...m . . .

...RT J. HEANEY

July 27, 1973

A. W. Huffaker:

Subject: Proposed Paper on Lead Survey

Please have the attached paper, "Lead Accumulation in Soil, Vegetation, and Surface Litter at Varying Distances from Heavy-Metal Smelters," reviewed by your staff. Return comments by 8/20/73.

R. J. Heaney

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Environmental Sect.

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Att.

UTAH STATE UNIVERSITY · LOGAN, UTAH 84322 ·
COLLEGE OF AGRICULTURE

DEPARTMENT OF
VETERINARY SCIENCE
UMC 56

July 20, 1973

Dr. R. J. Heaney
Process Control and Environment Engineer
Kennecott Copper Corporation
P.O. Box 11299
Salt Lake City, Utah 84111

Dear Dr. Heaney:

Enclosed is a copy of the manuscript that we have prepared concerning the lead survey we made in cooperation with Kennecott Copper Corporation and International Smelting and Refining Company. This is in response to your suggestion that we write an article in the form usually used for publication in a scientific journal and then submit it for you to review.

The manuscript is written in style and form for the journal, Environmental Science and Technology, a publication of the American Chemical Society. If published in this journal the data would be seen principally by physical scientists. We would be appreciative if you would go over it and give us your reaction. If you can give your approval to submit it for publication but would like to see changes made in the text, please write in the suggested changes and return the copy.

We are appreciative of your position and are anxious to have your response.

Sincerely yours,

J. T. Blake

J. T. Blake, Professor

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JTB/mr
copy: Dr. Richard Krablin

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ROBERT J. HEANEY

LEAD ACCUMULATION IN SOIL, VEGETATION, AND SURFACE LITTER AT VARYING DISTANCES FROM HEAVY-METAL SMELTERS

Blake[a], J.T., Miller, R.W., Smart, R.A., and Shupe, J.L.

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ABSTRACT

A geographic area of approximately 7 x 12 miles, extending from and between a copper smelter and lead smelter in Tooele County, near Salt Lake City, Utah was studied to ascertain the accumulation and dissemination of lead (Pb) in the soil and on and in vegetation and ground litter of a botanical nature. Section corners were used to locate sampling sites. Lead concentrations in parts per million were ascertained separately for the top 5 cm of soil and for the unwashed vegetation and litter. The sampling area used was measured at each site so that Pb deposition could also be calculated on an area-volume basis. Seven soil profile samples were taken and partitioned into 0-2.5 cm, 2.5-5 cm, 5-10 cm, 10-15 cm, 15-22.5 cm, and 22.5-30 cm depths.

All samples were digested with nitric and perchloric acids and the Pb content measured using an atomic absorption spectophotometer.

It was determined that (1) Pb deposition generally decreased markedly with increasing distance away from each smelter, (2) an apparent additive accumulation of Pb had occurred in some of the area between the two smelters, and (3) the greatest quantities of Pb were present in the vicinity of and extending from the Pb smelter. The most consistent measure of geographic dissemination of Pb appeared to be given by the Pb-per-volume data.

At more than 10 percent of the sampling sites a potential lead

toxicology problem appeared to exist if livestock ingested unwashed vegetation. However, by far the greater danger would be to animals managed or fed in such a way that they ingested topsoil or surface litter since Pb deposition on the soil surface was much more highly concentrated than lead in or on the growing vegetation.

Lead (Pb), accumulates in the tissues of man and other animals from both inhalation and ingestion and when the level exceeds a tolerated threshold results in irreversible pathology, even to death.

There are many sources of environmental pollution with Pb. Some of the uses of Pb in modern day technology are as follows: cable covering; caulking compounds; solder and the welding industry; storage batteries; gasoline, paint and plumbing industries; building trades; and metallurgy (Hall, 1972; Fairhall, 1957). Less than one-half of the Pb used in these capacities is recovered (Hall, 1972). The balance remains in the environment and may contribute to a potential health hazard. Pollution of the environment with Pb has increased at an alarming rate coincident with the rapid evolution of industrialization and transportation advances. Dated snow samples in Northern Greenland indicate that ambient Pb contents increased from 20 μg/ton of ice in 1750 to 50 μg in 1860, 80 μg in 1940, 120 μg in 1950, and 210 μg in 1965 (Hall, 1972). Today Pb is a ubiquitous element present in food, air, soil, water, and other natural resources.

