Arch. Environ. Contam. Toxicol. 21, 65–71 (1991)

Archives of Environmental Contamination and Toxicology

Lead Exposure from Conventional and Cottage Lead Smelting in Jamaica[1]

Thomas D. Matte*, J. Peter Figueroa**, Stephanie Ostrowski***, Gregory Burr†, Linnette Jackson-Hunt††, and Edward L. Baker†††

*Office of the Director, National Institute for Occupational Safety and Health, Centers for Disease Control, Atlanta, Georgia, USA; present address: Lead Poisoning Prevention Branch, Mailstop F28, Center for Environmental Health and Injury Control, Centers for Disease Control, Atlanta, Georgia 30333, USA; **Epidemiology Unit, Ministry of Health, Jamaica; ***Division of Environmental Hazards and Health Effects, Center for Environmental Health and Injury Control, Centers for Disease Control, †Division of Surveillance, Hazard Evaluations and Field Studies, National Institute for Occupational Safety and Health, Centers for Disease Control, Cincinnati, Ohio, USA; ††Emory University Master of Public Health Program, Atlanta, Georgia, USA and †††Public Health Practice Program Office, Centers for Disease Control, Atlanta, Georgia, USA

Abstract. A survey was conducted to determine the distribution and determinants of environmental and blood lead levels near a conventional and several cottage lead smelters and to assess the relationship between environmental and blood lead levels in a tropical, developing-country setting. Fifty-eight households were studied in the Red Pond community, the site of the established smelter and several backyard smelters, and 21 households were studied in the adjacent, upwind Ebony Vale community in Saint Catherine Parish, Jamaica. Households were investigated, using questionnaires, soil and housedust lead measurements, and blood lead (PbB) measurements from 372 residents. Soil lead levels in Red Pond exceeded 500 parts per million (ppm) at 24% of households (maximum—18,600 ppm), compared to 0% in Ebony Vale (maximum 150 ppm). Geometric mean PbB in Red Pond, where 44% of children <6 years of age had PbB levels ≥ 25 micrograms per deciliter (μg/dL), was more than twice that Ebony Vale in all age groups ($p < 0.0005$). Within Red Pond, proximity to backyard smelters and to the conventional smelter were independent predictors of soil lead ($p < 0.05$). Soil lead was the strongest predictor of PbB among Red Pond subjects under 12 years of age. The blood lead—soil lead relationship in children differed from that reported in developed countries; blood lead levels were higher than expected for the household-specific soil lead levels that were observed. These data indicate that cottage lead smelters, like conventional ones, are a hazard for nearby residents and that children exposed to lead contamination in tropical, developing countries may be at higher risk for developing elevated blood lead levels than similarly-exposed children in developed countries.

[1] The results of this investigation were presented at the APHA annual meeting in Boston, MA, November, 1988.

Lead poisoning associated with conventional lead smelting in developed countries has been described among both workers (Lilis *et al.* 1977) and community residents (Popovac *et al.* 1982; Landrigan *et al.* 1975; Brunekreef *et al.* 1981). While airborne lead fume from smelters is the main vehicle of environmental contamination, the most important route of community lead exposure in such settings appears to be ingestion of lead-contaminated soil and housedust, especially by children (Roels *et al.* 1980). Children of smelter workers may be at particularly high risk from exposure to lead dust brought home on work clothes (Morton *et al.* 1982; Baker *et al.* 1977).

Workers and their families may also be at risk of lead poisoning when lead-related work is done at home. Lead-related cottage industries have caused lead poisoning in both developed (Kawai *et al.* 1983) and in less developed countries (Koplan *et al.* 1977), where cottage industries are relatively prevalent (Phoon 1982). Cases of lead-poisoning associated with lead smelting near the home have been reported previously (Dolcourt *et al.* 1981). However, such establishments are typically scattered and we are aware of no systematic study of lead exposure from cottage lead smelting.

The relationship between environmental lead contamination and blood lead levels in children has been extensively studied (Duggan and Inskip 1985), and data from such studies have been used to propose "maximum permissible levels" of lead in soil (Madhavan *et al.* 1989). However, nearly all previous studies have been carried out in developed countries with temperate climates. Because unintentional soil and dust ingestion may be related to hygiene and to time spent outdoors (Duggan and Inskip 1985), and because lead absorption is influenced by nutrition (Mahaffey 1982), one might expect soil lead-blood lead relationships to differ in tropical, developing countries.

