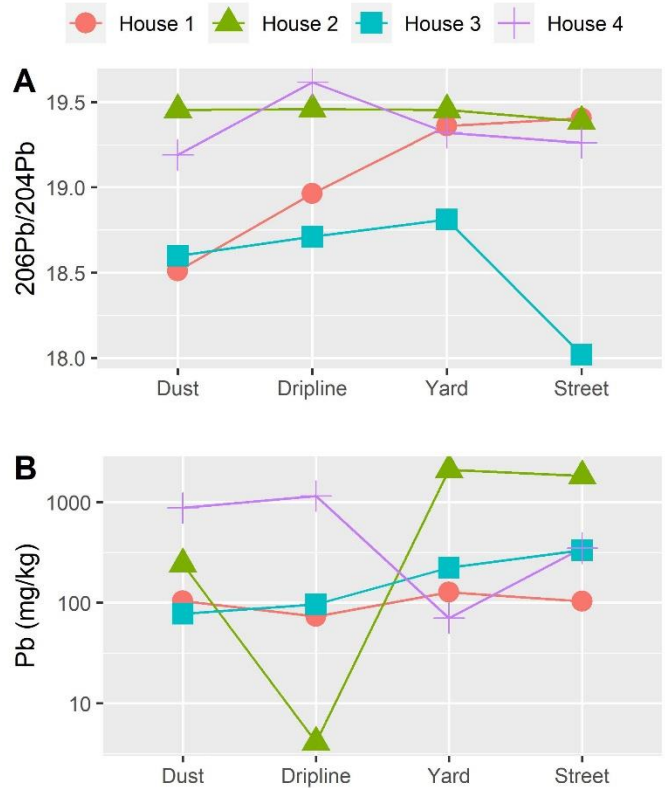
Fig. 1: Trends in ^{206}Pb/^{204}Pb based on sample type and house (A), as well as trends in bulk Pb concentration (mg/kg) based on sample type and house (B). Similar trends were seen for other isotopic ratios, albeit with slight variability (Fig. S4).

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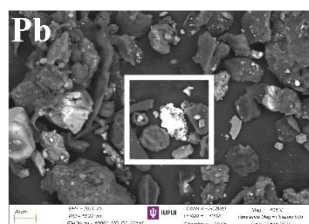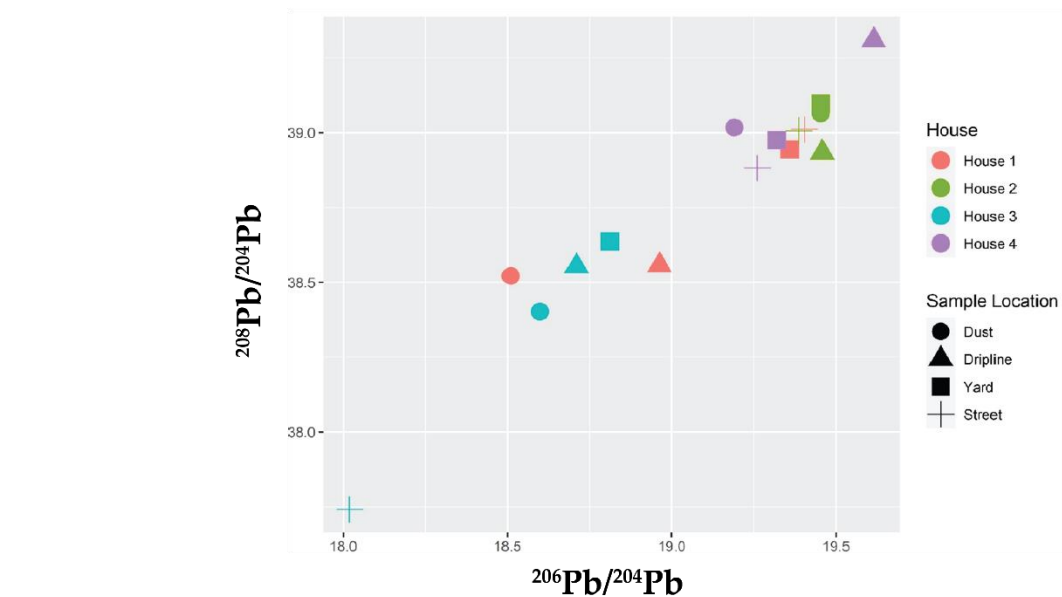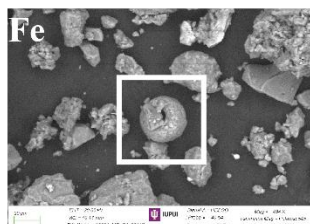
House 1: Indoor Dust[1]   House 1: Dripline[2]   House 1: Streetside[3]   House 1: Yard[4]
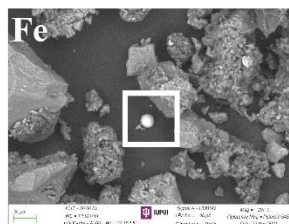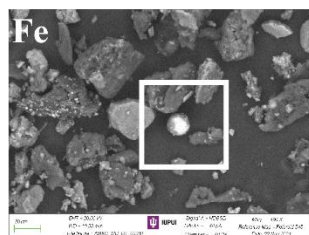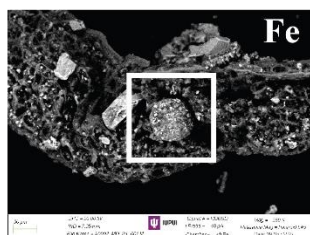
House 2: Indoor Dust[5]   House 2: Dripline[6]   House 2: Streetside[7]   House 2: Yard[8]
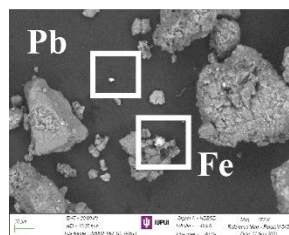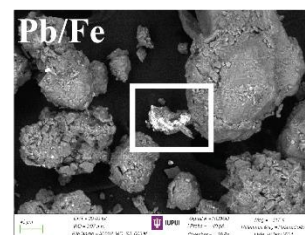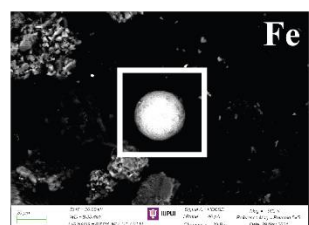
House 3: Indoor Dust[9]   House 3: Dripline[10]   House 3: Streetside[11]   House 3: Yard[12]
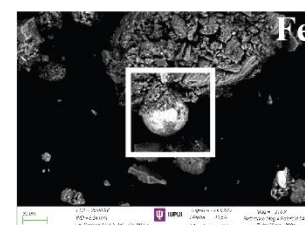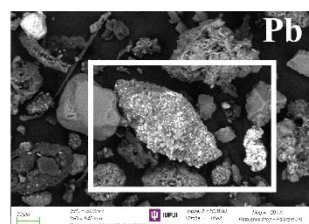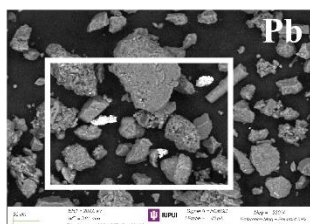
House 4: Indoor Dust[13]   House 4: Dripline[14]   House 4: Dripline[15]   House 4: Streetside[16]
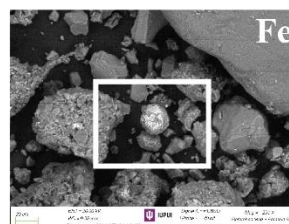
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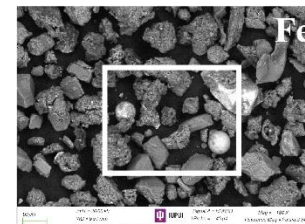
Fig. 2: Bivariate plot of Pb isotopic ratios, grouped by house and sample location. 2σ analytical variability is minimal relative to the sample symbol size and are thus only displayed in Table S2. SEM images are listed below the plot, with anthropogenic particles outlined in white. The corresponding EDS spectra for each superscript notation are listed in the Supplementary Information (Figs. S6-S21). Images labeled "Pb" contain Pb-rich particles within the white outline, while images labeled "Fe" contain Fe-rich particles within the white outline. It is noted that the paint particles in House 2: Streetside[7], House 4: Indoor Dust[13] and House 4: Dripline[14] also contain traces of Fe.

Statements and Declarations

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Author Contributions

Matthew Dietrich: Conceptualization, Funding acquisition, Investigation, Methodology, Visualization, Writing – original draft, Data curation. **Shelby T. Rader:** Methodology, Writing – review & editing. **Gabriel M. Filippelli**: Resources, Supervision, Writing – review & editing.

Ethical Approval

"Not applicable"

Consent to Participate

"Not applicable"

Consent to Publish

All authors agree to publish the manuscript in its present form.

Availability of data and materials

All data and materials are included in the manuscript and supplementary documentation.

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Supplementary Information

Using community science for detailed pollution research: A case-study approach in Indianapolis, IN, USA

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Supplementary Text

Test S1-Instrument Analyses

The Pb isotopes ^{204}Pb, ^{206}Pb, ^{207}Pb, and ^{208}Pb were detected along with ^{202}Hg, ^{203}Tl, and ^{205}Tl with a Nu Plasma II Multicollector Inductively Coupled Plasma Mass Spectrometer (MC-ICP-MS). All Pb isotope results were Hg-corrected, albeit the Hg correction was nominally zero, and corrected on-line for mass discrimination using the known Tl ratio of the NIST 997 spike. All results were then normalized offline to values reported by Galer and Abouchami (1998) for the NIST 981 standard (^{206}Pb/^{204}Pb = 16.9405, ^{207}Pb/^{204}Pb = 15.4963, and ^{208}Pb/^{204}Pb = Pb 36.7219). The errors are derived from the reproducibility of the NIST 981 Pb standard over the course of the run.

Text S2-Quality Control

To address any possible metal contamination through sieving the household soil and dust samples, 5 subsamples of NIST SRM 2702 – Inorganics in Marine Sediment were processed through either dust sieves (NIST_2702_1 and NIST_2702_2) or a 2 mm soil sieve (remaining SRM 2702 samples), as well as through the rest of the sample prep (i.e., digestions). The elements Cd, Tl, Pb, and Sb were deemed acceptable based on mean % recoveries between 80-106% (Table S1), and Pb isotopic contamination was deemed minimal based on low standard deviations for all isotope ratios within the SRM 2702 samples (Table S2), and good agreement with the peer review published ^{207}Pb/^{206}Pb avg value of 0.8377 (calculated from ^{206}Pb/^{207}Pb ratio of 1.1937 for SRM 2702; Jeong et al., 2021—99.62% similarity of our mean ratio to the published ratio).

As a quality control check on sample preparation and analysis, ICP-MS samples included periodic blanks run between samples, which confirmed background levels negligible. Isotopic

35 analyses via MC-ICP-MS included the analysis of a USGS reference material (AGV-2a),
36 prepared and processed as an unknown sample, which was in agreement with previously
37 published isotopic compositions (Table S2), and multiple analyses of an unknown sample during
38 the analytical session (within analytical error of one another), which confirmed instrument
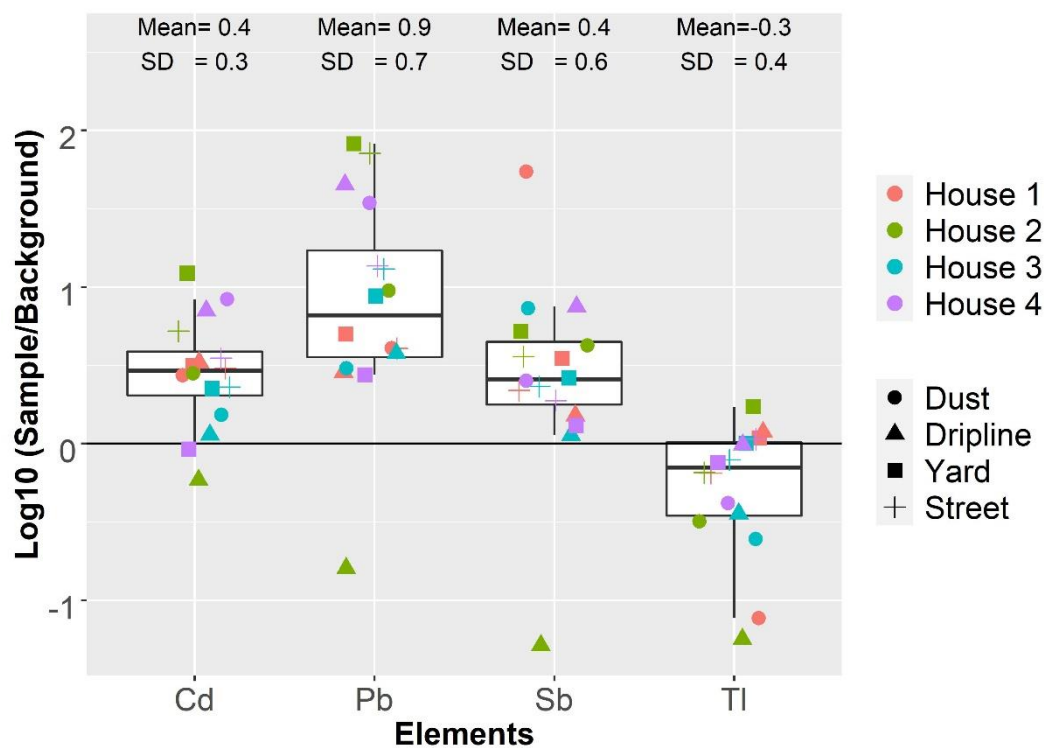39 stability across the analysis period.