This report concerns Pb accumulations in soil, vegetation, and the surface litter. The Pb in the reported area is principally from non-recovered emission of Pb from heavy-metal smelters near Salt Lake City, Utah. A national highway passes through the geographic area studied and automobile exhaust fumes plus normal extraneous littering with Pb-containing manufactured products over the years contributed an undetermined percentage

of the Pb accumulation reported in this study. Since Pb moves out of soil and vegetation very slowly, the accumulated quantities and accumulation rate are important in potentiating a toxicity problem via both animal and human food chains.

In the foothills of the mineral-rich Oquirrh Mountains that separate Salt Lake and Tooele Counties in Utah two large smelting and refining plants have been operating for many years. A copper smelter is located at the north end of the mountain range, near the south shore of Great Salt Lake and a lead smelter under different ownership on the western slope of the mountains approximately 12 miles southward. Westward from the mountains is a valley with irrigated farmland, rural homes and the city of Tooele. The foothills between the two smelters, the transitional land, and a contiguous part of the valley floor provided the site for assaying Pb accumulation in this study. The geographic features are depicted in Figure 1.

This study was initiated due to possible litigation concerning animal losses from claimed Pb poisoning. The objectives of the study were to determine the quantities of Pb in soil, vegetation, and surface litter in relation to the location of the two smeltering companies, and to use these data in evaluating the potential toxicity danger to livestock in the area.

REVIEW OF LITERATURE

Lead in Soils

Lead in soils is not very mobile. Dedolph *et al.* (1970) recovered less than 1 part per billion (ppb) in water moved through soil even when 40 ppb had been in the applied water. Lead in soils adsorbs onto the cation exchange sites or forms slightly soluble salts of sulfates, hydroxides, sulfides, silicates, and others. Aerosol Pb striking the ground surface results in highest Pb concentrations at the soil surface, and decreasing concentrations with depth. The leaching rate into lower soil strata is dependent upon several factors including soil type. Leaching would be rapid in sandy soils but in clay and organic-rich soils due to a high cation exchange capacity.

Soils vary in Pb content. Non-ore areas have reported most values to be less than 50 parts per million (ppm): 14 ppm in Alaska (Swaine, 1955); 28 ppm in Poland (Roszyk, 1968); 40 ppm by the U.S. Geochemical Survey (Swaine, 1955); and 17.7 ppm in California soils (Page and Ganje, 1970). Near ore deposits, contents may be very high, such as 4,200 ppm and 7,000 ppm in western U.S. mines (Swaine, 1955).

Limited mobility of Pb in soils makes it possible to measure the uncontaminated Pb levels at relatively shallow soil depths, such as at 30 cm or slightly deeper (Page and Ganje, 1970).

Lead in Plant Materials

Lead in soil and fallout dust containing lead should be harmful only to the extent that it interferes with plant metabolism or accumulates in plant tissue and subsequently enters the animal or human food chain. Unfortunately, some literature does not specify whether the data obtained was from washed or unwashed plant material. Vandenabeel (1971) reported Pb concentrations ranging from 2.3-14.5 ppm in washed grass and shrub species growing near a highway. He found that an unwashed grass had 57.6 ppm Pb on the surface but only 11.3 ppm internally.

The uptake and translocation of Pb by growing plants is not extensive, either from adsorption via the roots or from contamination of the aerial parts. Brewer (1966) found only limited uptake of Pb by various species of vegetable plants growing in soil containing only a background concentration of Pb. The roots took up considerable Pb but there was limited translocation to the aerial parts. This finding was substantiated by other investigators. Keaton (1937) found less than 4 ppm Pb in barley tops but 808 ppm in the roots, in soil containing up to 3000 ppm. Lagerwerff (1971) reported only minimal translocation of Pb in the radish.

Potential Biologic Toxicity of Pb

The toxicity of Pb to plants is not great. Brewer (1966) observed

no measurable growth depression of apple trees or grapevines by 200 ppm of Pb salts added to a gravel-culture solution.

In contrast to the low sensitivity of plants to Pb, the accumulative nature of Pb in animal tissues poses potential chronic lead poisoning to man and other animals at relatively low Pb intake levels. Toxicities in cattle and horses occurred in Minnesota from hay and corn silage containing 148-284 ppm Pb (Hammond and Aronson, 1964). Marten and Hammond, (1966) suggest that 150 ppm Pb in the diet would be toxic in these species.

Humans are consistently consuming small quantities of Pb. Harley (1970) estimated an annual consumption of 103 mg Pb by people in New York. The mean daily oral intake of Pb in humans in the United States is estimated at 300 μg, with about 21 μg being absorbed, and an additional 25 μg entering the body daily via inhalation (Hall, 1972). Although these ubiquitous exposures are ostensibly tolerable, a potential danger exists if exposure rates increase either from increased contamination of the food chain or via air pollution.