Cottage lead smelters are scattered throughout Jamaica. The clustering of several of these so-called "backyard" lead smelters in a community near a conventional, secondary lead smelter provided the opportunity to assess, during a cross-sectional survey conducted in October 1987, the amount of environmental contamination associated with both cottage and conventional smelting in the same community. In addition, the relationshp between environmental contamination and blood lead levels in a tropical, developing country was examined.

Methods

Study Site and Population

The conventional lead smelter ("established smelter") has operated at the southeast corner of the Red Pond Road community (estimated population 2500) since 1963, reclaiming lead from spent car batteries. The smelter, which usually operated for about two weeks out of every two month period, did not operate during the several weeks before or during the survey. Several crude backyard lead smelters are also known to operate in this relatively poor community, and some residents have reportedly used lead oxide-containing drums and dross (slag) from the established smelter grounds for fencing and landfill material. A middle-class housing development, known as Ebony Vale (estimated population 1600), was recently completed just east of the conventional smelter. Prevailing winds in the area come from the northeast. Lead poisoning cases have been recognized in Red Pond but not in Ebony Vale.

Potential study households were sampled within Red Pond and Ebony Vale by numbering dwellings on community survey maps and selecting dwellings according to a generated list of random numbers. Households with children less than six years of age were over-sampled in Ebony Vale to increase the precision of the mean blood lead estimate in that age group. Survey procedures were completed at 49 Red Pond households (86% of those sampled) and 21 Ebony Vale households (68% of those sampled). Of households sampled but not surveyed, three refused participation (one in Red Pond, two in Ebony Vale) and no adults were at home at 15 households. In addition, all nine households in Red Pond reported by established smelter employees to be at, or adjacent to, backyard smelter sites ("possible backyard smelter" households) were surveyed.

Blood lead measurement was offered for all residents of surveyed households who were at least six months of age. All participating subjects or their adult guardians provided informed consent. Most non-participants were not at home when the dwelling was surveyed. The results of household and subject selection are summarized in Table 1.

Table 1. Household and subject selection, community lead survey, Saint Catherine Parish, Jamaica, October 1987

	Community		
	Red Pond		Ebony Vale
Selection criteria	Possible backyard smelter	Random sample	Random sample
Households			
No. participating (% of those sampled)	9 (100)	49 (86)	21 (68)
Mean household size	5.3	7.6	4.4
Mean household income (US $/week)	32	42	93
Subjects tested for blood lead (% of eligible subjects in participating households)			
By Age:			
6 months–5 years	8 (100)	57 (93)	16 (84)
6–11 years	9 (90)	53 (88)	14 (82)
≥12 years	20 (69)	157 (64)	38 (67)

Data Collected

At each participating household, a responsible adult was interviewed. Information collected included household income, whether there had been smelting or use of lead oxide drums or lead dross in a yard, and demographic information on household members. Depending on the age of household members, information about occupation, smoking, pica, and time unattended by an adult was also collected.

At each household a one centimeter deep core soil sample in the approximate center of the yard was collected. Lead (Pb) levels in such samples will be referred to as "Pb soil-area". Soil was also sampled near potential sources of lead contamination, such as oxide drum fencing or lead scrap. The highest soil lead found in each yard will be referred to as "Pb soil-peak". Dust samples were collected, using a published procedure (Vostal *et al.* 1974), from the center of the floor in the room where children spend the most time. Area soil samples were lost or omitted for five households (four in Red Pond and one in Ebony Vale) and dust samples were lost or omitted at four households (three in Red Pond and one in Ebony Vale). Scrapings of housepaint were taken at households where peeling paint was observed. Blood samples were obtained by venipuncture.

Lead levels in whole blood (Searle *et al.* 1973) and environmental samples (National Institute for Occupational Safety and Health 1984) were measured by published procedures. The limits of quantitation (LOQ) were 5 micrograms per deciliter (μg/dL) for blood lead (PbB), 5 parts per million (ppm or μg/g) for soil lead, 24 μg per square meter (μg/m^2) for dust lead (PbD), and 0.01% for paint lead. Samples with lead below the LOQ were assigned a value midway between zero and the LOQ for data analysis.