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Supplementary Figures

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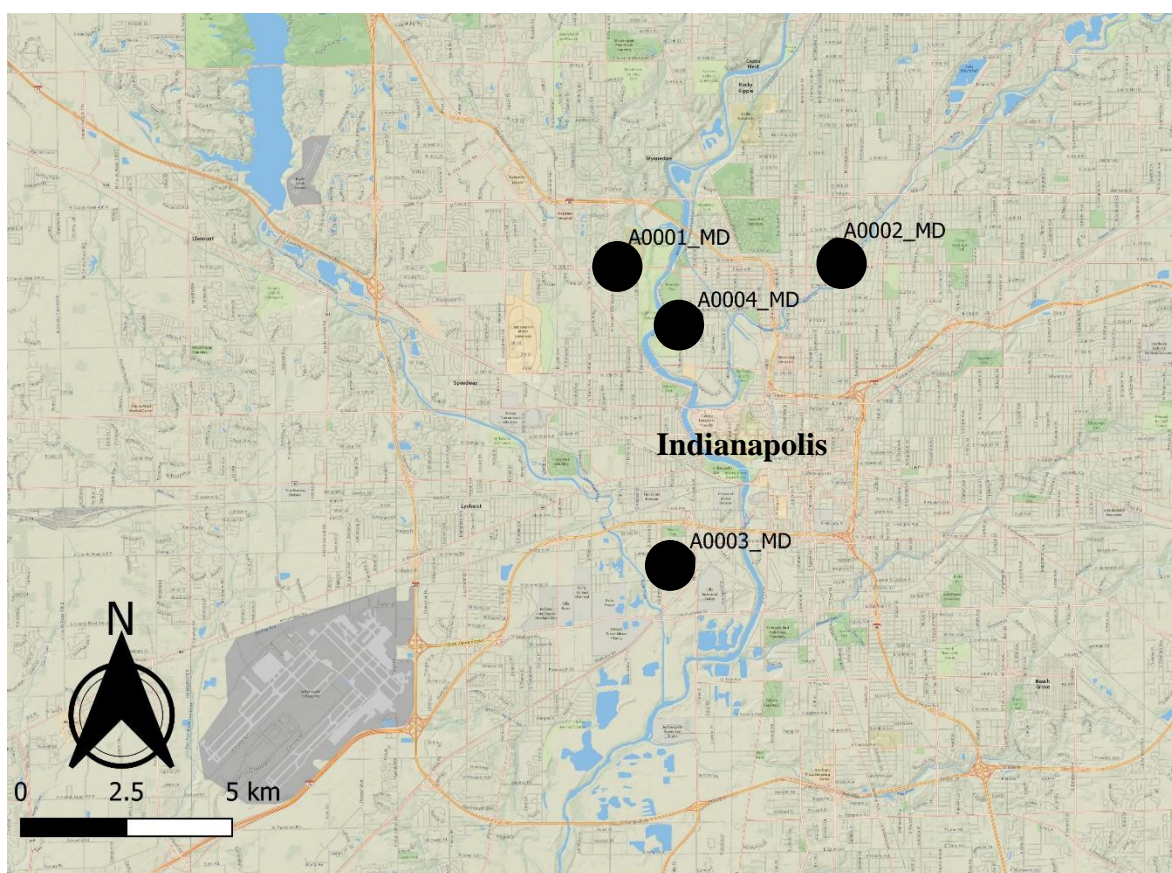
Fig. S1: Locations of the homes that provides samples, with symbol size enlarged and the map zoomed out to protect privacy.

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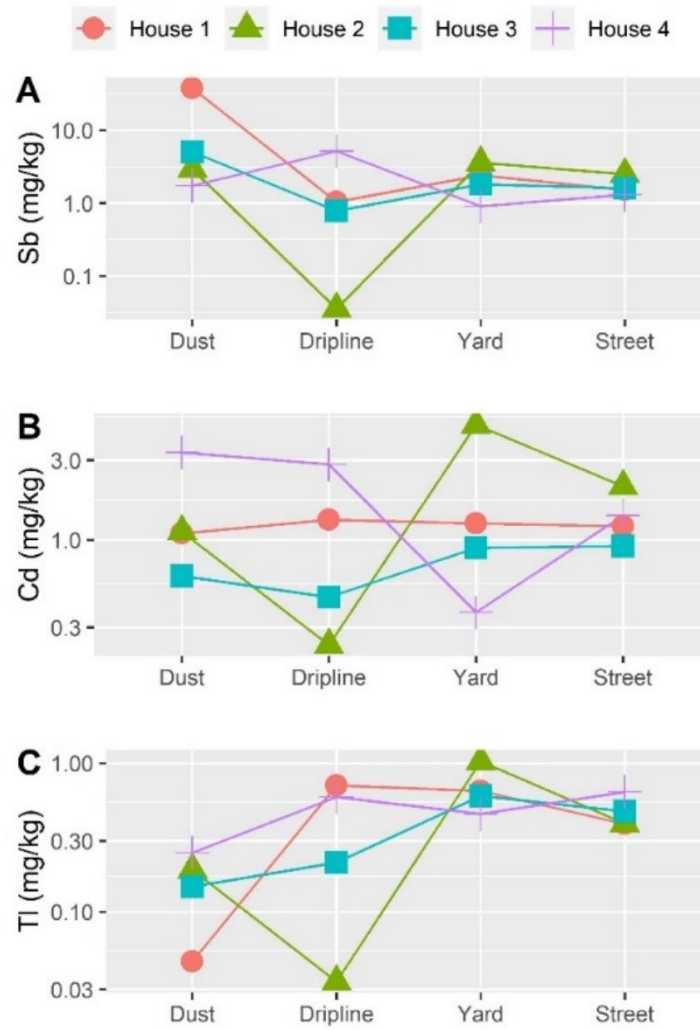
Fig S3: Bulk metal concentrations (mg/kg) for each household based on sampling location.

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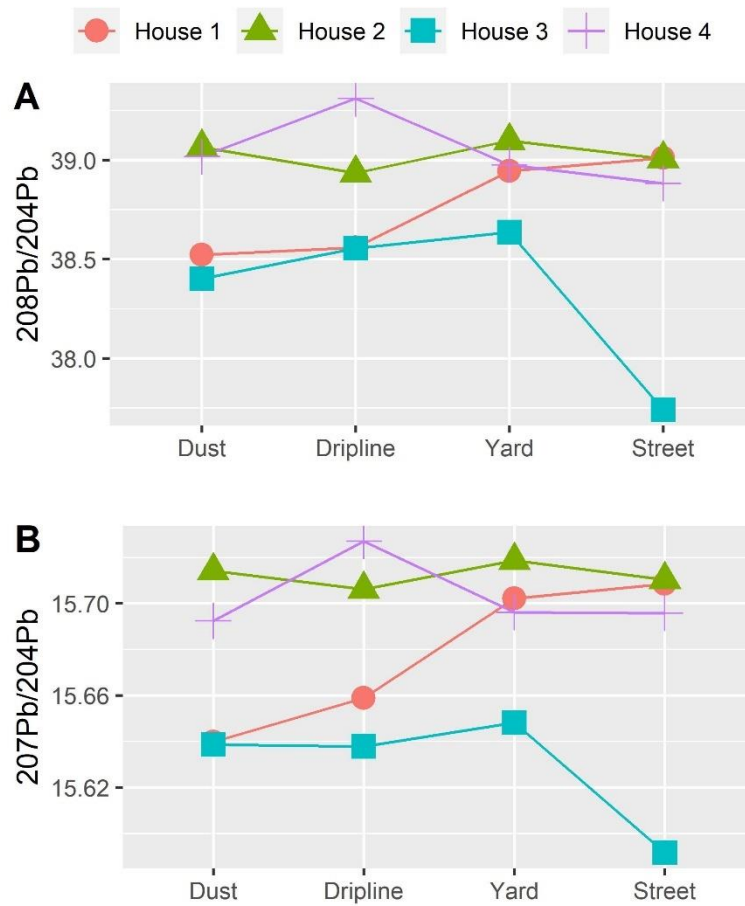
142   **Fig. S4**: Additional Pb isotope plots for each household based on sampling location.
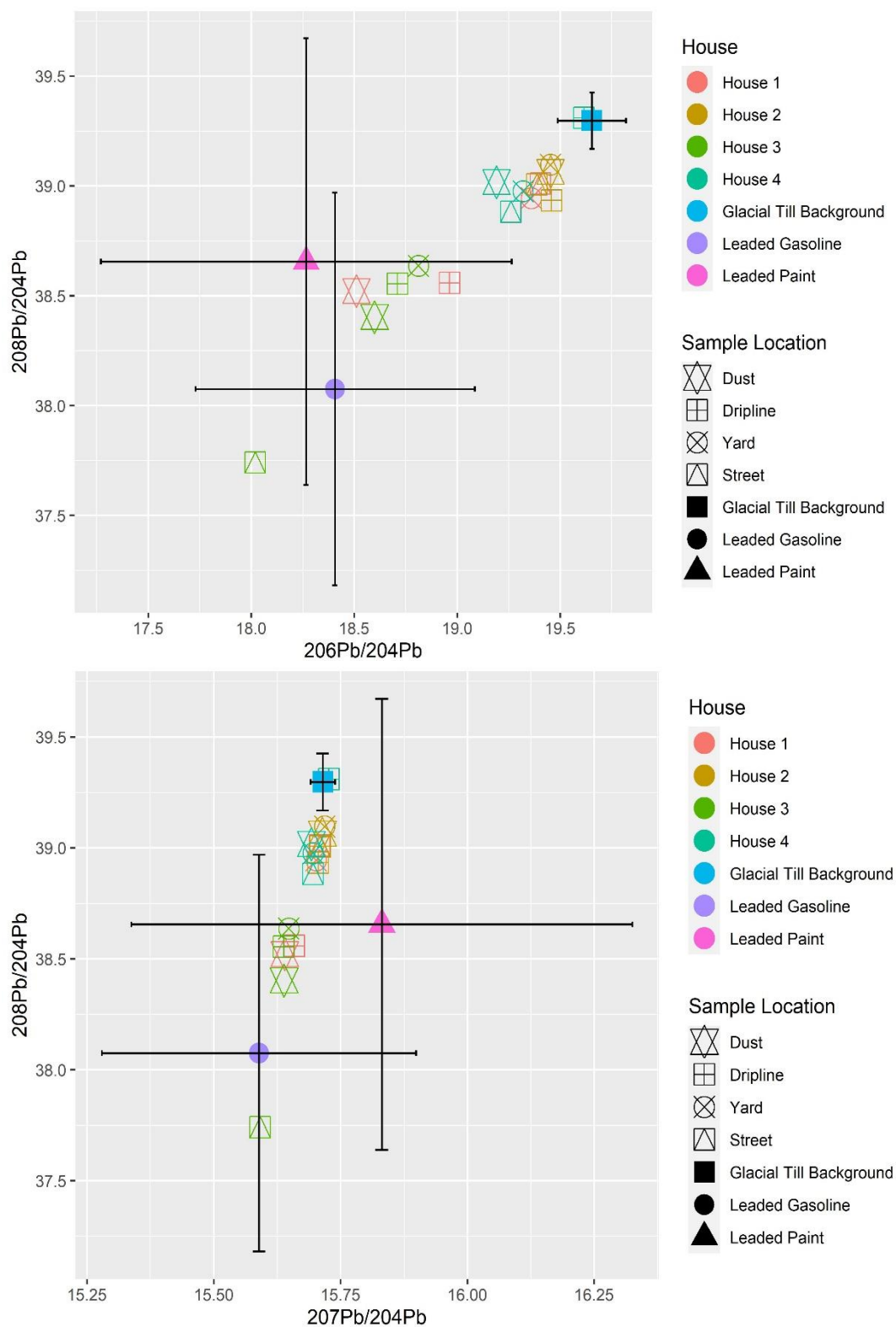
Fig. S5: Bivariate plots of Pb isotopic ratios for all samples and main potential pollution source
endmembers, with error bars representing 1σ variability in the source endmembers (Midwest