EXPERIMENTAL PROCEDURE

Sampling

The objective of the study was to assay the quantities of lead in soil and in vegetation residues in proximity to two smelting plants, that might be ingested by livestock. A geographic area lying between the two plants (12 miles) and extending westward (7 miles) into the valley floor was mapped out as the study

area (Figure 1). The section corners were used as a natural grid pattern for sampling soil and vegetation. An exact site near each section corner was chosen that had the least discernible disturbance of the soils and vegetation. Some adjustments were necessary at inaccessible section corners. The sampling sites were numbered consecutively in a criss-cross pattern, from 1 to 88, as shown in Figure 1. Site 66 could not be sampled from since it lay within the restricted boundaries of a U.S. Army Depot. This left a total of 87 sampling sites. At each site samples were taken of topsoil, vegetation, and surface litter, as described below.

At all 87 sites samples of soil were triplicated, within approximately a 10 m. circle. A vertical cut was made with a spade then the top 5.0 cm were separated with stainless steel knife and placed into a 6 ounce size polyethylene bag and sealed. Bulk density of the soil at each location was estimated but not measured. Seven sites randomly distributed across the grid were sampled as profile sites. The same procedure was used as in other samples except the vertical cut was made to a 30 cm depth and partitioned with stainless steel knife into the following depths: 0-2.5 cm, 2.5-5 cm, 5-10 cm, 10-15 cm, 15-22.5 cm, and 22.5-30 cm.

In proximity of each soil sampling site, an exact site for collecting vegetation and surface litter was randomly located by throwing a 1600

cm^2 (~23 cm diameter) circular loop over the shoulder. At each site all vegetation was cut near ground level with stainless steel scissors and placed into a large polyethylene bag, and all surface litter of a botanical nature was gathered and placed into another large polyethylene bag. In areas of either scarce vegetation or litter, repeated samples were collected and composited into single vegetation and litter samples. At or near 8 of the section sites water samples were taken fron canal, pond or well sources.

Sample Preparation and Digestion

Soil samples were screened through stainless steel screen to remove material greater than 2 mm diameter. From each sample, a 2-gram aliquot was refluxed at 110-120°C for 20-30 minutes in a 250 ml. covered beaker with HNO_3 acid at a soil:acid ratio of ~1:5. This reaction was rapid and required constant attention to avoid bumping or splattering. After the reaction subsided, the solution was boiled ~15 minutes longer, but not to dryness! Then ~15 ml. of a 2:1 acid mixture of HNO_3: $HClO_4$ were added and digestion was carried to near dryness at 120-130°C (~ 2 hours). About 25 ml. of water was added, the flask was warmed and the digest was filtered and made to 50 ml. Lead contents were determined, using a Perkin-Elmer, Model 303, atomic absorption spectrophotometer.

The vegetation and litter were not washed. They were cut into small pieces with stainless steel scissors and mixed. Four-gram samples

of each were digested in duplicate, using the same digestion procedures as for soil. More acid was needed in the first digestion with HNO_3. Lead contents of these digests were also determined by atomic absorption spectrophotometry. Water samples were analyzed for lead content without any pre-treatment.

RESULTS AND DISCUSSION

The Pb concentrations in the top 5 cm of soil, and in the vegetation and litter on the ground surface at the various sampling sites are shown in Table I on a weight basis (ppm) and on an area-volume basis (micrograms per cm^2 of ground surface for vegetation and litter and per cm^2 surface area and to a depth of 5 cm for the soil). The total Pb per cm^2 surface area, including the vegetation, litter, and the soil to a 5 cm depth per sample site is represented by contour concentration lines drawn by inspection (Figure 2). As would be expected, the Pb concentration generally decreased with distance from each smelter. The irregular patterns are at least in part a result of site heterogeneity. Soils differed in textures and in extent of cultivation or other type of disturbance. More recently cultivated, mixed, or eroded sites were lower in Pb content in the surface 5 cm.

At nearly all sampling sites the Pb in the soil comprised the major part of the total Pb on an area-volume basis, and the Pb in vegetation and litter comprised but a small percentage of the total. Because of

this, the contour concentration lines would be markedly influenced by cultivation of the soil or leaching of Pb into deeper strata. The relatively low value at site 1 close to one smelter was due to it being beach sand and thus well washed and leached. At sites 25, 53, 64, 68 and 73 the soil was coarse textured, either sandy, rocky, or silty, thus accounting for lower Pb values per volume than expected by Pb in nearby sites. At some of the other sites having Pb values lower than expected there were evidences of recent cultivation (sites 5, 25, 31, 32, 38, 46, 47, 75, 76) or erosion (sites 25, 52, 70). The low values at sites 18, 24, 82, and 85 are less clearly explainable but slope or location suggest erosion is possible on all of these except site 18. At site 88 the Pb value was high. It was determined that there had been tailings deposited there many years previous.