Data Analysis

Continuous variables were transformed to correct skewness in distributions and apparent non-linear relationships between variables. T-tests and ordinary least squares regression were used to analyze environmental lead data. Blood lead data were analyzed by statistical programs (Shah 1981; Holt 1982) that employ a Taylor series approximation to compute standard errors of estimated means and regression coefficients using households (rather than individuals) as sampling units. Separate analyses were conducted for three age groups: six months through five years (pre-school children), six through 11 years (school-aged children), and 12 years and older ("adult", *i.e.*, beyond the age of compulsory schooling). Multivariate models were arrived at by backwards selection, eliminating the predictors that were least statistically significant by partial F tests until only those significant at the $p < 0.05$ level remained (Kleinbaum and Kupper 1978).

Table 2. Environmental and blood lead levels at survey households

Measurement		Red Pond: Possible backyard smelter	Red Pond: Random sample	Ebony Vale: Random sample
Pb soil-area (ppm)	GM[c]	1089*	133***	6
	% ≥500 ppm	75[a]	24[b]	0[a]
	Range	9–31,000	<5–18,600	<5–150
Pb soil-peak (ppm)	GM	7691**	221***	7
	% ≥500 ppm	89	27	0
	Range	9–320,000	<5–520,000	<5–150
Pb dust (μg/m²)	GM	2790*	690***	100
	% ≥1500 μg/m²	56	24[b]	0[a]
	Range	100–109,180	50–294,680	20–338
Blood Pb (μg/dl), by age				
≤5 years	GM	25[NS]	21***	9
	% ≥25 μg/dL	50	44	0
	Range	<5–94	5–98	<5–19
6–11 years	GM	62***	17***	7
	% ≥25 μg/dL	100	40	7
	Range	35–139	<5–95	<5–25
≥12 years	GM	28*	12***	5
	% ≥25 μg/dL	60	17	3
	Range	<5–90	<5–85	<5–27

[a] Missing for 1 household
[b] Missing for 3 households
[c] GM = geometric mean
P values for differences in geometric means, possible backyard smelter compared with randomly-selected Red Pond households and randomly-selected Red Pond households compared with Ebony Vale households: *$p < 0.05$, **$p < 0.005$, ***$p < 0.0005$, NS = not significant.

Results

Environmental and Blood Lead Levels

Geometric mean Pb soil-area, Pb soil-peak, and Pb dust were 22, 31, and 7 times, respectively, higher in Red Pond than Ebony Vale ($p < 0.0005$, Table 2). Furthermore, 24% of randomly selected Red Pond households had soil lead levels greater than 500 ppm, a threshold above which elevated blood lead levels in children are said to occur (Centers for Disease Control 1985). In contrast, the highest soil lead level in Ebony Vale was 150 ppm, and 14 Ebony Vale households had Pb soil-area levels below 5 ppm. Geometric mean Pb soil-peak was 30 times higher at possible backyard smelter households than at other Red Pond households ($p < 0.005$), and four possible backyard smelter households had Pb soil-peak levels greater than 50,000 ppm. Peeling housepaint was observed at one Ebony Vale and 27 Red Pond households. Ten samples exceeded 1% lead by weight (maximum 6.0%), all from Red Pond.

Among subjects of randomly-selected households, geometric mean PbB was significantly higher in Red Pond than Ebony Vale in each age group ($p < 0.0005$, Table 2), and decreased with age in both communities. Elevated PbB (≥25 μg/dL (Centers for Disease Control 1985)) levels were common in Red Pond (44% of children under six years) but unusual in Ebony Vale. The prevalence of elevated PbB was higher among subjects at possible backyard smelter households than at randomly-selected Red Pond households, and the geometric mean PbB levels were significantly higher at smelter households among subjects six through 11 years ($p < 0.0005$) and subjects 12 and older ($p < 0.05$).

