r	= radial coordinate
U	= fluid velocity far from collector
v_θ	= particle velocity tangent to collector surface
v_R	= particle velocity normal to collector surface
x	= distance coordinate tangent to collector surface
y	= distance coordinate normal to collector surface
Y	= y/a_P, dimensionless distance coordinate normal to collector surface
η	= collector capture efficiency
θ	= angular coordinate
κ_{ret}	= retardation coefficient
$\kappa_2, \kappa_3, \kappa_4, \kappa_5, \kappa_6, \kappa_5', \kappa_6'$	= numerical constants
λ	= wavelength in retardation function
μ	= fluid viscosity
Ψ	= stream function

Subscripts

F	= fiber collector
P	= particle
S	= spherical collector

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Accumulations of Lead in Soils for Regions of High and Low Motor Vehicle Traffic Density

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■ Accumulation of lead in soils over a period of approximately 40 years was compared for areas of high and low motor vehicle traffic densities. Where motor vehicle traffic density was less than 80 motor vehicles per square mile, no lead accumulations were observed, but where the motor vehicle traffic density was greater than 580 motor vehicles per square mile, the concentration of lead in the surface 2.5 cm. of soil increased by a factor of two to three times. Although large percentage increases were observed in the surface soils from the areas of high motor vehicle traffic density, the amount of lead found in the surface soil did not exceed 52 p.p.m., a level which is common to many soils from areas of low motor vehicle traffic density and not subjected to atmospheric or industrial lead contaminations.

Recent reports have demonstrated that atmospheric pollution of lead (Pb), caused principally by combustion of leaded gasoline and liquid and vapor wastes from coal-burning and metal-melting establishments, has contributed to the increased Pb content of waters (Johnson, Rossano, *et al.*, 1966; Tsaihwa, 1966), plants (Cannon and Bowles, 1962; Everett, Day, *et al.*, 1967; Lagerwerff, 1966), and soils (Cannon and Bowles, 1962; Lagerwerff, 1966; Marten and Hammond, 1966) in industrial and urban areas. But information relative to accumulations in soils is fragmentary and inadequate.

Bashirova (1966) reported the content of Pb at depths from 9 to 30 cm. in city soils as 8000 p.p.m. (mgm. of Pb per Kgm of soil) compared to 25 p.p.m. at similar depths for virgin soils. Cannon and Bowles (1962) found an average of 515 p.p.m. of Pb with a range of 100 to 1000 p.p.m. of Pb in six soil samples collected 15 meters from a street in the city of Canandaigua, N.Y. Near a battery smelter in Minnesota, Marten and Hammond (1966) found 680 p.p.m. of Pb in the surface 2.5 cm. of soil, and 95 p.p.m. of Pb at a depth of 15 cm. The surface 2.5 cm. of soil from the bank of a well-traveled four-lane highway contained 59 p.p.m. of Pb (Marten and Hammond, 1966).

The previously cited references provide only scanty information and are not sufficiently detailed to evaluate possible accumulations of Pb in soils in regions subjected to abnormally high levels of Pb in the atmosphere. The objective of the present study was to evaluate lead contents and accumulations of Pb in regions of high and low motor vehicle traffic density in southern California.

Experimental

The Department of Soils and Plant Nutrition, University of California, Riverside, has kept soil samples from field experiments which date back as early as 1919. The samples are stored in closed containers, and records providing the date, location, and depth sampled are on file. The Pb contents of a number of these soils, which were collected from 35 to 50 years ago, were determined.

Soil samples were collected from the same locations and depths in 1967 and their Pb contents determined. The locations sampled were selected from areas of high and low population and motor vehicle traffic density.

Total Pb content of the soils was determined as follows. The bulk soil sample was air dried at room temperature and passed through a 1-mm. plastic screen. A representative subsample was then passed through a 40 mesh (0.42 mm.) screen and ground to a fine powder in an agate mortar. Duplicate samples of 0.250 gram of the finely powdered soil were weighed into platinum dishes and ignited at 450° C. to destroy the organic matter. The samples were decomposed using a mixture of $HClO_4$ and HF (Bradford, Pratt, *et al.*, 1965). The residue was dissolved in about 40 ml. of 0.003N HCl. Two and one-half milliliters of 5% ammonium pyrrolidine dithiocarbamate (APDC) were added and the mixture adjusted to pH 2.8 with HCl. This pH was maintained throughout the entire Pb extraction process. The mixture containing the APDC was warmed to a temperature of about 70° C. for 1 hour and then transferred to a separatory funnel. After the contents of the funnel had cooled to room temperature, 5 ml. of chloroform were added. The mixture was shaken and the Pb separated in the chloroform phase. Extracting with chloroform was repeated two additional times. The chloroform phase was taken to dryness using heat from an incandescent lamp. The residue was dissolved in an appropriate volume of 4N HNO_3 and the Pb content determined using an atomic absorption spectrometer. Using the procedure described, the recovery of Pb added to soils ranged between 95 and 105%; so the methods used were sufficiently quantitative for our purposes.