One purpose of the study was to determine the dissemination pattern for Pb in the area of and at varying distances from the two smelters. The contour lines (Figure 2) demonstrate this. For further convenience to the reader the top 10 percent (highest concentrations of Pb) and bottom 10 percent (lowest concentration) are tabulated (Table II). From the data it is evident that (1) Pb concentration tended generally to diminish with distance from each smelter, (2) the Pb concentration was accumulative in some areas between the smelters, and (3) the lead smelter disseminated more Pb than did the copper smelter.

The distribution of Pb in deeper soil depths is presented in Table III and Figure 3. These profile sites were selected for distribution over the entire grid. Site 60 was close the the Pb smelter which accounts for its high Pb concentration. At depths below 15 cm the Pb concentration at all sites tended to become nearly the same except at site 60. This suggests a "background" or reference Pb level of 14-26 ppm.

Although Pb concentrations per surface volume given in Tables I and II and contoured in Figure 2 indicate a realistic dissemination pattern, the potential toxicity of Pb to animals is better estimated by concentration (ppm) in the vegetation, litter, and surface soil. These data are also shown in Tables I and II. The values for vegetation and litter are for unwashed material which is what an animal would ingest. Lead values appear to be nonconforming at some of the sites for vegetation and/or litter (1, 12, 18, 25, 42, 44, 60, 61, 71, 73, 74, 75, and 82). The reasons are not evident except at sites 1 and 75 where sampling was done after an early snowstorm and washing would have occurred. However, dense growth on some sites would "dilute" the fallout concentration on a unit area. Also, grazing losses, wind currents, or dust and soil contamination of litter might alter the concentration from that which was expected.

The eight sites of greatest Pb concentrations had Pb (Table II) exceeding 150 ppm in the vegetation, litter, and topsoil. Marten and Hammond (1966) have suggested that an average of 150 ppm in the total roughage-type ration is potentially toxic to livestock. The litter and surface soil had far greater concentrations of Pb than did the vegetation, undoubtedly due to dust and accumulated fallout over several years. Accordingly, the greatest toxicity potential would occur with livestock that ingested the litter and soil. This is most apt to occur when management permits or forces animals to be on a low quality diet or low ration.

Table I. Lead Contents of Vegetation, Surface Litter, and Topsoil at or Near Section Corners[a] in Tooele County, Utah

	Weight Basis (ppm)[b]			Area-Volume Basis (μg per)		
Site	Veg.	Litter	Topsoil	Veg. cm^2[c]	Litter, cm^2[c]	Topsoil, cm^3[d]
1	96	261	70	6.1	2.9	91
2	320	749	1289	7.7	16.4	1004
3	167	367	1113	1.9	4.7	1022
4	116	538	153	2.8	9.8	145
5	88	245	314	1.0	3.2	261
6	34	76	138	0.8	0.8	89
7	63	248	89	0.3	1.4	105
8	69	418	157	1.6	3.9	167
9	43	159	135	0.2	0.9	171
10	38	199	171	1.0	2.7	201
11	65	106	190	0.4	0.5	226
12	30	38	310	0.4	0.2	368
13	47	207	391	0.3	1.1	386
14	42	183	282	0.5	3.8	256
15	41	164	198	0.3	1.3	206
16	57	149	432	0.2	1.5	238
17	96	147	299	0.8	1.3	313
18	60	60	100	1.2	0.3	117
19	49	199	191	4.5	2.1	229
20	41	131	355	1.7	0.5	195
21	30	66	114	0.7	0.5	111
22	38	36	132	5.5	0.4	143
23	53	104	132	8.2	1.4	162
24	84	220	58	4.4	1.7	69
25	33	54	53	1.2	0.1	66
26	41	308	169	0.5	5.3	178
27	78	304	208	0.9	3.0	213
28	50	167	133	1.0	0.9	150
29	37	195	139	0.2	1.0	159
30	66	231	139	0.7	0.4	145
31	63	326	87	1.2	5.3	95
32	47	326	73	0.8	7.6	86