Determinants of Environmental and Blood Lead Levels

The soil and dust levels in Ebony Vale, being low and quite uniform, were not significantly correlated with either proximity to the conventional smelter (Figure 1) or to blood lead levels. Because of this and because there were no cottage smelters in Ebony Vale, the analyses reported below were limited to the Red Pond community. For these analyses, households were classified as confirmed backyard smelter sites (7 households), suspected smelter sites (4 households), or non-smelter sites (all others) according to questionnaire responses and/or field observations, regardless of why the households were sampled. Two additional smelter sites were confirmed just outside of the community. In assigning

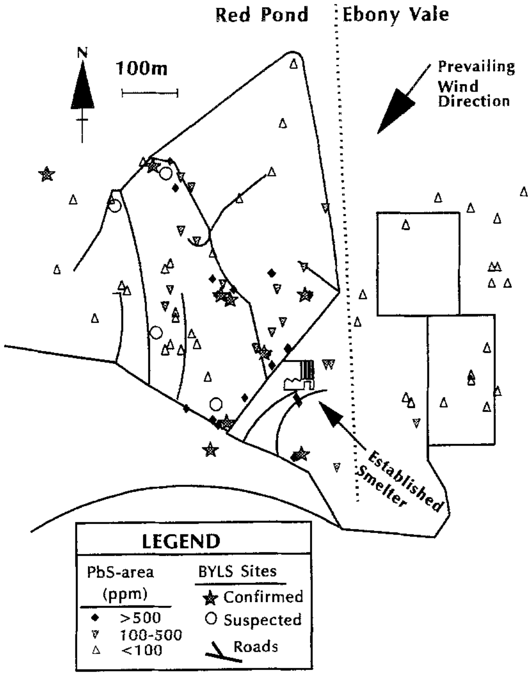

Fig. 1. Map of area soil lead levels (PbS-area) at survey household yards
Footnotes: ppm = parts per million, BYLS = backyard lead smelter

Table 3. Correlation coefficients (r) between environmental lead, distances to smelters, and blood lead levels in the Red Pond community

	Pb soil-area[a]	Pb soil-peak[a]	Pb dust[a]
N Households:	54	58	55
Backyard smelter distance[b]	−0.77***	−0.74***	−0.63***
Stack distance[b]	−0.58***	−0.45***	−0.28*
Blood lead levels[a], by age (N subjects)[c]			
≤5 years (N = 62)	0.75***	0.74***	0.57***
6–11 years (N = 52)	0.71***	0.69***	0.37
≥12 years (N = 156)	0.56***	0.59**	0.42**

[a] log-transformed
[b] square-root transformed
[c] only includes subjects in households with no missing environmental levels
P values for correlation coefficients: *$p < 0.05$, **$p < 0.005$, ***$p < 0.0005$

Table 4. Multivariate models of environmental lead levels in the Red Pond community

Dependent variables:	Pb soil-area[a]	Pb soil-peak[a]	Pb dust[b]
Model characteristics			
N households	54	58	51
Variance explained (r^2)	0.82	0.75	0.59
Y intercept	3.37	3.71	1.66
Beta and (se) of variables in final models[c]			
Backyard smelter distance[d]	−0.10 (0.02)	−0.10 (0.03)	NS[f]
Stack distance[d]	−0.05 (0.003)	−0.07 (0.02)	NS
Lead waste[e]	0.43 (0.16)	1.15 (0.25)	NS
Pb soil-area[a]	NA[g]	NA	0.52 (0.08)
Direction from smelter stack:			
north-northwest	0.65 (0.14)	0.70 (0.22)	0.25 (0.16)
east	0.49 (0.20)	0.30 (0.33)	−0.09 (0.21)
southwest	1.11 (0.22)	0.76 (0.34)	−0.72 (0.26)

[a] $\log_{10}$(ppm)
[b] $\log_{10}(\mu g/m^2)$
[c] Variables which remained after backwards elimination of variables not significant at $p < 0.05$ level. All starting models included variables shown in table and lead in peeling house paint, smelter worker in house. Starting model for Pb dust also included Pb soil-peak and % of yard with bare soil.
[d] $meters^{0.5}$
[e] Observed or reported contamination by solid lead waste: yes = 1, no = 0
[f] NS = not significant, dropped by backwards elimination
[g] NA = not applicable or not assessed in model

"sectors" of direction from the established smelter for subsequent analyses, the northeast and southeast quadrants were combined because of small numbers and similar environmental lead levels. The northwest quadrant was divided into two sectors because most study households were in that quadrant.