171 U.S. Glacial Till/Soil Background—Kousehlar and Widom, 2020, LeGalley et al., 2013; U.S.
172 Leaded Gasoline—Dietrich et al., 2021 and the references therein; Leaded Paint—Wang et al.,
173 2019 and the references therein). 2σ sample analytical variability is minimal relative to the
174 symbol sizes, and thus only displayed in Table S2.
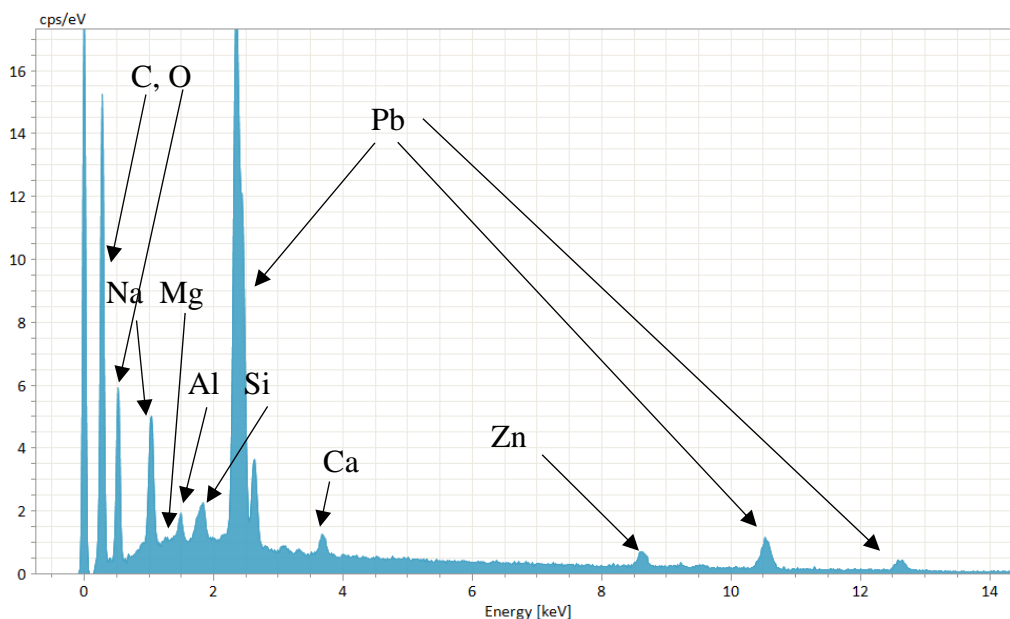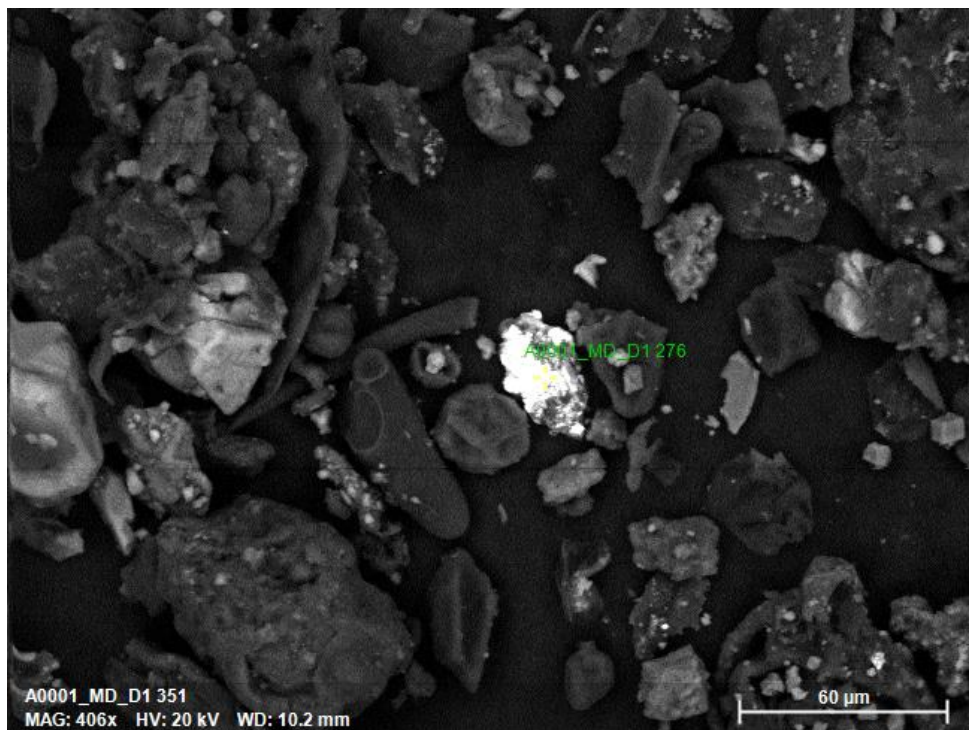
Fig. S6: EDS spot analysis of House 1: Indoor Dust[1].

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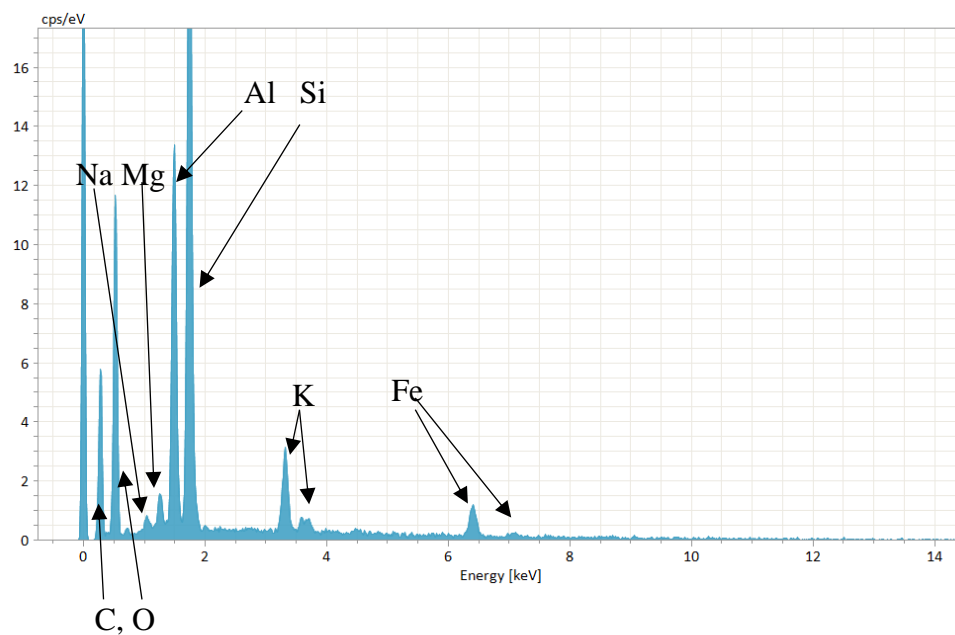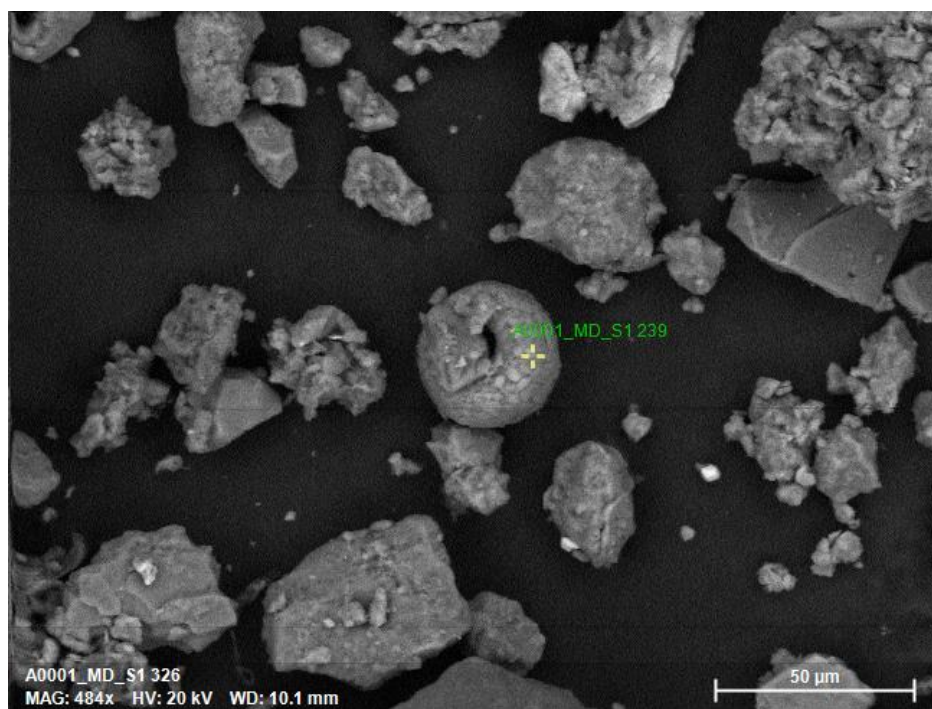
Fig. S7: EDS spot analysis of House 1: Dripline[2].

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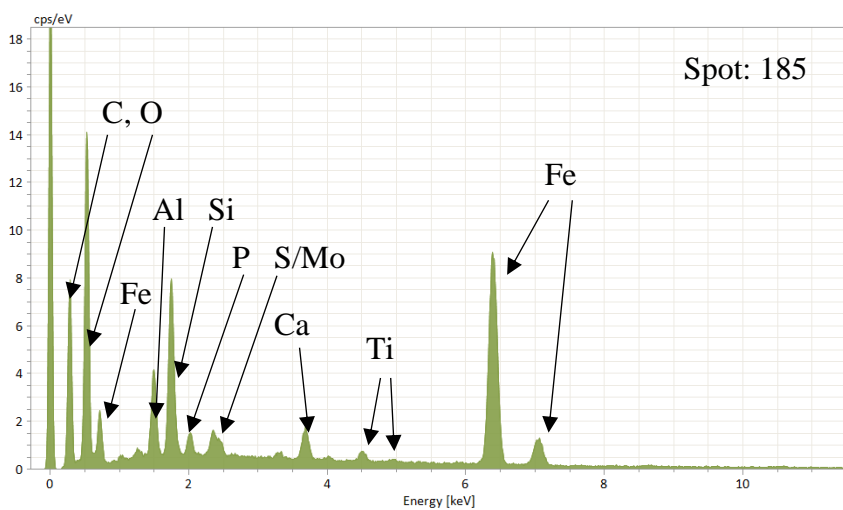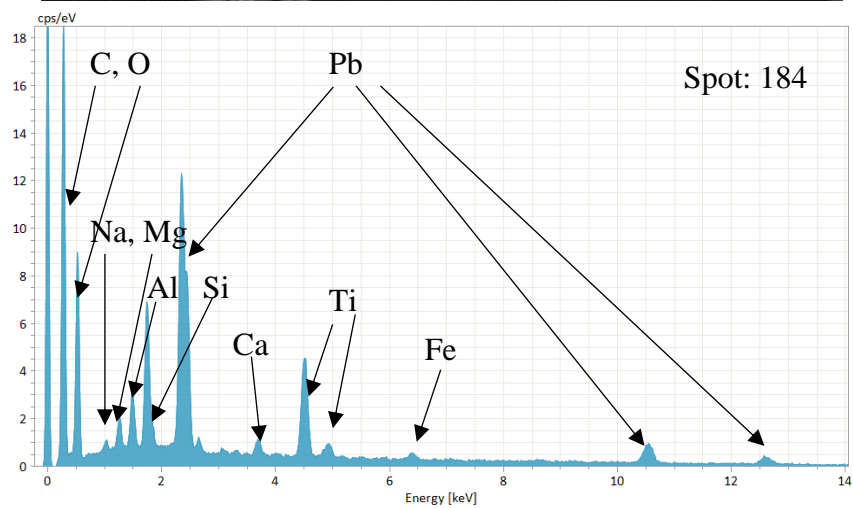234
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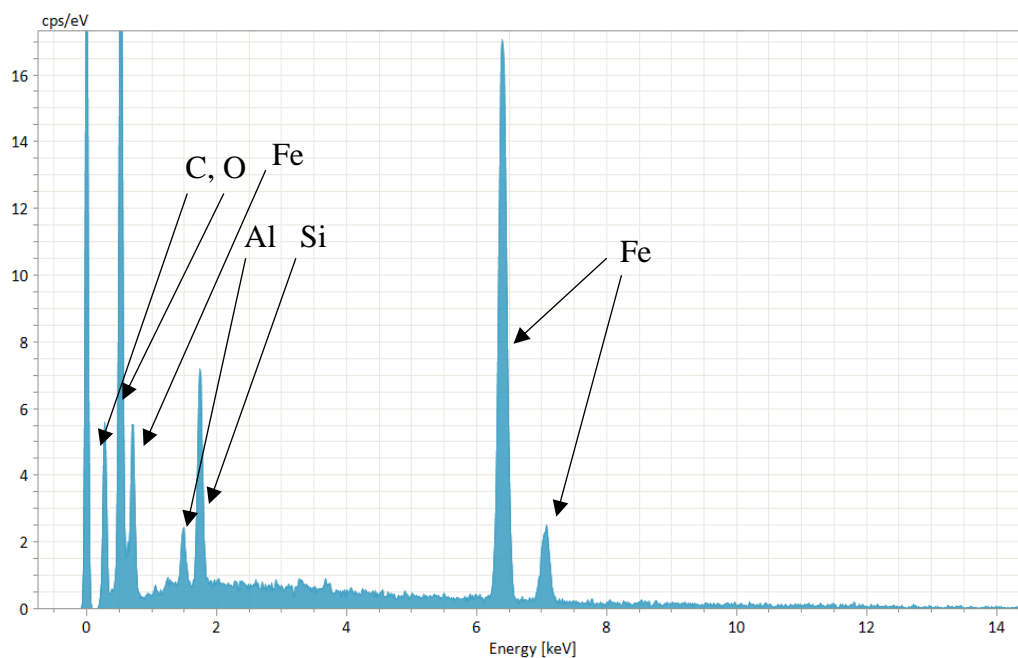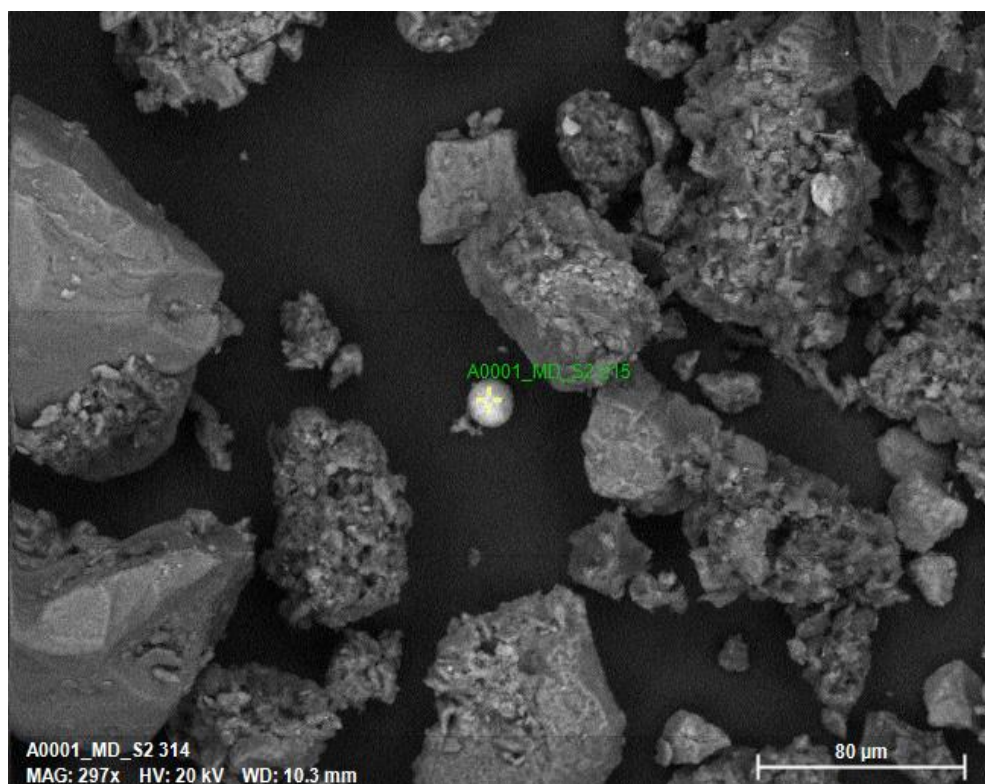
Fig. S8: EDS spot analysis of House 1: Streetside[3].

