

Atmospheric pollution in Beijing, China, as recorded in sediments of the Kunming Lake

Mao Meizhou¹, Liu Zihui¹, Dong Huiru¹, Liu Jingyi¹

Kathe K. Bertines², Minoru Koide³ and Edward D. Goldberg³

(Received November 8, 1989)

Abstract—The fluxes of heavy metals and magnetite, a fly-ash component, from coal burning, to sediments of the Kunming Lake in Beijing have increased measurably over the last fifty years. Ages were introduced to the sediment strata through Pb-210 geochronologies. Even with a doubling of coal usage by the year 2000, the anthropogenic metal fluxes will still be less than those recorded in metropolitan Tokyo and U.S. lakes.

Keywords: atmospheric pollution; sediment; heavy metal; geochronology.

INTRODUCTION

A historical record of environmental pollution may be recorded in sediments of closed or semi-close bodies such as lakes or reservoirs. Especially attractive are those deposits that are anoxic and undisturbed by the activities of burrowing organisms. Previously, we have studied such records recovered from the Palace Moat sediments of Tokyo, Japan (Goldberg, 1979), the California Basins (Bruland, 1974), Lake Michigan (Goldberg, 1981) and New Haven, Connecticut (Bertine, 1978). For example, in the Tokyo sediments over the three decades following World War II there were increasing concentrations of such metals as zinc, copper, chromium, silver, lead, cadmium, cobalt and nickel in the deposits, reflecting increased industrial activities and energy production. Materials introduced to the atmosphere such as these metals and organic compounds enter the deposits through dry or wet fallout to the water body and subsequent sedimentation processes. The time frames in these studies were introduced through Pb-210, Cs-137 and Pu-239+240 geochronologies.

Herein, the historical records of metal pollution resulting from the extensive coal burning and industrial activity in Beijing, China, are sought through analysis of sediment recovered from the Kunming Lake in the city.

¹Research Center for Eco-Environmental Sciences, Academia Sinica, Beijing 100083, China.

²San Diego State University, San Diego 92182, California, USA.

³Scripps Institution of Oceanography, La Jolla 92093, California, USA.

MATERIALS

The core was taken from the lake bed in one meter deep of water in shore of the Kunming Lake, Beijing on 13 April 1987. The core of sediment in 40cm long was recovered within a 10cm polyvinyl chloride tube which was inserted into the deposit by hand. Aquatic weeds were growing in the vicinity of the deposit and there were some weed remanats in the core itself. This coverage protected the deposit from erosion and trespass by humans. The surface sediments in the central part of the lake had been disturbed by the activities of boaters and fishermen who sought their catch by dragging nets along the bottom.

Immediately after sampling, the sediment was frozen with dry ice. The following day after extrusion and partial thawing, the sediment was sectioned into one centimeter segments and subsequently dried at 110°C.

ANALYTICAL TECHNIQUES

The analyses for metals were carried out in Beijing, The People's Republic of China, using X-ray fluorescence methods. The Pb-210 determinations were made in La Jolla, California, USA, through the measurement of Pb-210. The results were corrected to radioactive equilibrium for the two nuclides. The magnetic susceptibility measurements using an AC bridge (Locke, 1986) were carried out in La Jolla.

RESULTS

There appears to be a valid time frame based upon the Pb-210 geochronolgy. An exponential decay is observed for the stratum from the surface of sediment down to about 7 or 8 cm depth at which there is a disappearance of unsupported Pb-210. The supported Pb-210 is taken as 1.69 dpm (the average value from 19 to 37 cm) at a sedimentation rate of 1.4 mm/a computed (Table 1 and Fig. 1). Thus, the upper seven centimeters maintain a record of about fifty years.

The metals analyses are presented in Table 2. It is evident that increased levels of some metals (Zn, Cu, Ni, Co, Fe, Mn, Al, Mg and Pb) occur in the upper 7 cm, corresponding to the latest fifty years. For these metals, the values above 7 cm are two standard deviations or greater than those below 7 cm where nearly constant concentrations are found.