Higher Pb soil-area in Red Pond clustered near both the established smelter and backyard smelter sites (Figure 1). Despite the prevailing wind direction, higher levels were also found near the road running northwest from the established smelter past four backyard smelter sites. Univariate analysis was consistent with the observed spatial pattern as soil and dust lead levels were strongly and negatively correlated with square-root-transformed distances to the nearest confirmed backyard smelter and to the smelter stack (Table 3). The correlations were stronger with backyard smelter distance.

In multivariate models (Table 4), significant, independent predictors of soil lead levels were: distance to the nearest backyard smelter, distance and direction from the smelter stack, and lead waste contamination (smelting, dross landfill, or lead oxide drum fencing in a yard). Together, these variables explained 82% of the variance in Pb soil-area and 75% of the variance of Pb soil-peak. Direction from the smelter stack and Pb soil-area explained 59% of the variance in Pb dust levels. Adjusted for other covariates, the highest soil lead levels occurred in the southwest quadrant, downwind from the stack, while the highest dust levels occurred in the north-northwest quadrant. Lead level in peeling paint was not an independent predictor of soil or dust lead levels.

Analyses of predictors of blood lead within Red Pond included those 51 households (270 subjects) for which soil lead and house dust lead were obtained. In each age group, blood lead was more strongly correlated with soil lead than with dust lead (Table 3). The relationship with soil lead was strongest among children under 6 years of age ($r = 0.75$, $p < 0.0005$, Figure 2).

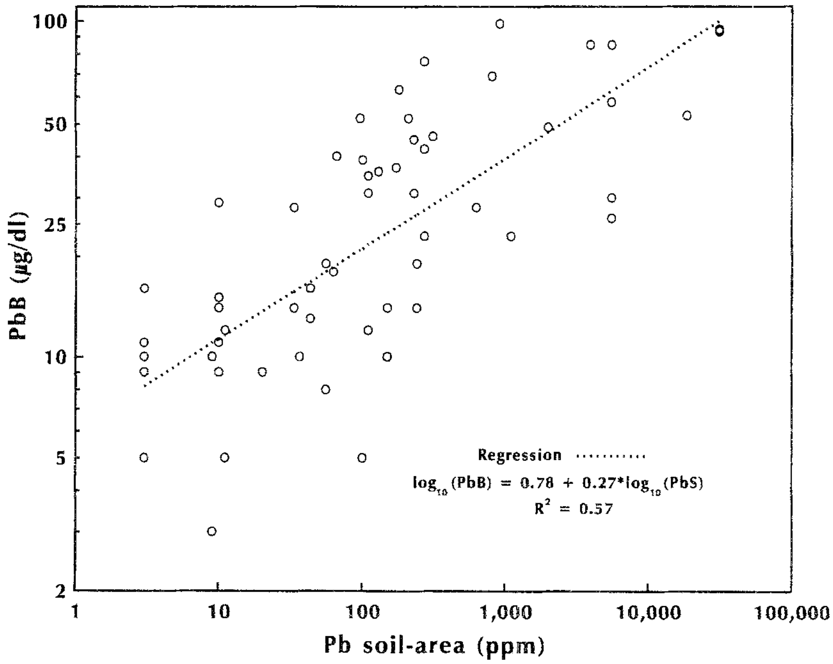

Fig. 2. Relationship between area soil lead (Pb) and blood lead (PbB) among children less than six years of age in the Red Pond community Footnotes: µg/dl = micrograms per deciliter of whole blood, ppm = parts per million

In multivariate models (Table 5) Pb soil-area was a significant ($p < 0.05$) independent predictor of PbB among subjects less than six years and 6–11 years of age, but not among older subjects. Pb soil-area was the only significant predictor of PbB among children 6–11, explaining 51% of the variance in PbB. Among children under six, PbB also varied with direction from the established smelter, and increased with the percent of a household yard that was covered by bare soil. Among subjects 12 and older, distance to a backyard smelter, occupation, and sex were significant, independent predictors of blood lead.