The soils collected were virgin alluvial soils, slightly acid to slightly alkaline (pH saturated paste ranged between 5.4 and 7.4) and, except for the surface samples, contained less than 1% organic matter. All locations sampled were one mile or more from a major highway.

Motor vehicle traffic densities were computed by taking the total 1967 population within a 10-mile radius from the location sampled, and dividing by 1.9, the average number of persons per motor vehicle for southern California.

The total Pb content of the soils was expressed on the basis of the weight of the soil dried at 110° C. for 48 hours.

Results and Discussion

Lead Contents in Surface Soils as Related to Motor Vehicle Traffic Density. In Table I, the Pb contents of soil samples collected 35 to 50 years ago are compared to the Pb contents of soil samples collected from the same location in 1967. The data show no direct relation between motor vehicle traffic density and Pb accumulation in soils, but do show much greater accumulations in soils from areas of high motor vehicle traffic density (*i.e.*, >580 motor vehicles per square mile as compared to <80 motor vehicles per square mile).

The cities of La Verne, Puente, Whittier, La Habra, and Tustin are within the Los Angeles metropolitan area. The Los Angeles metropolitan area includes parts of both Los Angeles and Orange counties. Its area encompasses some 3200 square miles, with an estimated population, in 1967, of 8,500,000 (Commercial Atlas & Marketing Guide, 1968). The average number of persons per motor vehicle in southern California is 1.9 (Dept. of Motor Vehicles, Riverside, Calif.) so the traffic density for the Los Angeles metropolitan area is about 1400 motor vehicles per square mile. The atmospheric Pb concentration in the city of Los Angeles in 1963 averaged 5.08 μg. per m.^{3} with a low and high of 2.91 and 9.05 μg. per m.^{3}, respectively (Robinson and Ludwig, 1967). Our data (Table I) show a maximum accumulation of Pb in the surface 2.5 cm. of soils from the metropolitan Los Angeles area to be 40 p.p.m. over a period of about 40 years. Lead concentrations of soils throughout the world which are not subjected to atmospheric pollution vary widely with a normal range of 10 to 200 p.p.m. (Mitchell, 1964). Extreme values considerably in excess of 200 p.p.m. are found near Pb ore deposits. Under the conditions outlined above, the data point out that, on a regional basis, Pb accumulations for the area tested do not exceed Pb contents of soils from many parts of the world which have not been subjected to excessive atmospheric pollution from Pb.

Table I. Accumulations of Pb in the Surface 2.5 cm. of Soils as Related to Motor Vehicle Traffic Density

Location	Pb Content,[a] p.p.m., Year Sampled: Between 1919 and 1933[b]	1967	Motor Vehicle Traffic Density,[c] Motor Vehicles per Sq. Mi.
La Verne	17	52	735
Puente	16	52	1525
Whittier	16	39	2475
La Habra	17	50	1475
Tustin	16	31	1370
Riverside	17	38	580
San Bernardino	12	24	630
Hemet	19	21	25
Santa Paula	21	23	80
Meloland	26	25	50

[a] Oven dry weight basis, 110° C. for 48 hours.
[b] Year sampled: Whittier and Riverside, 1919; Santa Paula, 1926; San Bernardino, 1927; La Verne, Puente, Tustin, 1928; Hemet, 1930; Meloland, 1931; La Habra, 1933.
[c] Computed by taking total 1967 population within a 10-mile radius from the site sampled, and dividing by the average number of persons per motor vehicle for southern California.

Others (Cannon and Bowles, 1962; Lagerwerff, 1966) have shown that Pb contents of soils collected within 30 meters from well-traveled highways are considerably greater (100 to 1000 p.p.m.) than those we have observed. Our study was not designed to evaluate this factor but was designed to examine accumulations of Pb over long periods of time. All locations sampled in our study were 1 mile or more from major highways, so comparing our results to those of others suggests that the more excessive accumulations of Pb in soils caused by heavy motor vehicle traffic are localized near the point where the Pb is discharged into the atmosphere.