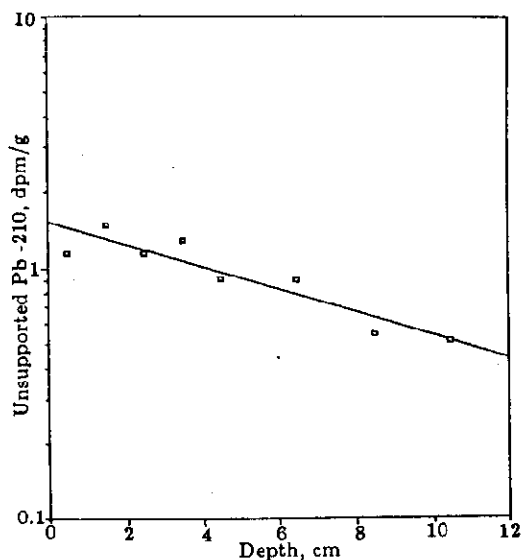


Fig. 1 The Pb-210 profile in the sediment of the Kunming Lake
The points represent the mid-points of one centimeter segments of the core

Table 1 The Pb-210 activities in the core, adjusted to be in equilibrium with Pb-210 and corrected for supported Pb-210 taken as 1.69 cpm/g

Depth, cm	Pb-210 dpm/g	
	Uncorr.	Corr.
0.00	2.91	1.22
	3.25	1.56
1.00	2.91	1.22
2.00	3.06	1.37
3.00	2.67	0.98
4.00	2.66	0.97
6.00	2.30	0.61
8.00	2.27	0.62
10.00	1.86	0.17
19.00	1.91	0.22
23.00	1.54	
29.00	1.93	
34.00	1.85	
38.00	1.57	
	1.57	
Average		
19 to 39	1.69	

Table 2 The metal concentrations in the sediments of the Kunming Lake

Depth, cm	Zn, ppm	Cu, ppm	Ni, ppm	Co, ppm	Fe, %	Mn, ppm	V, ppm	Ti, ppm	Al, %	Mg, ppm	Sr, ppm	Pb, ppm	Magnetite, %
0.00 - 1.00	68.00	26.00	10.00	6.20	2.10	240.00	49.00	2600.00	4.90	11000.00	1300.00	27.00	0.20
1.00 - 2.00	59.00	28.00	5.80	4.50	1.80	220.00	35.00	2200.00	4.20	9900.00	1700.00	24.00	0.08
2.00 - 3.00	49.00	21.00	5.50	2.80	1.60	200.00	33.00	2000.00	3.60	9000.00	1900.00	15.00	0.08
3.00 - 4.00	44.00	21.00	4.40	2.40	1.50	180.00	24.00	1800.00	3.60	8900.00	2300.00	14.00	0.06
4.00 - 5.00	51.00	22.00	5.10	3.50	1.60	200.00	35.00	2100.00	4.00	9200.00	2000.00	17.00	0.03
5.00 - 6.00	47.00	23.00	2.70	2.80	1.50	180.00	25.00	1900.00	3.60	8700.00	2300.00	14.00	0.02
6.00 - 7.00	39.00	18.00	0.80	2.60	1.30	170.00	24.00	1800.00	3.30	8400.00	2400.00	13.00	0.02
7.00 - 8.00	42.00	20.00	0.80	2.50	1.40	180.00	26.00	1800.00	3.30	8200.00	2500.00	17.00	0.02
8.00 - 9.00	40.00	18.00	1.30	2.30	1.40	170.00	30.00	1700.00	3.30	8600.00	2300.00	8.00	0.02
9.00 - 10.00	38.00	19.00	1.50	2.40	1.40	180.00	21.00	1700.00	3.10	7900.00	2500.00	7.50	0.02
10.00 - 11.00	40.00	21.00	nd	1.40	1.40	180.00	25.00	1700.00	3.20	8100.00	2500.00	11.00	0.02
11.00 - 12.00													0.02
12.00 - 13.00	39.00	18.00	nd	1.70	1.30	180.00	19.00	1600.00	3.10	7700.00	2500.00	8.50	0.02
13.00 - 14.00	39.00	19.00	0.00	2.00	1.30	170.00	19.00	1600.00	3.00	8100.00	2600.00	12.00	0.02
14.00 - 16.00	39.00	18.00	0.03	1.70	1.30	170.00	19.00	1700.00	2.90	7500.00	2500.00	11.00	0.02
16.00 - 18.00	37.00	17.00	1.50	1.90	1.30	170.00	26.00	1800.00	3.10	8100.00	2400.00	5.00	0.02
18.00 - 19.00	41.00	18.00	1.80	1.80	1.40	180.00	33.00	1800.00	3.30	8300.00	2400.00	11.00	0.03
19.00 - 20.00	42.00	18.00	0.60	1.80	1.30	170.00	26.00	1700.00	3.20	8300.00	2400.00	5.90	0.03
20.00 - 21.00	41.00	15.00	1.30	2.40	1.40	170.00	27.00	1900.00	3.50	8600.00	2300.00	7.00	0.03