Discussion

This survey documented environmental lead contamination and elevated blood lead levels in the Red Pond Road Community. The lead hazard there is related, in part, to a well-known source: conventional, secondary lead smelting (Landrigan *et al.* 1975; Brunekreef *et al.* 1981; Roels *et al.* 1980). The spatial distribution of soil and dust lead levels in Red Pond also showed that a less familiar cottage industry, "backyard" lead smelting, causes high level lead exposure for nearby residents. While the efficiency of the backyard smelting process has not been formally studied, such operations may reclaim as little as 30% of the lead in scrap; much of the remainder is discarded in heavily-contaminated dross skimmed from the molten lead. In addition to fallout from lead fume generated by smelting, lead contamination may be spread by lead dust that is blown or tracked from piles of dross or lead scrap at backyard smelter sites. The limited impact of lead smelting in Ebony Vale is probably due partly to wind direction near the established smelter and to dilution of lead contamination by the more recent grading of land in that community. In addition, cottage smelters were found only in the older, poorer Red Pond community.

Use of lead oxide drum fencing or dross landfill in Red Pond yards was also associated with contamination of whole yards (high area soil lead levels), while leaded paint did not appear to be an important cause of dust or soil contamination in the area studied. The strong relationship between soil and dust lead levels and the high house dust lead levels along the road running northwest from the smelter suggest that tracking of lead-contaminated dust into dwellings is an important source of housedust contamination in Red Pond, as has been noted elsewhere (Bornschein *et al.* 1985).

Lead-contaminated soil appears to be a major vehicle of lead absorbed by children in Red Pond. This is supported by increased blood lead levels and stronger correlations between soil and blood lead in children—who tend to ingest more soil and absorb more lead—than in adults (Duggan and Inskip 1985). Pica was not predictive of increased blood lead levels in children in multivariate analysis. As in other studies near smelters (Landrigan and Baker 1981), unintentional soil ingestion from normal hand to mouth behavior is probably a more common source of absorbed lead among Red Pond children than is true pica.

The soil lead/blood lead relationship for children in Red Pond differed from that expected from guidelines and surveys in developed countries. A model derived from surveys near two smelters in the United States predicts a geometric mean PbB of 11 µg/dL among children less than six years old at a soil lead level of 500 ppm (Schilling and Bain 1988). In contrast, the univariate model of blood vs. soil lead in Red Pond children predicts a geometric mean PbB of 32 µg/dL among children under age six at a soil lead level of 500 ppm. In reviewing data from published studies, Madhavan *et al.* (1989) proposed as a "worst case" relationship for the blood lead/soil lead relationship an 8.59 µg/dL increase in PbB above "background" per 1,000 ppm of lead in soil. From the multivariate model for Red Pond children under age 6, the minimum predicted increase in geometric mean blood lead above background is 18 µg/dL at a soil level of 1,000 ppm.

Table 5. Multivariate models of blood lead (PbB) by age in the Red Pond community

Dependent variable-PbB[a] by age (years):	≤5	6–11	≥12
Model characteristics			
Number of subjects	62	52	156
Variance explained (r^2)	0.68	0.51	0.35
Y intercept	0.63	0.58	1.38
Beta and (se) of variables in final models[b]			
Pb soil-area[c]	0.27 (0.03)	0.31 (0.03)	NS
Bare soil[d]	0.0025 (0.0005)	NS	NS
Backyard smelter distance[e]	NS[f]	NS	−0.04 (0.01)
Male sex	NS	NS	0.14 (0.05)
Direction from smelter stack:			
north-northwest	0.16 (0.08)	NS	NS
east	0.20 (0.08)		
southwest	−0.12 (0.08)		
Occupation			
established smelter worker	NA[g]	NA	0.29 (0.06)
backyard smelter worker			0.06 (0.10)

[a] $\log_{10}(\mu g/dL)$
[b] Variables which remained after backwards elimination of variables not significant at $p < 0.05$ level. Starting models included variables shown in table, variables from multivariate analysis of environmental levels (Table 4), located at smelter site, and household income. According to age group, starting models also included: current cigarette smoking for subjects 12 and older; frequency of play near a smelter for subjects 11 and under; pica, part of day unattended by an adult, and age (≤2 years, 3–5 years) for subjects 5 and under.
[c] $\log_{10}(ppm)$
[d] % of yard
[e] $meters^{0.5}$
NS = not significant, dropped by backwards elimination
NA = not applicable or not assessed in model

Differences in soil lead/blood lead relationships observed across studies in developed countries may be due to several factors, such as differences in sampling methods, incomplete or inaccurate measurement of non-soil exposure sources, and differences in bioavailability of lead from different sources (Duggan and Inskip 1985). Such factors could account for much of the discrepancy between the findings of this study and those reported near other smelters. It is also possible, however, that children in Red Pond ingest and absorb more lead from soil than children in developed countries with temperate climates because of differences in time spent outdoors, hygiene, and nutrition. Duggan and Inskip (1985) proposed such factors as explaining differences in the soil lead/blood lead relationship found in different settings in developed countries, and one would expect even greater differences in these determinants of lead exposure and absorption in developing countries. This suggests that environmental health criteria for soil lead in developed countries may not be protective in developing countries.