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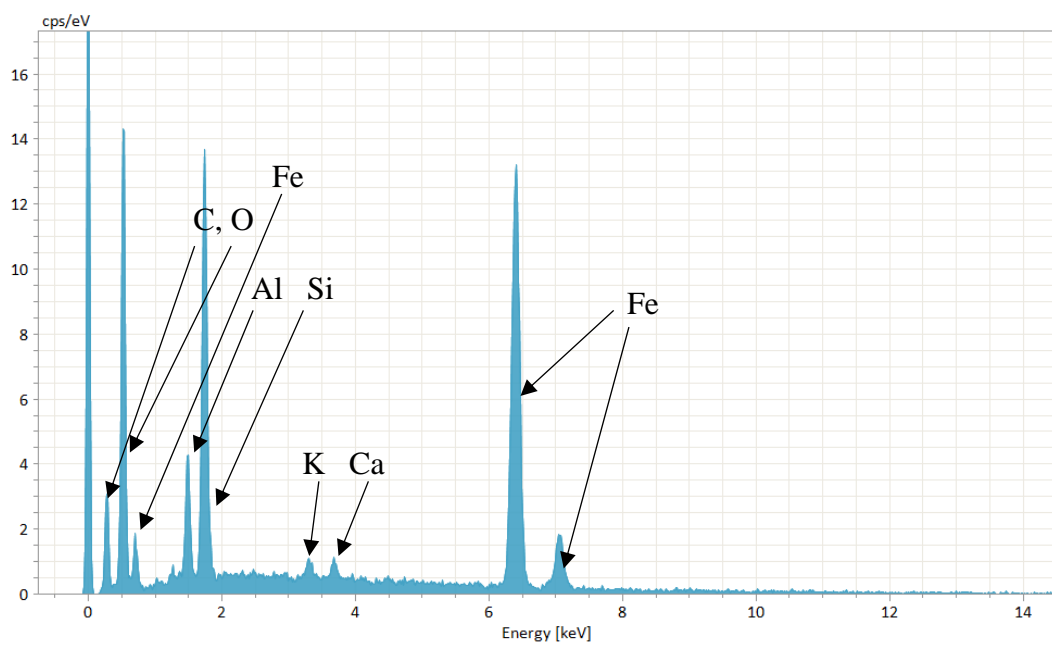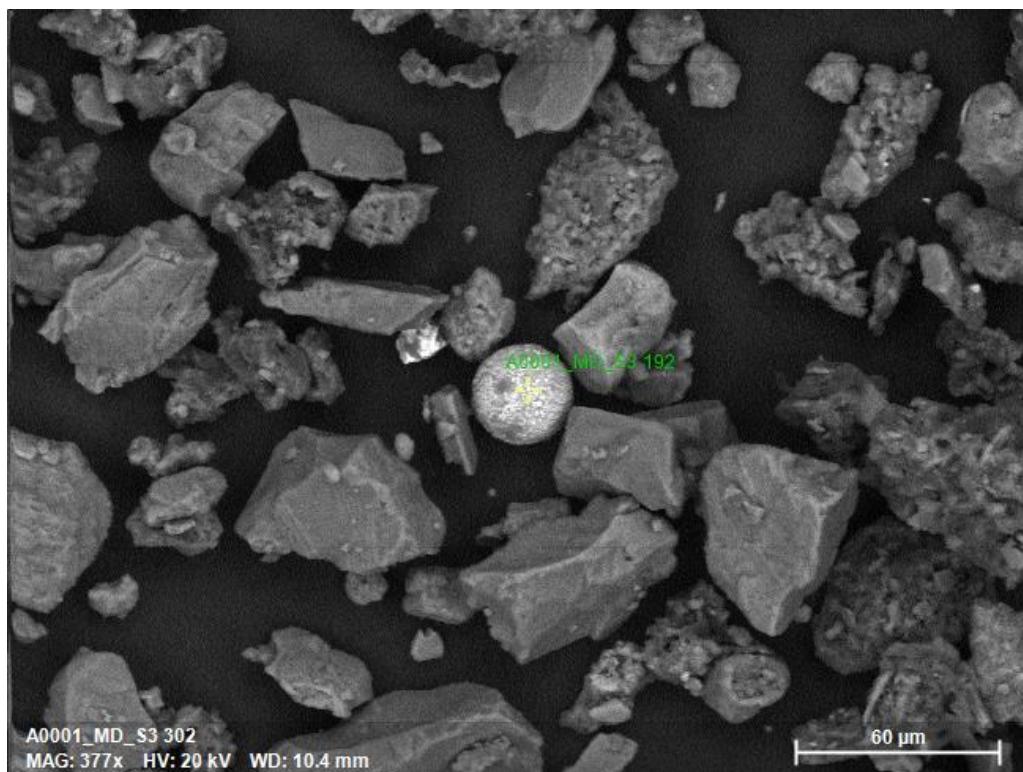
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Fig. S9: EDS spot analysis of House 1: Yard[4].
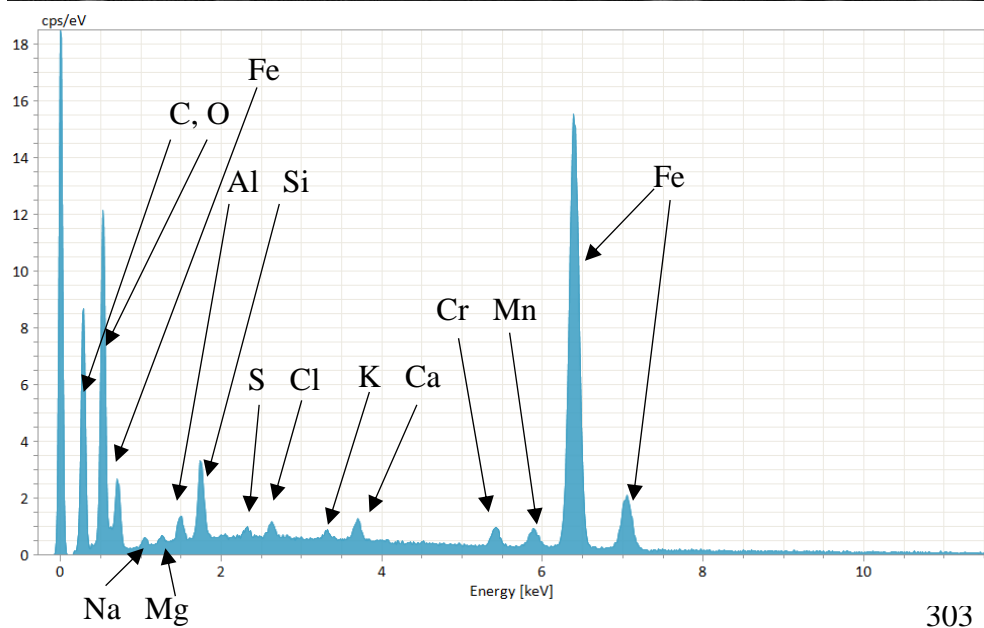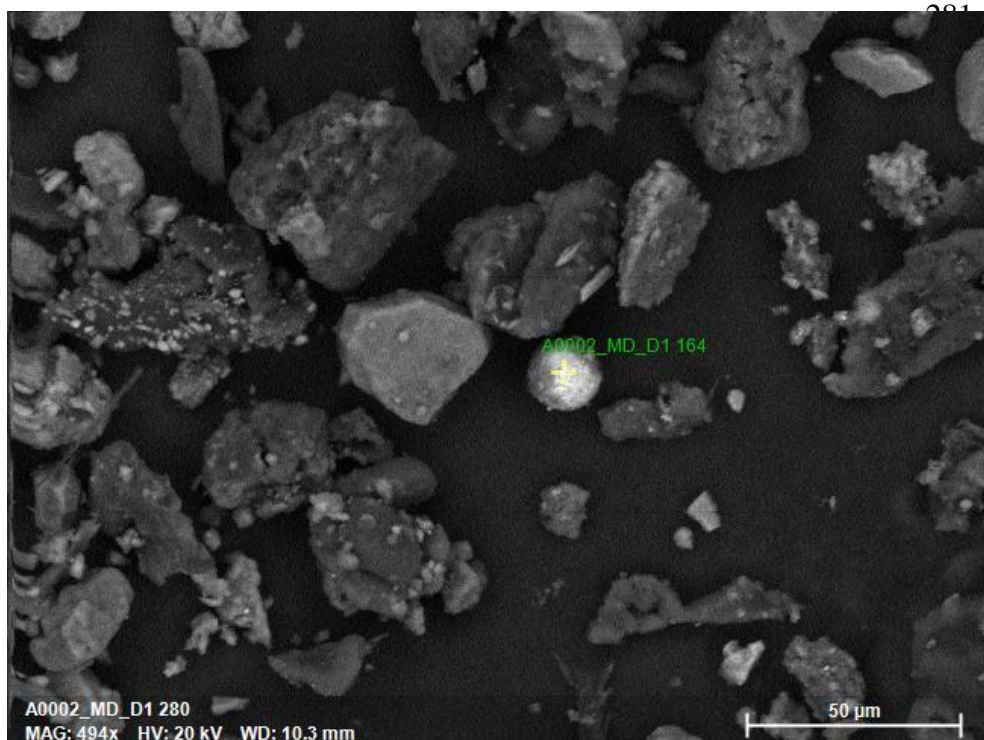
Fig. S10: EDS spot analysis of House 2: Indoor Dust[5].