In Los Angeles County, for the period 1940 through 1967, about 47 billion gallons of leaded gasoline were combusted (Fuller, 1968). If we assume that 75% of the Pb in this gasoline was released to the atmosphere and deposited uniformly over the surface of Los Angeles County (area 4083 square miles), that the proportion of regular and premium gasoline used are 70 and 30%, and taking the Pb contents of regular and premium gasoline as 1.5 and 2.1 grams per gallon, respectively, then the amount of Pb accumulated on the surface of Los Angeles County for the 27-year period would be about 15 metric tons per square mile. This figure neglects atmospheric transport of Pb outside of the county, as well as transport into the county. The above figure would be quite conservative for the heavily populated areas of Los Angeles and Orange Counties. However, on this basis, if we assume that Pb contamination is concentrated in the surface 2.5 cm. (the data in Table II show this to be the case) then Pb accumu-

Table II. Amounts of Pb in Contaminated Soils at Various Depths in the Soil Profile

Location	0–2.5	2.5–15	15–30	30–45
	Depth Sampled (cm.) Pb content[a] p.p.m.			
La Verne	52	19	12	16
Puente	52	15	13	16
Whittier	39	20	15	15
La Habra	50	19	16	15
Tustin	31	15	14	16
Riverside	38	18	16	20
San Bernardino	24	11	13	16
Hemet	21	15	13	15
Santa Paula	23	15	13	20
Meloland	25	18	14	15

[a] Oven dry weight basis, 110° C. for 48 hours.

lation for the soils in Los Angeles County for the 27-year period would be about 150 p.p.m. (mgm. Pb/Kgm. soil). The observed accumulation for the Los Angeles metropolitan area was about 40 p.p.m. for a 40-year period.

Riverside and San Bernardino, showing an accumulation of 21 and 12 p.p.m. of Pb for a period of 49 and 40 years, respectively, are about 60 miles east of the center of Los Angeles. The 1967 population for the Riverside-San Bernardino metropolitan area (1513 square miles) is estimated as 605,000 (Commercial Atlas and Marketing Guide, 1968). The area to the north, south, and east of the metropolitan area is sparsely populated, being either mountains or deserts.

The soils sampled near Hemet, Santa Paula, and Meloland showed no accumulation of Pb over the period observed (about 30 years). Hemet is an agricultural community located about 30 miles southeast of Riverside, at the base of the San Jacinto Mountains. The only large population area within a 30-mile radius is Riverside. Meloland is a desert agricultural community in the Imperial Valley. The nearest centers of population are Yuma, Ariz., about 50 miles to the east, and San Diego, Calif., about 120 miles to the west. Santa Paula is in Ventura County about 50 miles north of Los Angeles city. The Ventura-Oxnard metropolitan area, with a population of 182,000 (Commercial Atlas and Marketing Guide, 1968) is between 15 and 20 miles from the location where the soil samples were collected.

Lead Concentrations of Contaminated Soils at Various Depths in the Soil Profile. Results presented in Table II give the distribution of Pb as a function of depth in the soil profile. They show that practically all of the Pb which has accumulated remained in the surface a few centimeters. The soils investigated were virgin soils and, as far as we are aware, were not disturbed over the period of time tested. Consequently, the accumulations observed should represent maximum accumulations because periodic cultivation of soils will serve to dilute the surface concentration.

In those locations where little or no accumulation of Pb occurred (Hemet, Santa Paula, and Meloland), amounts of Pb in the surface 2.5 cm. are slightly greater than the amounts of Pb found at lower depths. This increase in the surface may be due to plant cycling of Pb which has been observed by others in other areas (Mitchell and Reith, 1966).

Summary and Conclusions

Amounts of Pb accumulated in the surface of 2.5 cm. of soils from the Los Angeles metropolitan area, over a period of about 40 years, ranged between 15 and 36 p.p.m. of Pb. These amounts are considerably below levels which may cause toxicities to economic plants, or which may cause abnormally excessive accumulations of Pb in the plants. Therefore, immediate problems associated with soil pollution of Pb caused by high motor vehicle traffic density for this area are not anticipated.

Soils from regions of low motor vehicle traffic density did not accumulate Pb over a period of about 40 years.

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