Among subjects age 12 and older, occupational exposure to lead smelting was associated with higher blood lead levels. It is possible that backyard smelter work was not always reported and that male sex and proximity to backyard smelters, which were also predictive of higher blood lead, were proxies for smelter work by some individuals.

Certain limitations of this study are evident. First, air lead levels could not be measured during smelter operation, and their impact on blood lead levels could not be assessed. Second, because of small sample size and collinearity between many study variables, some variables may contribute to environmental or blood lead but not be statistically significant in multivariate models. Third, imprecise measurement of certain study variables may have diluted real associations. Therefore, our analyses indicate the strongest determinants—but not the only ones—of environmental and blood lead in the Red Pond Road community.

The "epidemic" of elevated blood lead levels in Red Pond is not large compared to those reported near other smelters, but it is a major public health problem for this community. Data from this survey indicate that 44% of the estimated 390 children aged six months through five years in the Red Pond Road community have blood lead levels 25 μg/dL or greater, currently defined as "elevated" for screening purposes (Centers for Disease Control 1985). Neurobehavioral effects in children have been observed at blood lead levels of approximately 10–15 μg/dL and above (Bellinger *et al.* 1987; McMichael *et al.* 1988), and the definition of an elevated level may soon be revised downward (Falk and Ing 1988).

The findings of this survey have significance beyond a single community, because backyard lead smelters are not limited to the area surveyed. It is estimated about one third of spent lead-acid batteries in Jamaica are used by backyard recyclers or by small battery repair shops—where the lead is frequently smelted as well—scattered throughout the island. Because the social and economic conditions that encourage home lead smelting (and other lead-related cottage industries) are found in other developing countries, childhood and occupational lead poisoning from such activities may also occur elsewhere.

Acknowledgments. The authors thank the residents of the Red Pond Road and Ebony Vale communities for their cooperation during the survey; many individuals from the Ministry of Health, the Saint Catherine and Kingston/Saint Andrew health departments, and the Environmental Control Division in Jamaica for their work as interviewers, guides, phlebotomists, and drivers during the investigation; workers at the Government Chemist, Jamaica and the Divisions of Biological and Behavioral Sciences and Physical Science and Engineering, NIOSH for assistance with specimen processing; the Division of Environmental Health Laboratory Sciences, Center for Environmental Health and Injury Control for assistance with blood lead quality control; Richard Keenlyside, M.D. of the Caribbean Epidemiology Centre for advice and other assistance during the investigation; and the management of the established smelter for background information on the smelter. The authors are also grateful to the Pan American Health Organization for providing partial funding for travel and logistical support during the investigation.

References

Baker El, Folland DS, Taylor TA, Frank M, Peterson W, Lovejoy G, Cox D, Housworth J, Landrigan PJ (1977) Lead poisoning in children of lead workers. N Engl J Med 296:260–261

Bellinger D, Leviton A, Waternaux C, Needleman H, Rabinowitz M (1987) Longitudinal analyses of prenatal and postnatal lead exposure and early cognitive development. N Engl J Med 316:1037–1043

Bornschein RL, Succop P, Dietrich KN, Clark CS, Que Hee S, Hammond PB (1985) The influence of social and environmental factors on dust lead, hand lead, and blood lead levels in young children. Environ Res 38:108–118

Brunekreef B, Veenstra SJ, Biersteker K, Boleij JS (1981) The Arnhem lead study: I. Lead uptake by 1- to 3-year old children living in the vicinity of a secondary lead smelter in Arnhem, The Netherlands. Environ Res 25:441–448

Centers for Disease Control (1985) Preventing lead poisoning in young children. U.S. Department of Health and Human Services, Atlanta, GA

Dolcourt JL, Finch C, Coleman GD, Kilmas AJ, Milar CR (1981) Hazard of lead exposure in the home from recycled automobile storage batteries. Pediatrics 68:225–230