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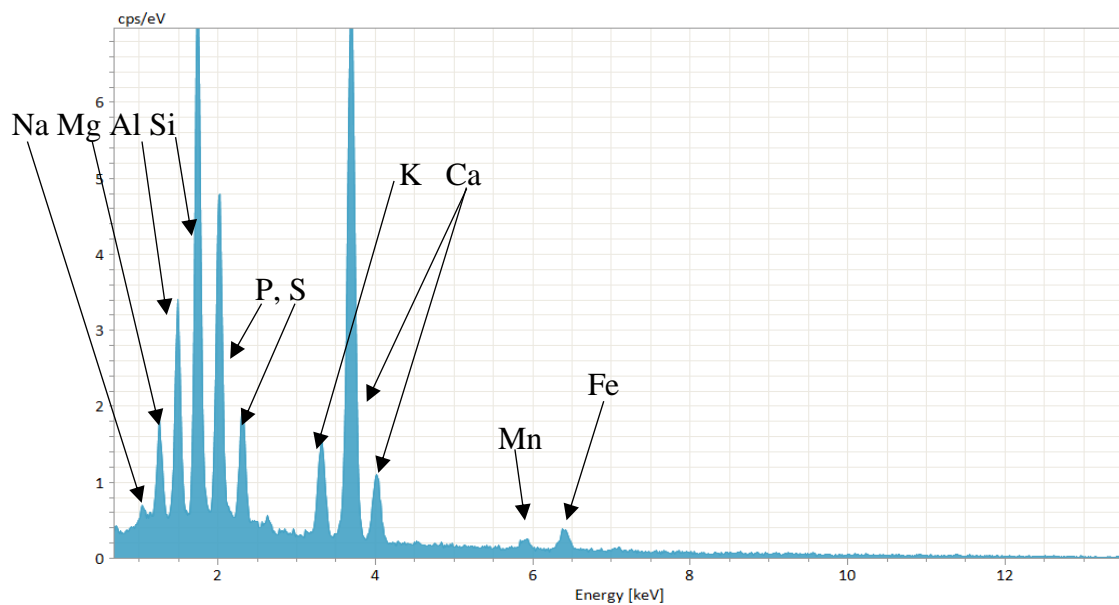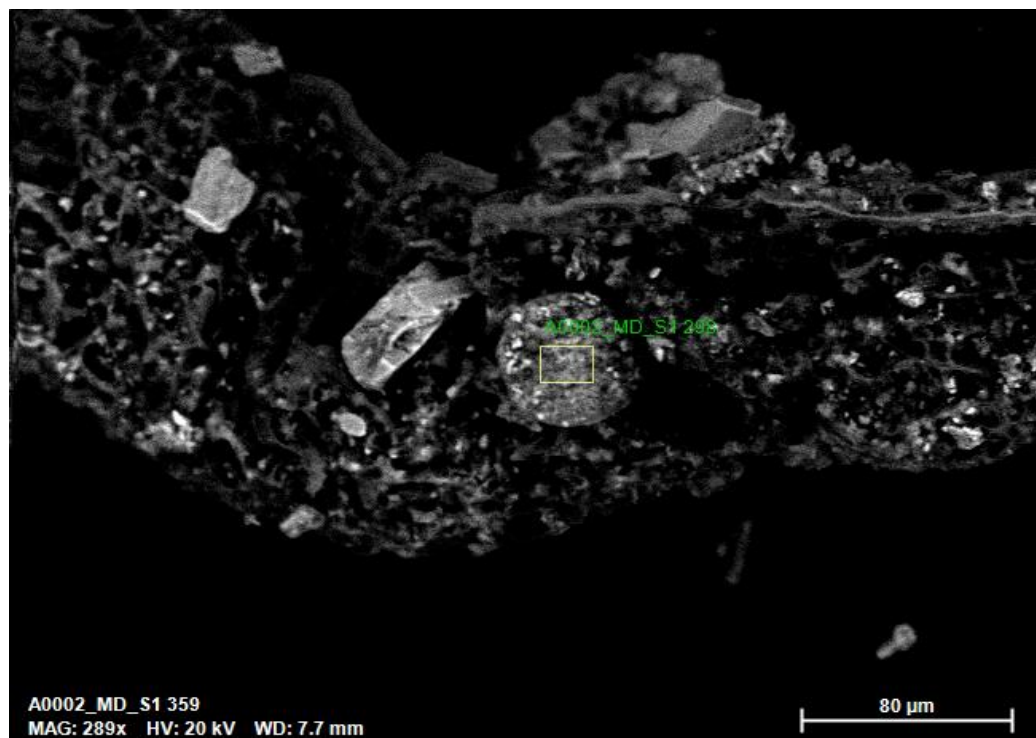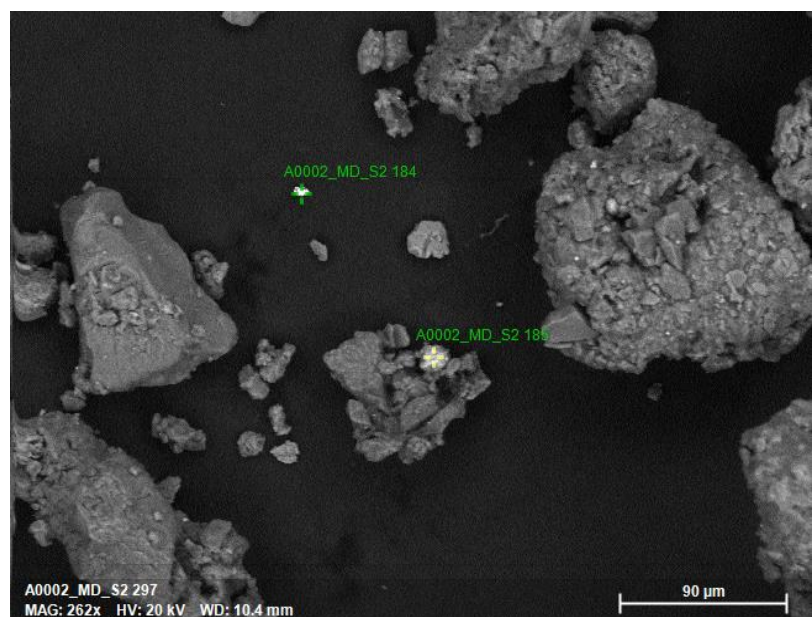

334   **Fig. S11:** EDS spot analysis of House 2: Dripline[6].

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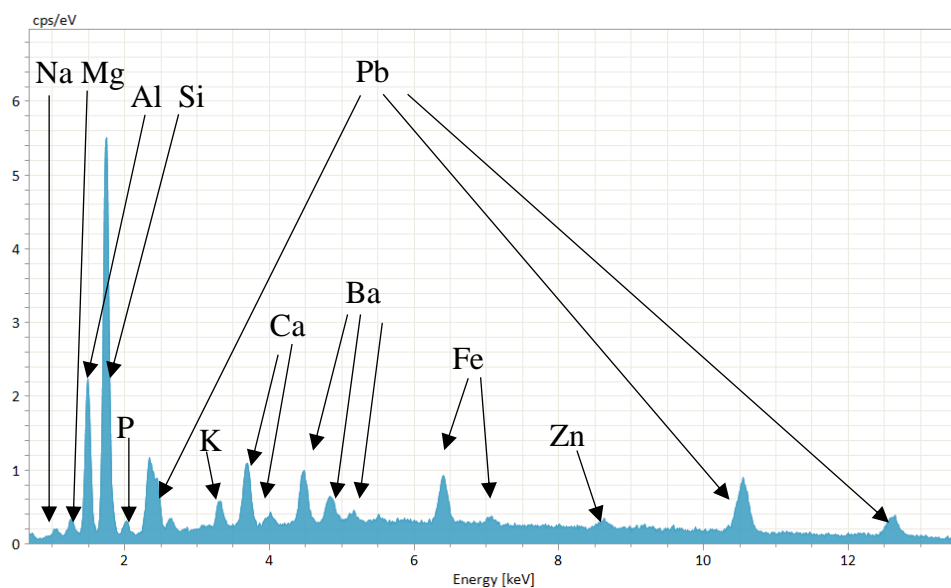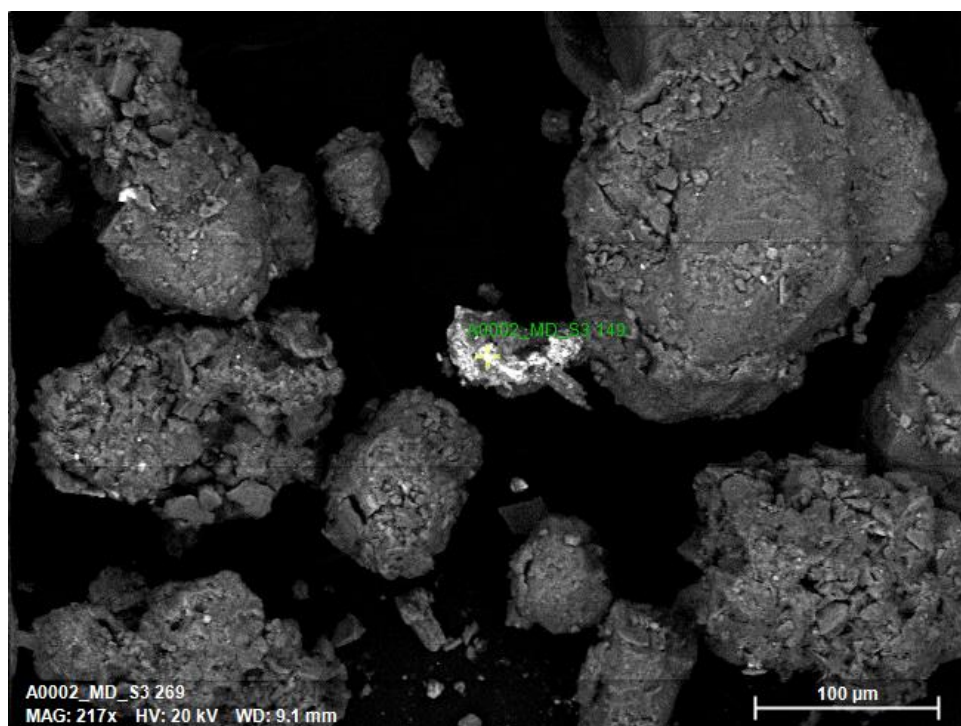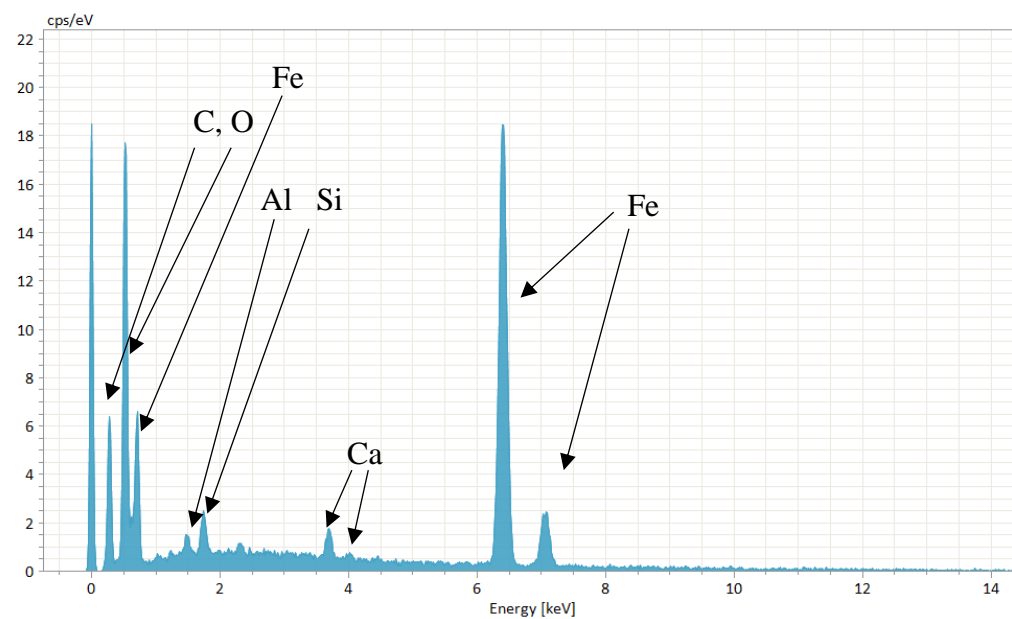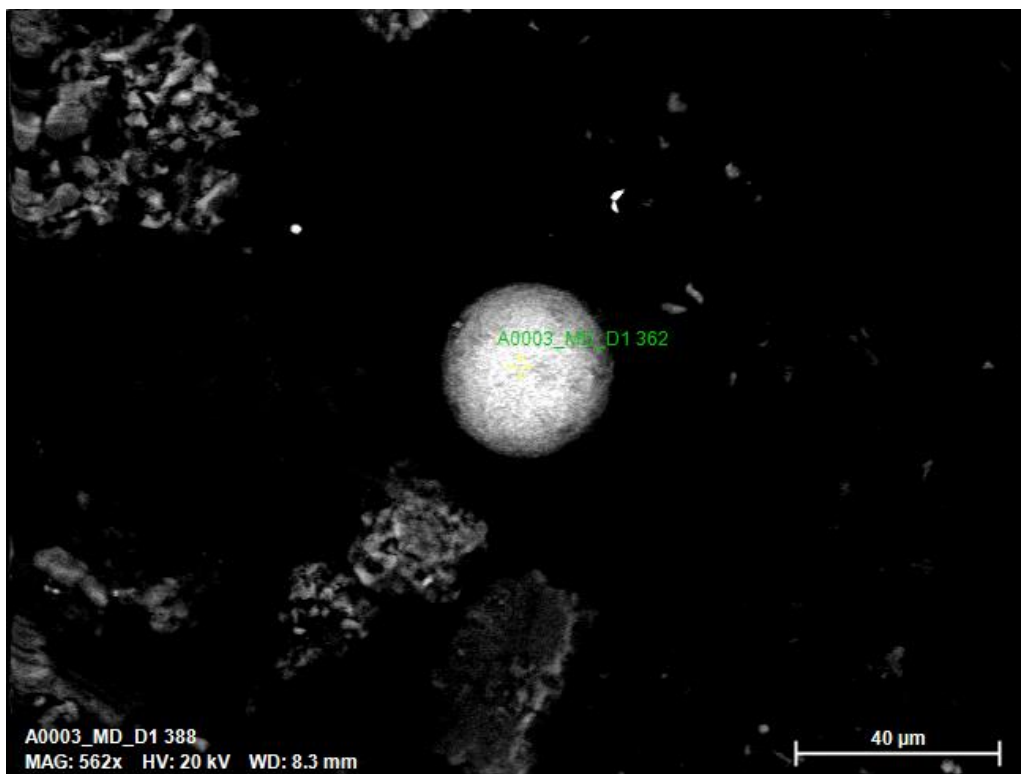**Fig. S12:** EDS spot analyses of House 2: Streetside[7].