	Weight Basis (ppm)[b]			Area-Volume Basis (μg per)		
Site	Veg.	Litter	Topsoil	Veg. cm^2[c]	Litter, cm^2[c]	Topsoil, cm^3[d]
33	71	175	251	2.9	8.6	147
34	27	140	101	0.9	0.5	119
35	24	69	99	0.2	0.7	116
36	13	70	105	0.3	0.6	134
37	23	103	108	0.6	0.4	204
38	46	132	95	1.0	0.5	114
39	91	365	231	1.6	4.3	258
40	49	511	112	0.3	6.2	135
41	78	513	395	2.7	13.2	186
42	78	209	283	0.3	1.3	239
43	131	646	544	2.6	6.7	552
44	127	609	449	0.9	3.6	532
45	67	308	186	2.5	18.3	219
46	64	798	129	0.8	4.1	142
47	40	231	188	0.7	1.3	112
48	35	78	209	0.4	1.3	247
49	22	90	145	0.5	1.1	157
50	32	71	133	0.2	0.1	154
51	32	66	143	0.3	0.2	170
52	33	127	95	0.7	0.4	107
53	118	926	148	4.3	132.5	152
54	207	901	405	6.5	15.4	439
55	33	894	697	0.7	9.7	810
56	422	834	798	5.8	11.4	766
57	386	1225	962	8.2	12.2	1086
58	41	2347	2377	1.8	66.5	1922
59	30	1320	764	0.9	28.4	992
60	171	669	3065	10.4	80.5	1568
61	257	608	406	13.6	21.3	440
62	121	1342	705	1.2	19.1	346
63	28	206	78	0.5	7.1	90
64	48	152	81	0.8	1.7	87
65	23	40	117	0.2	0.0	138
66[e]	--	--	---	---	---	---

Site	Weight Basis (ppm)[c] Veg.	Litter	Topsoil	Area-Volume Basis (µg per) Veg. cm^2[c]	Litter, cm^2[c]	Topsoil, cm^3[d]
67	20	39	79	0.3	0.5	87
68	38	142	91	0.8	0.7	107
69	22	289	192	0.5	13.4	228
70	196	1031	128	2.5	35.7	147
71	66	2303	2392	0.6	24.2	2706
72	1137	1155	2392	17.6	38.2	2340
73	149	479	1095	0.6	12.4	1160
74	167	884	446	6.1	17.5	398
75	43	240	91	2.0	10.7	86
76	55	118	68	3.2	0.8	76
77	27	120	95	0.6	0.6	104
78	56	264	91	0.5	3.1	96
79	50	225	126	1.5	3.1	144
80	19	95	84	0.3	1.0	89
81	116	413	189	3.1	9.8	164
82	25	185	107	0.5	6.5	116
83	117	389	140	1.6	2.1	157
84	42	82	156	1.0	1.2	172
85	21	63	50	0.6	4.7	54
86	104	265	142	2.1	7.2	137
87	49	204	109	0.5	3.4	120
88	54	288	408	1.1	1.7	474

a For site locations see Figure 1.
Each value represents average of duplicate determinations for vegetation and litter and triplicate determinations for soil.

b Parts per million in: aerial parts of composited vegetation; composited surface plant litter; soil to a depth of 5 cm. All analyses on absolute dry matter basis.

c Micrograms in: vegetation regardless of height or growth stage and litter regardless of thickness, covering one cm^2 surface area; formula = Pb/g dry matter x total dry sample collected ÷ collection area in cm^2.

d Micrograms: average per cm^3 of soil, sampled to a depth of 5 cm; formula= Pb/g dry matter x estimated bulk density x percent of soil screened to a particle size diameter of 0-2 mm.

e No sampling made. Site inaccessible because inside Tooele Ordinance Depot.

Table II. Concentrations of Lead in Vegetation, Surface Litter and Topsoil, Highest and Lowest Ten Percents of Sample Sites[a] in Tooele County, Utah

	ppm Basis[b]						Area-Volume Basis[b]					
	Veg.		Litter		Topsoil		Veg.		Litter		Topsoil	
Ranking	Site	Value	Site	Value	Site	Value	Site	Value	Site	Value	Site	Value
Highest	72	1137	58	2347	60	3065	72	17.6	53	132.5	71	2706
2nd	56	422	71	2303	71	2392	61	13.6	60	80.5	72	2340
3rd	57	386	62	1342	72	2392	60	10.4	58	66.5	58	1922
4th	2	320	59	1320	58	2377	23	8.2	72	38.2	60	1568
5th	61	257	57	1225	2	1289	57	8.2	70	35.7	73	1160
6th	54	207	72	1155	3	1113	2	7.7	59	28.4	57	1086
7th	70	196	70	1031	73	1095	1	6.1	71	24.2	3	1022
8th	60	171	53	926	57	962	74	6.1	61	21.3	2	1004
80th	65	23	21	66	67	79	80	0.3	52	0.4	80	89
81st	37	23	18	60	63	78	7	0.3	22	0.4	64	87
82nd	49	22	85	63	22	73	35	0.2	18	0.3	67	87
83rd	69	22	25	54	1	70	29	0.2	12	0.2	32	86
84th	85	21	65	40	76	68	50	0.2	51	0.2	75	86
85th	67	20	67	39	24	58	16	0.2	25	0.1	76	76
86th	80	19	12	38	25	53	65	0.2	50	0.1	24	69
87th	36	13	22	36	85	50	9	0.2	65	0.0	25	66

[a] For site locations see Figure 1.