Duggan MJ, Inskip MJ (1985) Childhood exposure to lead in surface dust and soil: A community health problem. Public Health Rev 13:1–54

Falk H, Ing RT (1988) The Centers for Disease Control perspective on lead in soil. In: Davies BE, Wixson BG (eds) Lead in soil: Issues and guidelines. Science Reviews Limited, Northwood, Great Britain, pp 55–64

Holt MM (1982) The SURREGR procedure. Research Triangle Institute, Research Triangle Park, NC

Kawai M, Toriumi H, Katagiri Y, Maruyama Y (1983) Home leadwork as a potential source of lead exposure for children. Int Arch Occup Environ Health 53:37–46

Kleinbaum DG, Kupper LL (1978) Applied regression analysis and other multivariable methods. Duxbury Press, Boston, MA, pp 229–230

Koplan JP, Wells AV, Diggory HJ, Baker EL, Liddle J (1977) Lead absorption in a community of potters in Barbados. Int J Epidemiol 6:225–229

Landrigan PJ, Gehlback SH, Rosenblum BF, Shoults JM, Candelaria RM, Barthel WF, Liddle JA, Smrek AL, Staehling NW, Sanders JF (1975) Epidemic lead absorption near an ore smelter. N Engl J Med 292:123–129

Landrigan PJ, Baker EL (1981) Exposure of children to heavy metals from smelters: Epidemiology and toxic consequences. Environ Res 25:204–224

Lilis R, Fischbein A, Eisinger J, Blumberg WE, Diamond S, Anderson HA, Rom W, Rice C, Sarkozi L, Kon S, Selikoff IJ (1977) Prevalence of lead disease among secondary lead smelter workers and biologic indicators of lead exposure. Environ Res 14:255–285

Madhavan S, Rosenman KD, Shehata T (1989) Lead in soil: Recommended maximum permissible levels. Environ Res 49:136–142

Mahaffey KR (1982) Role of nutrition in prevention of pediatric lead toxicity. In: Chisholm JJ and Ohara DM (eds.). Lead absorption in children. Urban & Schwarzenberg, Baltimore, MD, pp 63–78

McMichael AJ, Baghurst PA, Wigg NR, Vimpani GV, Robertson EF, Roberts RJ (1988) Port Pirie cohort study: Environmental exposure to lead and children's abilities at the age of four years. N Engl J Med 319:468–475

Morton DE, Saah AJ, Silberg SL, Owens WL, Roberts MA, Saah MD (1982) Lead absorption in children of employees in a lead-related industry. Am J Epidemiol 115:549–555

National Institute for Occupational Safety .nd Health (1984) NIOSH manual of analytical methods, 3rd edition. DHHS (NIOSH) publication no. 84-100, Cincinnati, OH

Phoon WO (1982) Recent developments in occupational health in tropical countries. Trop Dis Bull 79:653–666

Popovac D, Graziano J, Seaman C, Kaul B, Colakovic B, Popovac R, Osmani I, Haxhiu M, Begraca M, Bozovic Z, Mikic M (1982) Elevated blood lead in a population near a lead smelter in Kosovo, Yugoslavia. Arch Environ Health 37:19–23

Roels HA, Buchet JP, Lauwerys RR, Bruaux P, Claeys-Thoreau F, Lafontaine A, Verduyn G (1980) Exposure to lead by the oral and the pulmonary routes of children living in the vicinity of a primary lead smelter. Environ Res 22:81–94

Schilling RJ and Bain RP (1988) Prediction of children's blood lead levels on the basis of household specific soil lead levels. Am J Epidemiol 128:197–205

Searle B, Chan W, Davidow B (1973) Determination of lead in blood and urine by anodic stripping voltammetry. Clin Chem 19:76–81

Shah BV (1981) SESUDAAN: standard errors program for computing standardized rates from sample survey data. Research Triangle Institute, Research Triangle Park, NC

Vostal JJ, Taves E, Sayre JW, Charney E (1974) Lead analysis of house dust: A method for the detection of another source of lead exposure in inner city children. Environ Health Perspect 7:91–97

Walter SD, Yankel AJ, von Lindern IH (1980) Age-specific risk factors for lead absorption in children. Arch Environ Health 17:965–978

Manuscript received October 29, 1990 and in revised form February 20, 1991.