Table 2 (Continued)

Depth, cm	Zn, ppm	Cu, ppm	Ni, ppm	Co, ppm	Fe, %	Mn, ppm	V, ppm	Ti, ppm	Al, %	Mg, ppm	Sr, ppm	Pb, ppm	Magnetite, %
21.00 - 22.00	44.00	18.00	3.30	2.10	1.30	170.00	23.00	1800.00	3.40	8600.00	2300.00	11.00	0.03
22.00 - 23.00	39.00	18.00	0.10	1.80	1.30	170.00	25.00	1800.00	3.30	8700.00	2300.00	7.30	0.02
23.00 - 24.00	40.00	18.00	3.70	1.90	1.30	160.00	20.00	1700.00	3.30	8800.00	2400.00	13.00	0.03
24.00 - 25.00	40.00	19.00	3.50	2.20	1.20	180.00	22.00	1800.00	3.30	8900.00	2300.00	11.00	0.03
25.00 - 26.00	41.00	18.00	2.00	1.30	1.20	180.00	28.00	1800.00	3.30	8400.00	2300.00	6.70	0.03
26.00 - 27.00	40.00	15.00	0.60	1.70	1.20	170.00	28.00	1700.00	3.20	8400.00	2400.00	9.50	0.03
28.00 - 29.00	39.00	17.00	0.40	0.40	1.20	170.00	26.00	1700.00	3.30	8300.00	2300.00	12.00	0.03
29.00 - 30.00	40.00	17.00	3.30	1.90	1.30	170.00	29.00	1700.00	3.30	8600.00	2300.00	9.30	0.03
30.00 - 31.00	47.00	15.00	4.70	1.50	1.30	180.00	26.00	1800.00	3.40	8100.00	2200.00	5.20	0.03
31.00 - 32.00	49.00	14.00	4.30	1.90	1.30	170.00	28.00	1700.00	3.40	8100.00	2200.00	7.90	0.03
32.00 - 33.00	41.00	17.00	1.60	1.90	1.20	190.00	26.00	1700.00	3.30	8600.00	2300.00	12.00	0.03
33.00 - 34.00	36.00	19.00	3.40	2.10	1.20	180.00	22.00	1700.00	3.30	8500.00	2400.00	12.00	0.03
34.00 - 35.00	37.00	18.00	1.30	2.40	1.30	170.00	18.00	1800.00	3.40	8500.00	2300.00	6.80	0.03
35.00 - 36.00	39.00	18.00	3.70	2.20	1.30	180.00	20.00	1800.00	3.40	8500.00	2300.00	8.80	0.02
36.00 - 38.00	38.00	18.00	4.40	1.80	1.20	180.00	23.00	1700.00	3.40	8200.00	2300.00	9.00	0.03
38.00 - 39.00	39.00	17.00	1.10	2.40	1.20	180.00	20.00	1800.00	3.50	8600.00	2300.00	5.10	0.02
40.00 - 41.00	42.00	17.00	3.80	2.90	1.40	200.00	25.00	2000.00	3.80	9300.00	2100.00	13.00	0.03
Average 0 - 7cm	51.00	23.00	4.90	3.50	1.60	200.00	32.00	2100.00	3.90	9300.00	2000.00	18.00	0.07
Average 8 - 40cm	40.00	18.00	1.90	1.90	1.30	180.00	24.00	1800.00	3.30	8300.00	2400.00	9.40	0.03
Standard deviation	2.70	1.50	1.50	0.50	0.10	8.00	4.00	100.00	0.20	350.00	100.00	2.80	0.01