[b] For explanations and units see footnotes, Table I.

Table III. Decreasing Concentration of Lead With Soil Depth

Profile Site No.	Depth Strata, cm					
	0-2.5	2.5-5.0	5.0-10.0	10.0-15.0	15.0-22.5	22.5-30.0
	(Pb in ppm, dry matter[a])					
16	363	69	28	23	17	14
20	263	92	36	26	26	26
41	283	112	63	28	20	17
47	118	71	55	48	31	26
60	1,979	1,086	696	152	72	90
62	518	187	45	20	16	15
Av.	515	241	141	51	30	30

[a] Averages of triplicate sampling per depth, per site.

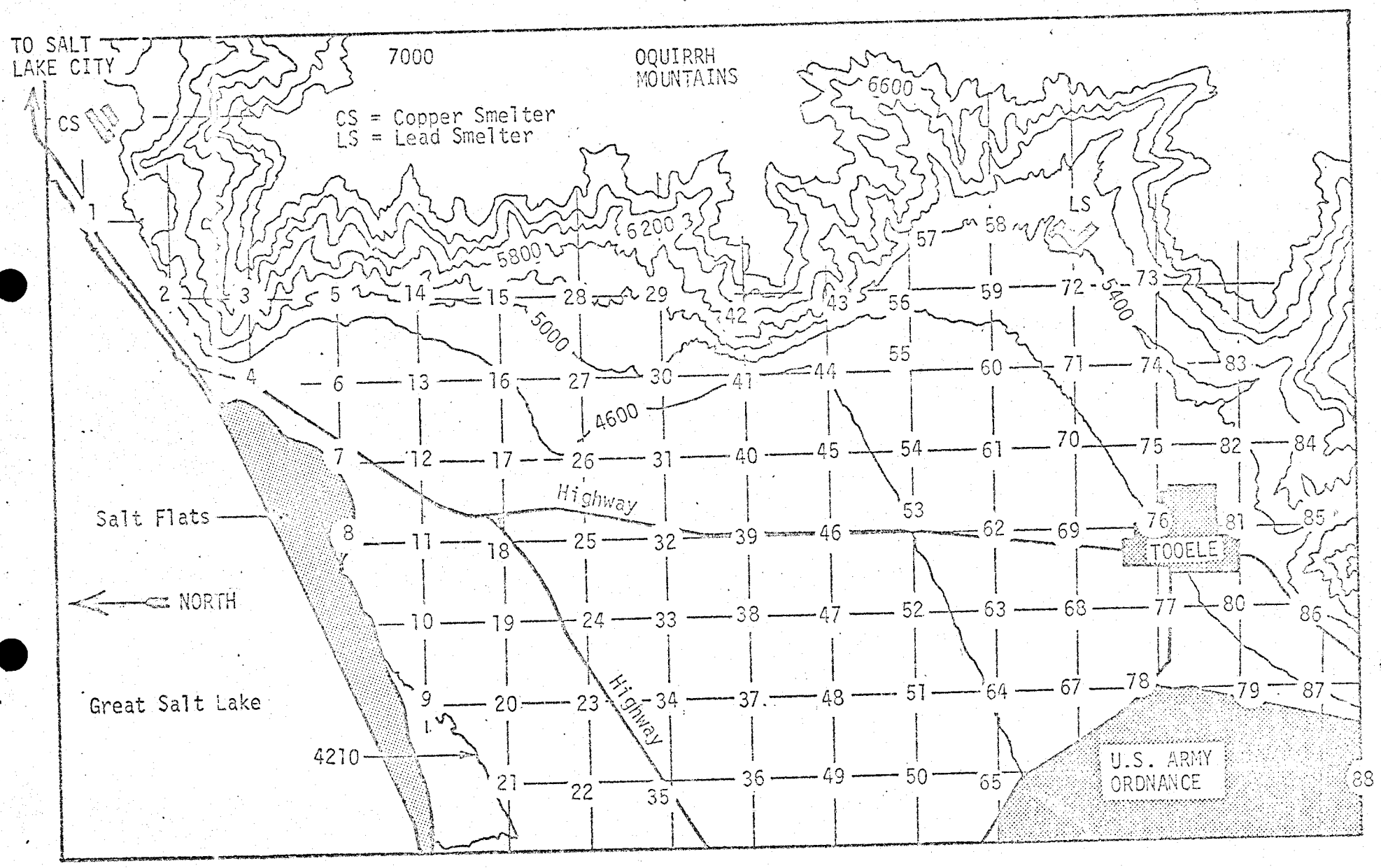

Figure 1. Location of sampling sites and general topography of Pb study. Each number 1 through 88 are sampling sites approximately at section corners