Fig. S13: EDS spot analysis of House 2: Yard[8].

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416   **Fig. S14:** EDS spot analysis of House 3: Indoor Dust[9].

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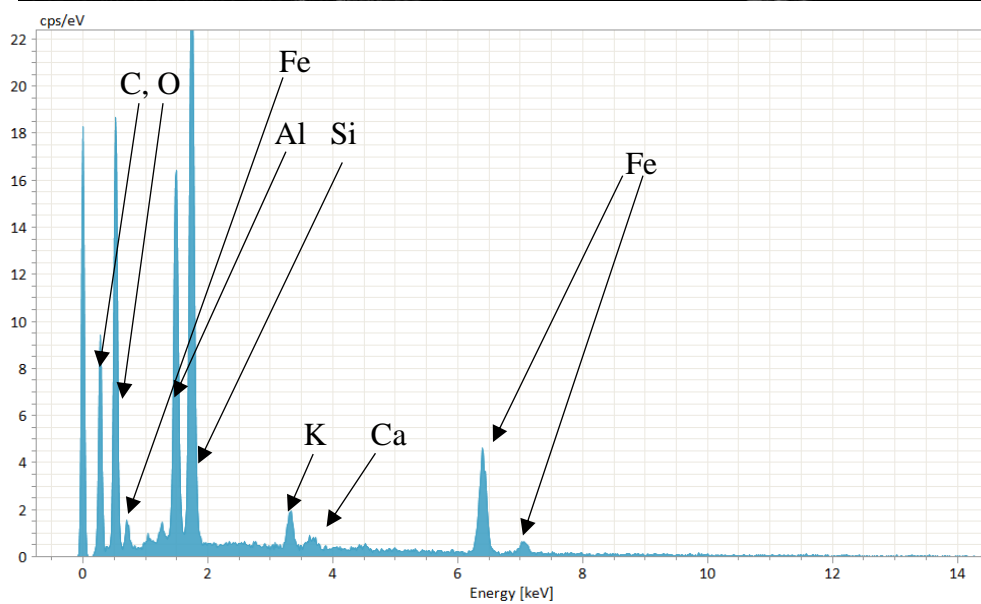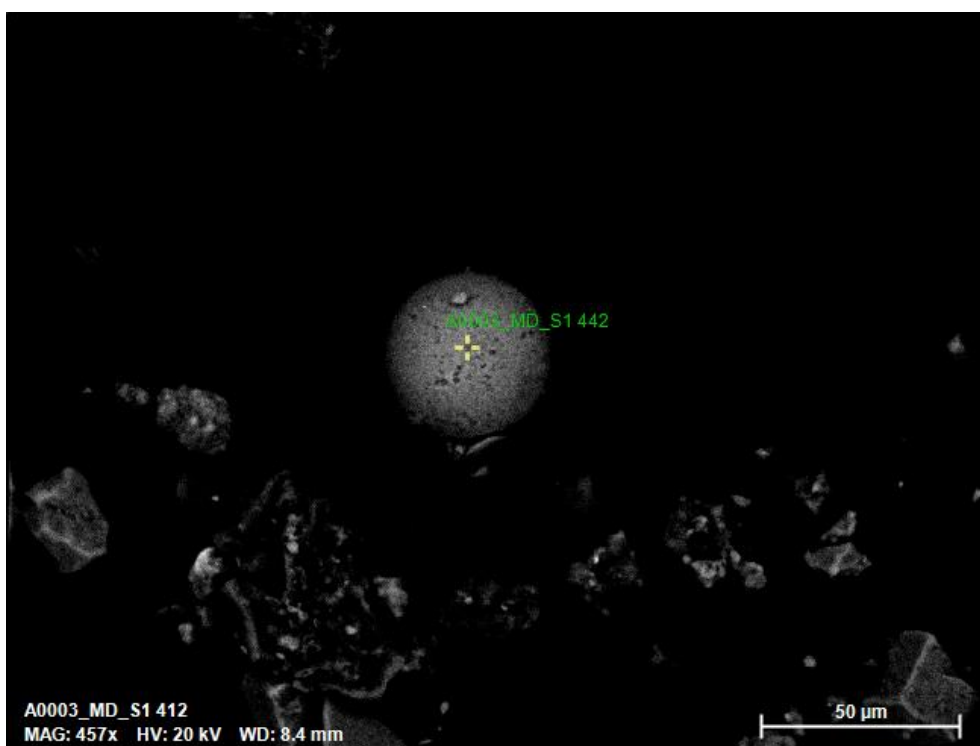433
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442 **Fig. S15:** EDS spot analysis of House 3: Dripline[10].
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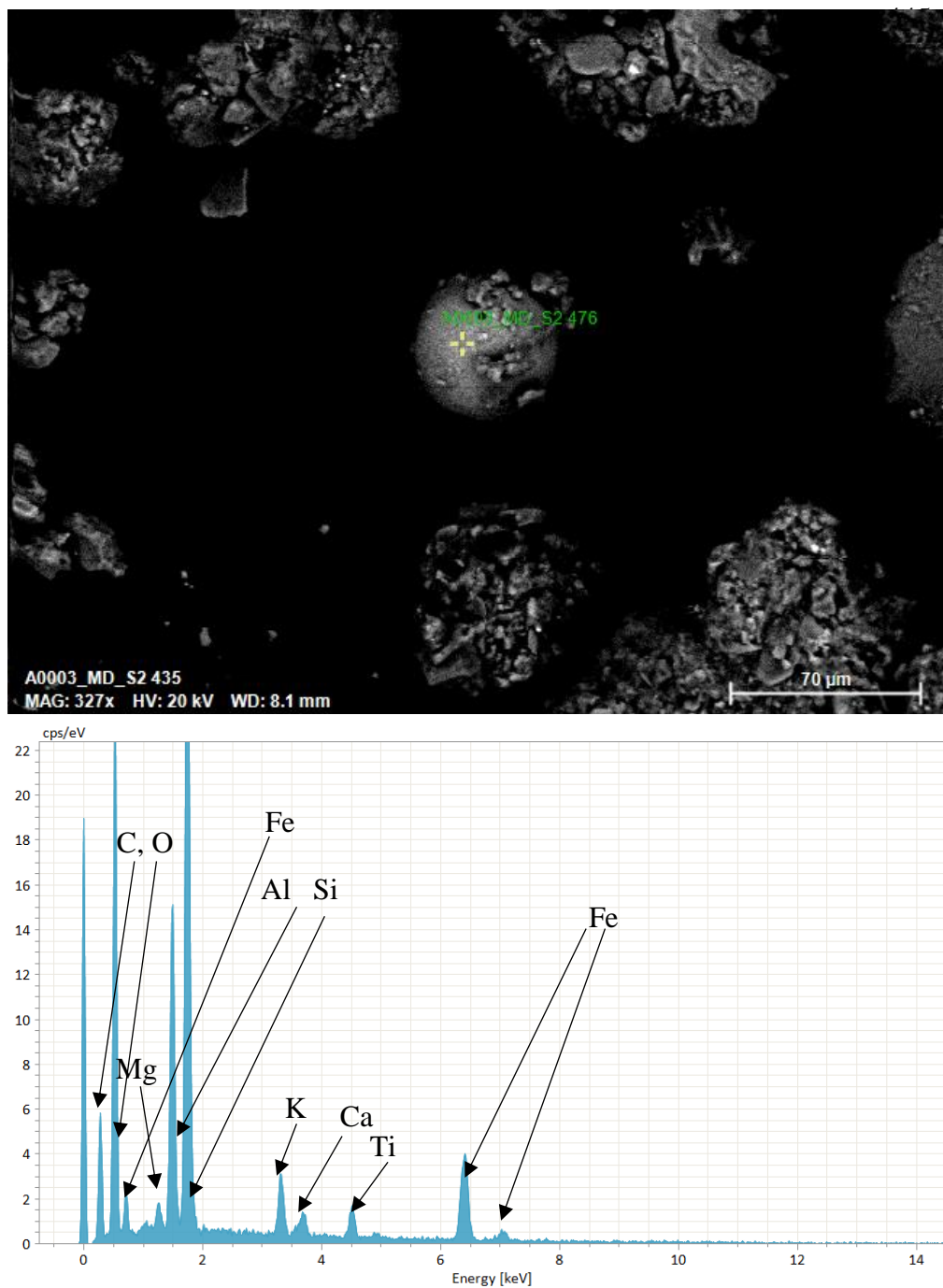
468   **Fig. S16:** EDS spot analysis of House 3: Streetside[11].