on a grid with adjacent sites one mile apart. Contour elevation lines are in intervals of 400 feet. The copper smelter is approximately 15 miles west of Salt Lake City.

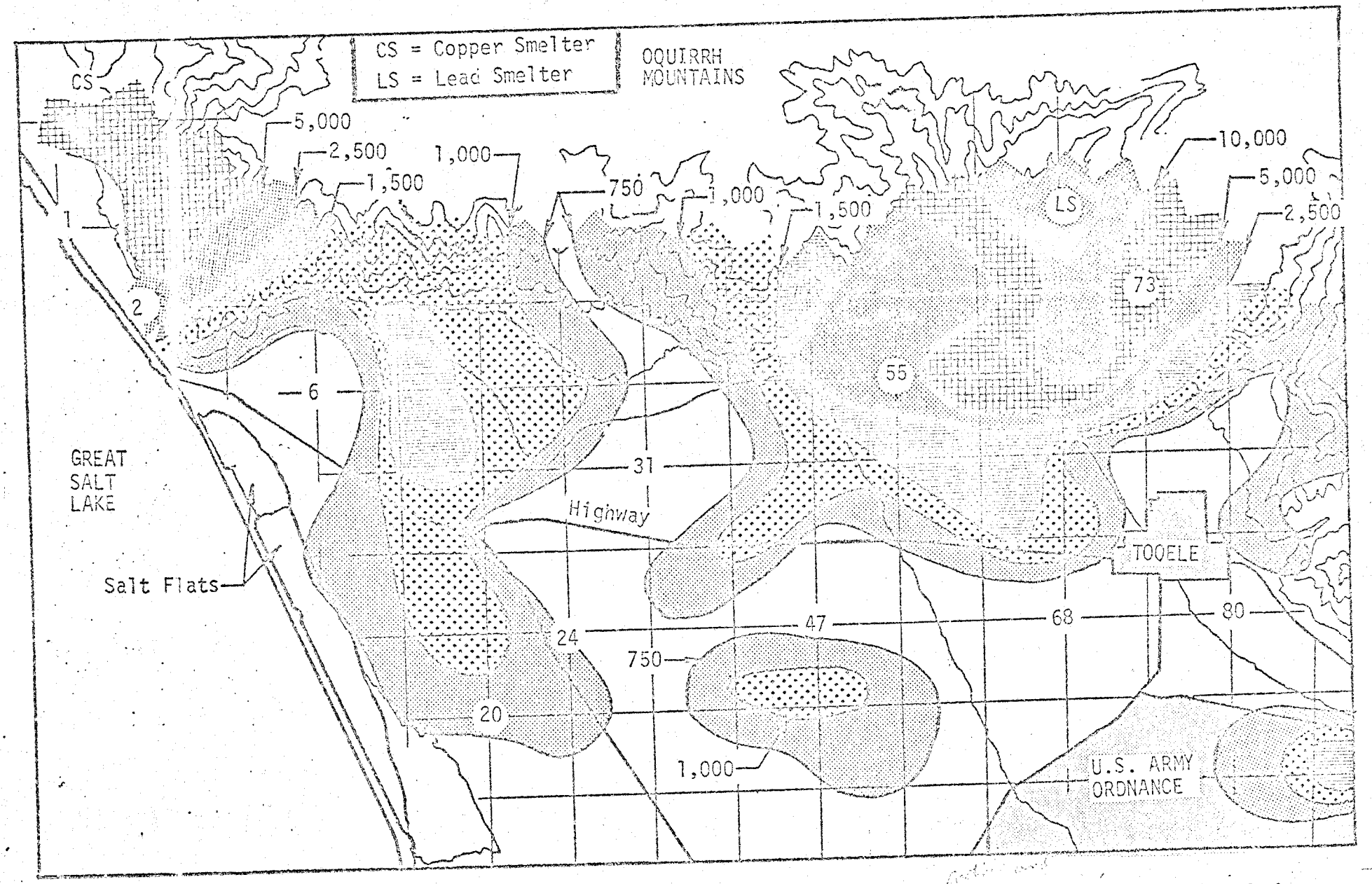

Figure 2. Approximate distribution of Pb in soil, litter and vegetation in arable land near Tooele, Utah. Concentrations of Pb are a summation of contents in a volume 1 cm^2 area x 5 cm deep into the soil, given in micrograms of Pb per 5 cm^3 volume. The sample includes Pb in litter and vegetation on the 1 cm^2 area. Values of Pb along the approximated contour lines are given with arrows. Area between adjacent contour lines are shaded.

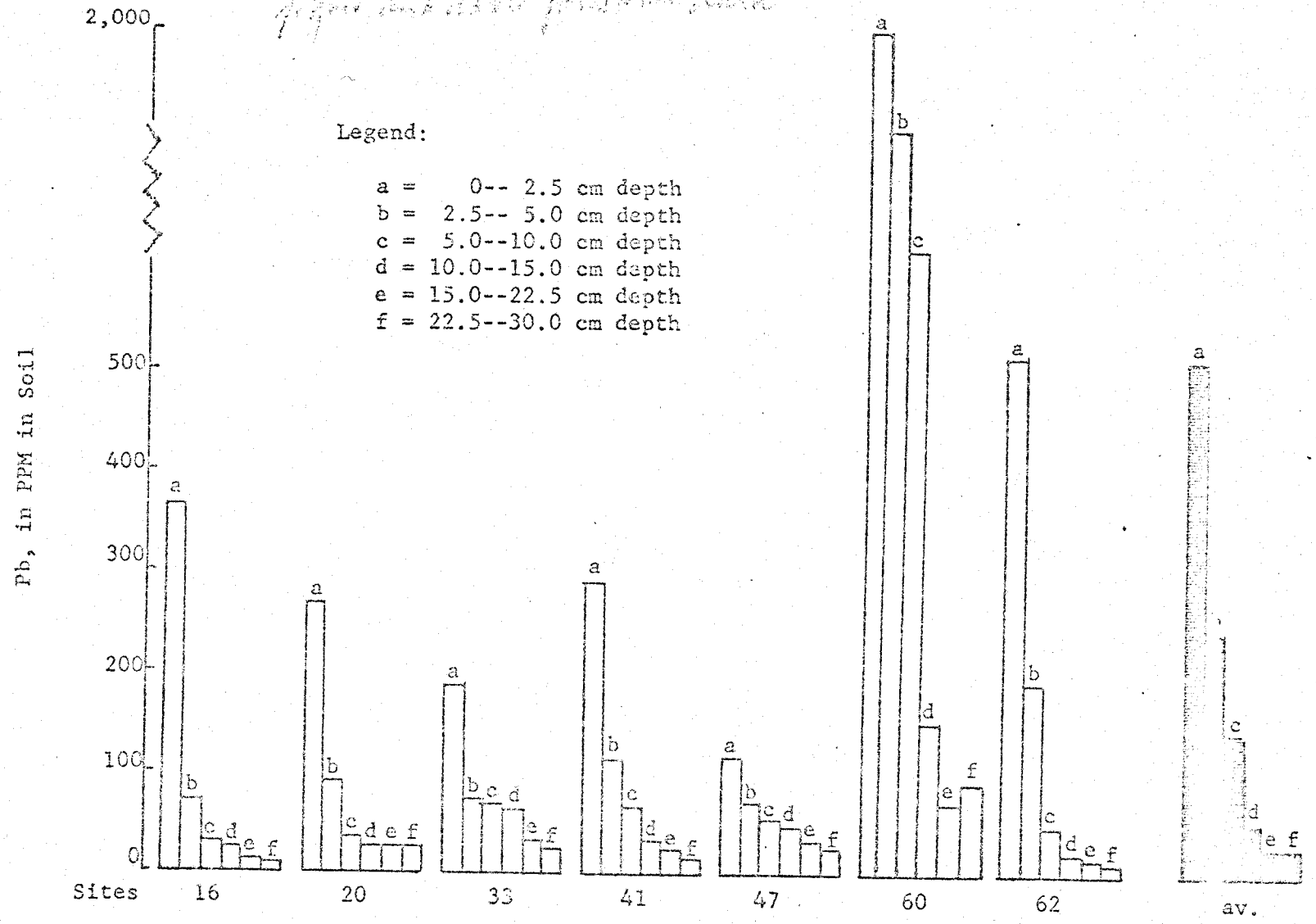

Fig. 3. Decreasing concentration of lead with soil depth, at various sampling sites.

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