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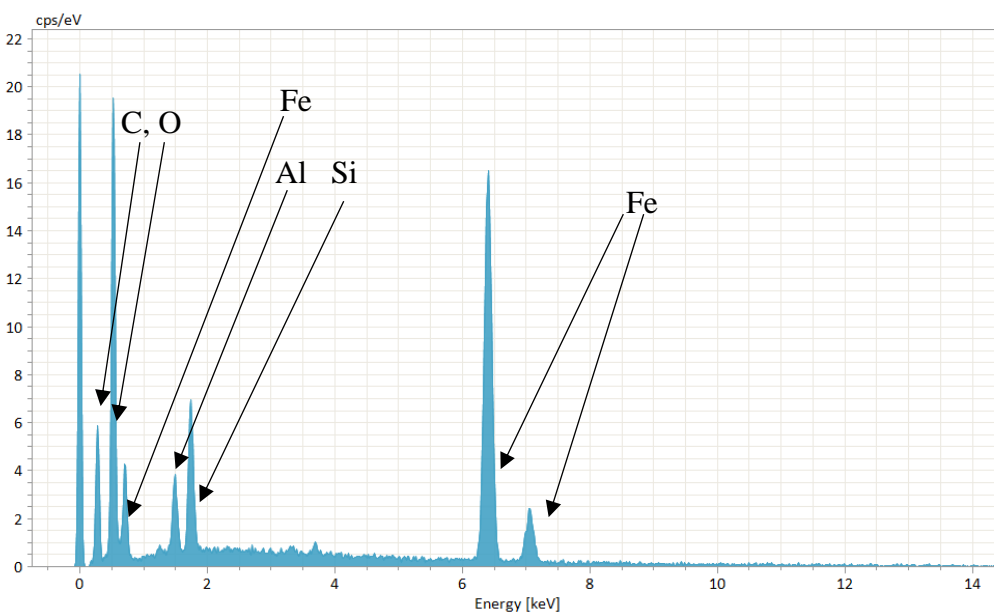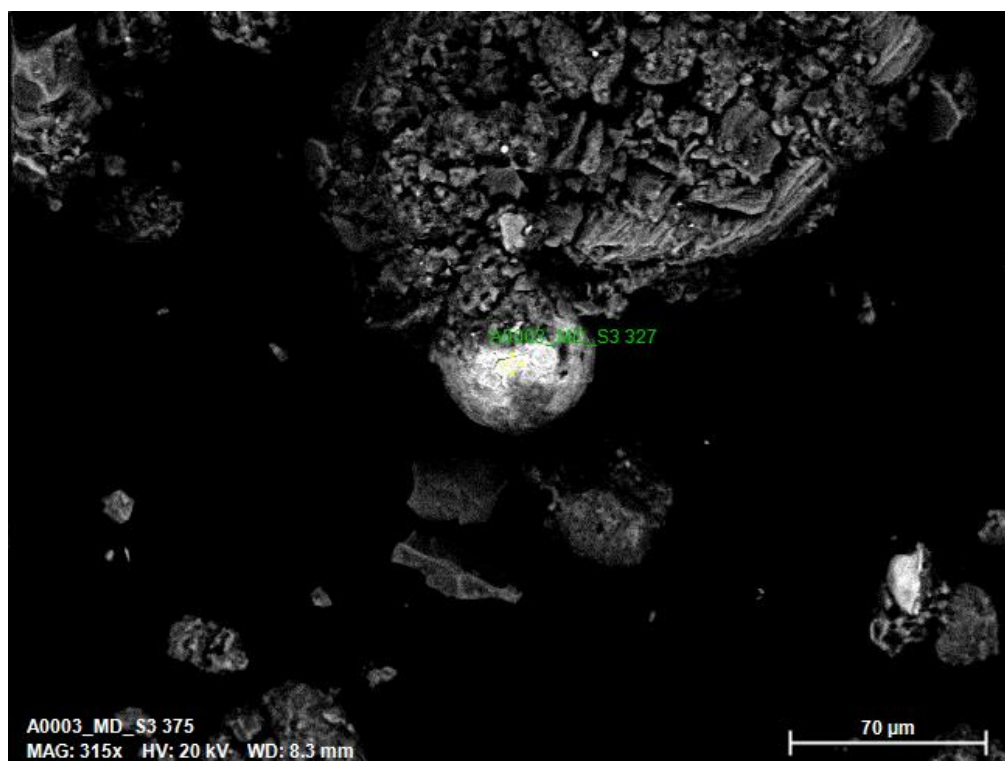
Fig. S17: EDS spot analysis of House 3: Yard[12].
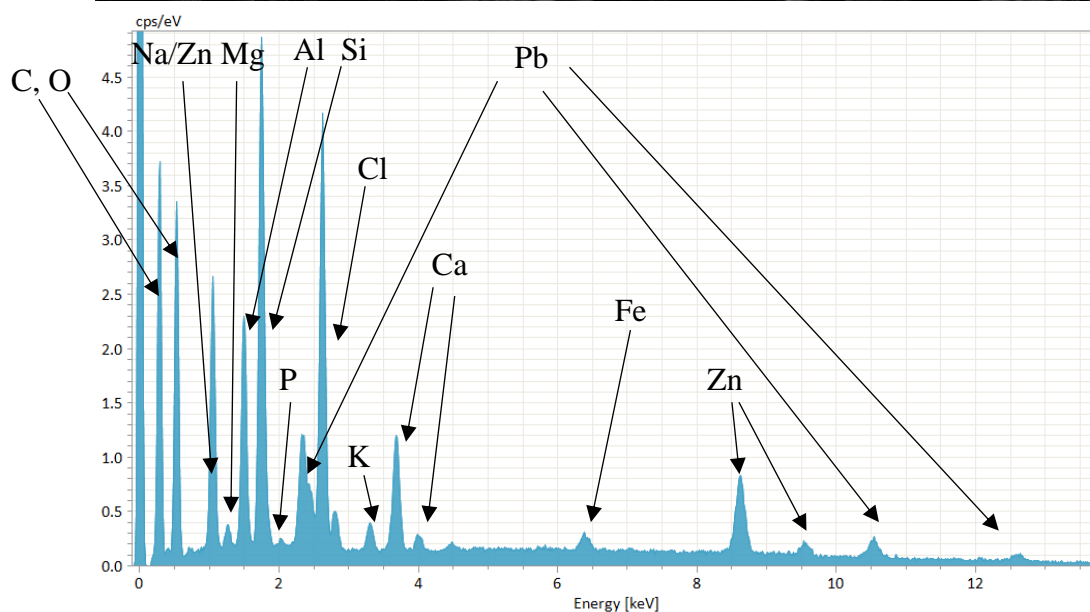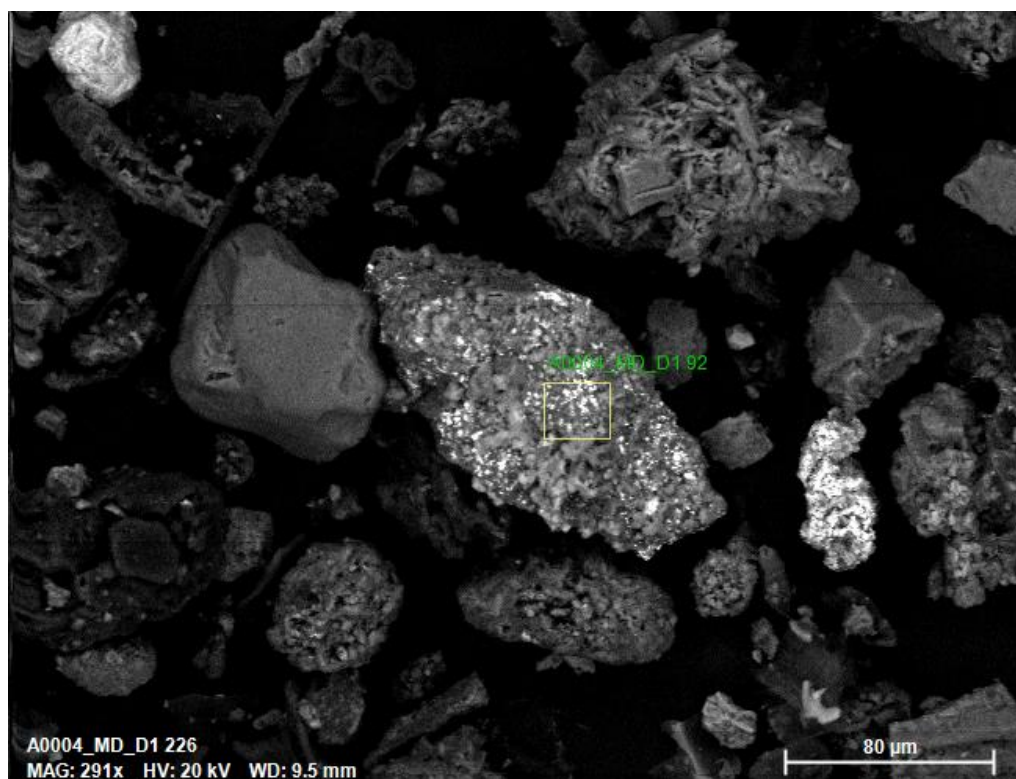
Fig. S18: EDS spot analysis of House 4: Indoor Dust[13].
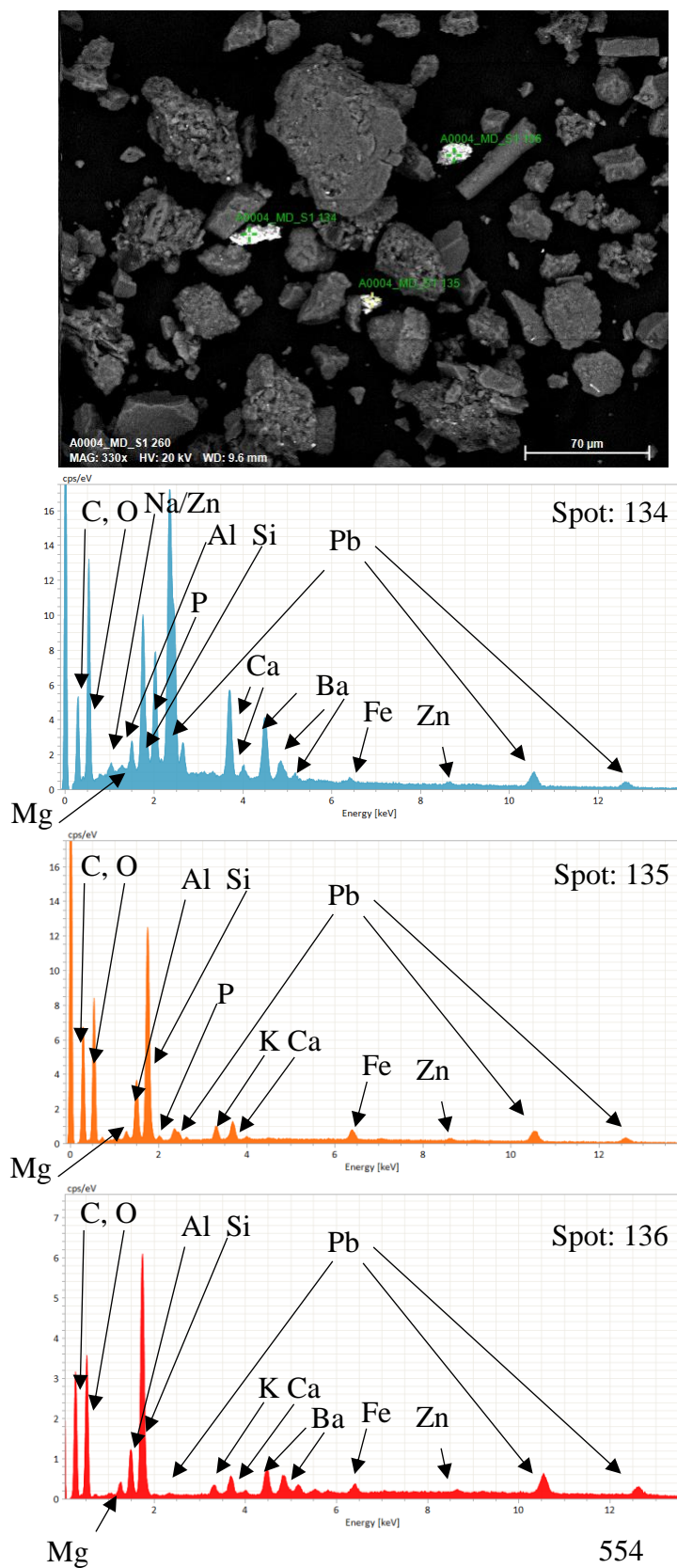
Fig. S19: EDS spot analyses of House 4: Dripline[14]. Spot 134 appears likely to be Pb-dominated paint, while Spots 135 and 136 contain much less of an initial Pb peak, indicative of possible X-ray shadowing due to an uneven spot surface. The general compositional similarity between the particles is indicative of Pb paint with slightly different elemental composition, possibly from different paint layers.

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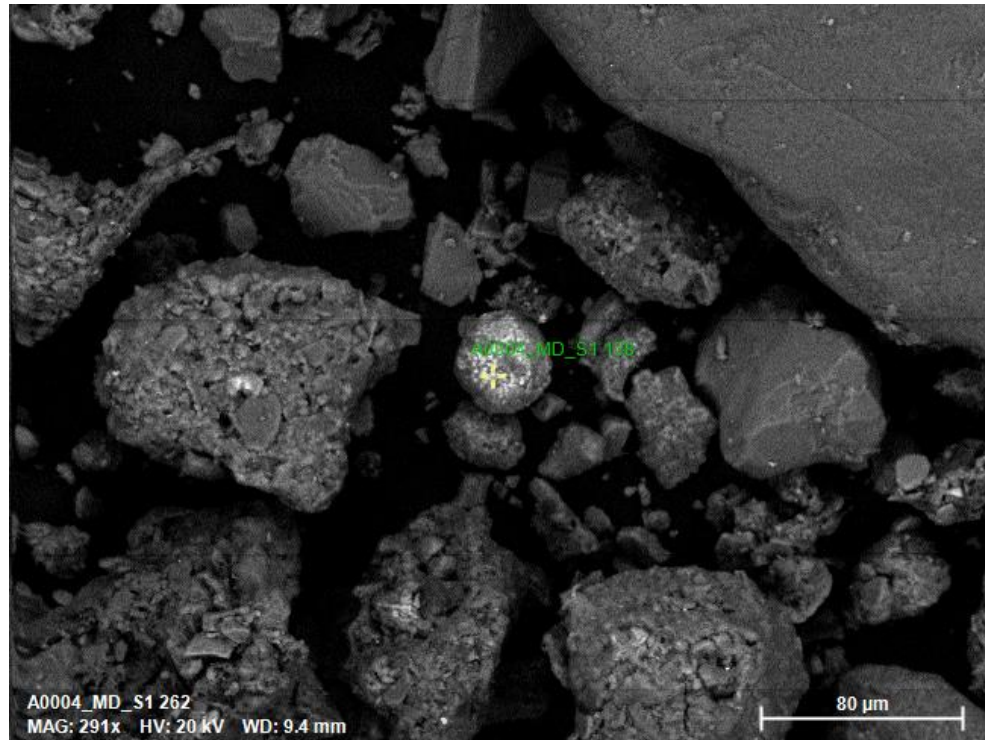
Fig. S20: EDS spot analysis of House 4: Dripline[15].

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610 **Fig. S21:** EDS spot analyses of House 4: Streetside[16].

Supplementary Tables

612 **Table S1:** Bulk metal concentrations (mg/kg) and % recovery relative to certified values for five
613 subsamples of NIST SRM 2702 – Inorganics in Marine Sediment.

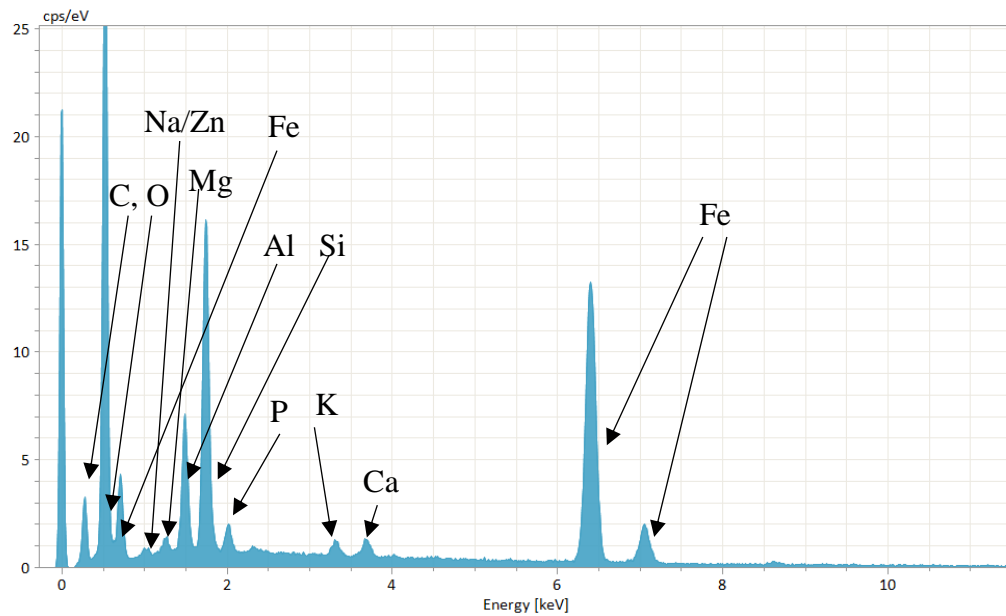|	Cd	Sb	Tl	Pb
Limits of Detection (LOD) (ppb)	0.02	0.03	0.004	0.02
NIST_2702_1	0.67	5.42	0.73	126.20
NIST_2702_2	0.71	5.08	0.76	130.76
NIST_2702_3	0.64	6.23	0.75	127.61
NIST_2702_4	0.66	6.70	0.80	113.82
NIST_2702_5	0.61	6.26	0.77	95.27
Certified Values (mg/kg)	0.817	5.6	0.8267	132.8
% Recoveries	81.51	96.74	87.82	95.03
	87.25	90.64	92.12	98.47
	78.05	111.34	91.06	96.09
	80.78	119.57	96.87	85.71
	74.16	111.73	92.86	71.74
Avg % Recovery	80.35	106.00	92.14	89.41
Std Dev % Recovery	4.82	11.91	3.27	11.00

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615 **Table S2:** Pb isotopic ratios for NIST SRM 2702 following sample prep that was the same as
616 soil/dust samples, and Pb isotopic ratios for AGV-2a following standard clean lab protocol, with
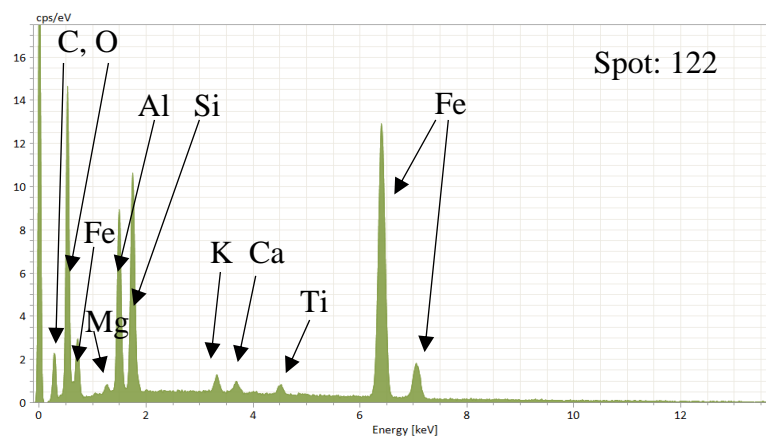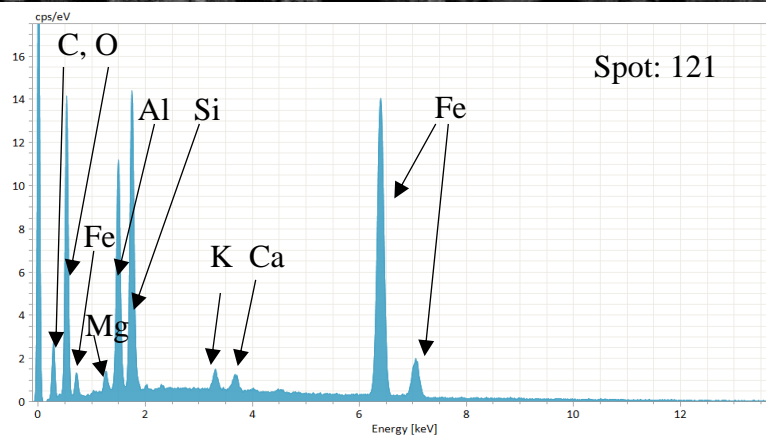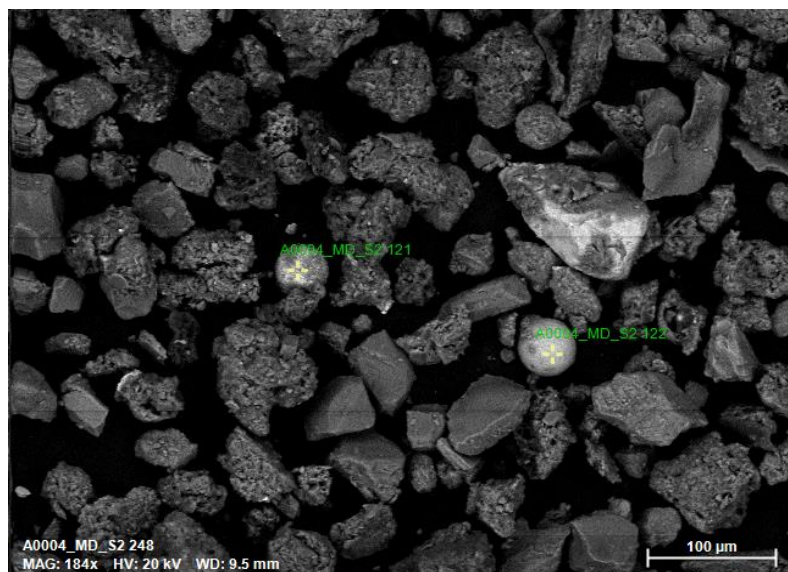617 the given USGS values. 2σ overall analytical error for all analyses is also provided (based on the
618 reproducibility of NIST SRM 981 over the course of the analytical session).

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Reference Standard		*208/206*	*207/206*	*208/207*	*206/204*	*207/204*	*208/204*
	981 2σ external error	0.0001	0.0000	0.0001	0.0014	0.0014	0.0044
	external error (%)	0.005%	0.002%	0.003%	0.008%	0.009%	0.012%
NIST_2702_1		2.05574	0.83455	2.46329	18.77388	15.66794	38.59431
NIST_2702_2		2.05504	0.83421	2.46344	18.78221	15.66851	38.59835
NIST_2702_3		2.05595	0.83479	2.46282	18.76686	15.66631	38.58354
NIST_2702_4		2.05620	0.83479	2.46314	18.76782	15.66712	38.59037
NIST_2702_5		2.05561	0.83441	2.46355	18.77909	15.66944	38.60262
NIST_2702 Std dev		0.00044	0.00025	0.00029	0.00675	0.00121	0.00734

AGV-2a	*2.04293*	*0.82777*	*2.46799*	*18.86955*	*15.61955*	*38.54962*
AGV-2a USGS values				18.864	15.609	38.511
2σ external error				0.007	0.006	0.020
AGV-2a published range	*2.0413 - 2.049*	*0.8271 - 0.8295*		*18.851 - 18.889*	*15.609 - 15.639*	*38.511 - 38.7127*

620

621 **Table S3:** Bulk metal concentrations for soil and dust samples in mg/kg, as well as assigned
622 house number and sample location.

Sample	Cd	Sb	Tl	Pb	*House*	*Sample Location*
A0001_MD_D1	1.09	37.60	0.05	104.14	House 1	Dust
A0001_MD_S1	1.32	1.04	0.71	73.05	House 1	Dripline
A0001_MD_S2	1.21	1.50	0.39	103.77	House 1	Street
A0001_MD_S3	1.25	2.42	0.65	127.69	House 1	Yard
A0002_MD_D1	1.12	2.92	0.19	242.47	House 2	Dust
A0002_MD_S1	0.23	0.04	0.03	4.10	House 2	Dripline
A0002_MD_S2	2.09	2.48	0.39	1823.68	House 2	Street
A0002_MD_S3	4.89	3.59	1.03	2098.49	House 2	Yard
A0003_MD_D1	0.61	5.05	0.15	77.61	House 3	Dust
A0003_MD_S1	0.45	0.78	0.21	96.41	House 3	Dripline
A0003_MD_S2	0.92	1.59	0.47	332.93	House 3	Street
A0003_MD_S3	0.90	1.81	0.60	223.74	House 3	Yard
A0004_MD_D1	3.34	1.74	0.25	878.37	House 4	Dust
A0004_MD_S1	2.83	5.17	0.59	1152.48	House 4	Dripline
A0004_MD_S2	1.40	1.30	0.64	347.80	House 4	Street
A0004_MD_S3	0.37	0.90	0.45	70.33	House 4	Yard

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624 **Table S4:** Pb isotope ratios for soil and dust samples.

Samples	*208/206*	*207/206*	*208/207*	*206/204*	*207/204*	*208/204*
A0001_MD_D1	2.081	0.845	2.463	18.510	15.640	38.521
A0001_MD_S1	2.033	0.826	2.462	18.963	15.659	38.558
A0001_MD_S2	2.010	0.810	2.483	19.404	15.708	39.011
A0001_MD_S3	2.012	0.811	2.480	19.360	15.702	38.944
A0002_MD_D1	2.008	0.808	2.486	19.453	15.714	39.063
A0002_MD_S1	2.001	0.807	2.479	19.458	15.706	38.934
A0002_MD_S2	2.012	0.810	2.483	19.387	15.710	39.006
A0002_MD_S3	2.010	0.808	2.487	19.453	15.719	39.096
A0003_MD_D1	2.065	0.841	2.456	18.599	15.639	38.402
A0003_MD_S1	2.061	0.836	2.465	18.710	15.638	38.554

A0003_MD_S2	2.095	0.865	2.421	18.019	15.592	37.741
A0003_MD_S3	2.054	0.832	2.469	18.812	15.648	38.636
A0004_MD_D1	2.033	0.818	2.486	19.190	15.692	39.017
A0004_MD_S1	2.004	0.802	2.500	19.615	15.727	39.310
A0004_MD_S2	2.019	0.815	2.477	19.261	15.696	38.882
A0004_MD_S3	2.017	0.812	2.483	19.320	15.696	38.976

625

626 **Table S5:** Relative distance between the adjacent main road and front of the household property
627 to the nearest meter, determined via the Google Maps "Measure distance" tool, oldest annual
628 average daily traffic (AADT) data available for the closest major street to the household from the
629 Indiana Department of Transportation* (oldest available data was used to try and match
630 historical traffic flow when leaded gasoline was prominent, although it is noted there is a large
631 disconnect of over 20-30 years from leaded gasoline usage and reported traffic data), and
632 potential industrial sources of pollution with distance determined via the Google Earth
633 measurement tool.

Sample	House	Distance from road to home (meters)	AADT	Potential industrial sources of pollution (distance in km)
A0001_MD	1	14	12,772[1]	Indianapolis Motor Speedway (2.4 km), lumber facility (1.3 km)
A0002_MD	2	8	2,339[2]	Indiana state fairgrounds (1.8 km), former American Lead facility (2.4 km), fabricated metals facility (1.7 km)

25

A0003_MD	3	7	21,979[3]	Industrial Park: Oils/solvents, automobile parts, construction company, storage units, pallets (<1 km)
A0004_MD	4	8	2,203[4]	Fabricated metals facility (1.7 km), Indianapolis Motor Speedway (3.6 km)

634 [1]W. 30th Street, 2013.

635 [2]N. Washington Blvd, 2013.

636 [3]S. Harding Street, 2016.

637 [4]N. Harding St., 2013.

638 *Traffic Count Database System (TCDS) (ms2soft.com)

639

640 **Supplementary References**

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