In comparison to the levels of metals below 7 cm, the excessive concentrations of metals in the surface sediment show a potential origin in fly-ash, especially from the sources without dust precipitation facilities. In Table 3, these excessive metal concentrations are compared with the metal levels in fly-ash from coal burning (Klein, 1975) and the strong similarities are noted. The metal concentrations of the Kunming Lake are around one order of magnitude less than in the fly-ashes. Clearly, the compositions of the fly-ashes are dependent on their sources.

The correspondence between the fly-ash and sediment compositions is permissive evidence for the entry of airborne coal burning residues to the lake deposits.

The magnetite concentrations begin their measurable increase toward the surface from about 4 cm depth which corresponds to about 1958 (Table 2). Like metals, magnetite has an origin in fly-ash. The magnetite concentrations, like the case of metals, in Beijing are similar to those in sediments from the coastal ocean, Connecticut Lakes, and Lake Michigan, adjacent to the regions of coal burning, but much lower than those from Tokyo (Goldberg, 1979; Bruland, 1974; Bertine, 1978; Locke, 1986).

Table 3 Excessive metal concentrations in surface sediments of the Kunming Lake compared with the concentrations in TVA and NBS fly-ashes

Elements	TVA fly-ash	NBS fly-ash	Kunming Lake Excess
Al	9.9%	12.7%	1.6%
Fe	12.1	6.37	0.8
Mg	10600 ppm	19800 ppm	2800 ppm
Zn	740	208	28
V	440	240	25
Mn	298	460	60
Ni	207	109	8
Cu	140	133	18
Pb	80	78	18
Co	39	46	1.3

COMPARISON OF DATA

The fluxes of metals to coastal marine or lacustrine sediments in Japan and in the United States as a function of time have been determined previously by the California laboratory. Different sampling techniques and analytical methods were used and thus there is always the possibility of systematic errors. The data are compared in Table 4.

Table 4 Anthropogenic fluxes of metals to the Beijing Kunming Lake, Tokyo Palace Moat, Connecticut Lakes and California Basins

Elements	Flux to sediment in $\mu\text{g}/\text{cm}^2$ per year				
	Beijing Kunming Lake	Tokyo Palace Moat	Calif. Basins	Lake Whitney	Lake Salton-stall
Zn	2.1	600	2.1	90	22
Cu	0.82	130	0	614	164
Ni	0.3	19	0	27	0.8
Co	0.18	7.7	0	0	0
Fe	600	2000	0	440	880
Mn	7.2	320	0	429	77
Pb	0.82	130	1.6	330	9.8
V			4	51	3.1

The anthropogenic fluxes of metals to the Kunming Lake are substantially less than those to the Tokyo Palace Moat and the U.S. lake sediments but similar to those to the California basin sediments (the same sediment parameters are used for the calculation of the Kunming Lake fluxes as did for the Tokyo Palace Moat). The anthropogenic contributions to the total metal contents of the surface sediments are similar for both the Palace Moat in Tokyo and the Kunming Lake in Beijing with the exception of copper and lead higher than those in the California Basin sediments (Table 5). These differences probably reflect the source terms

Table 5 The anthropogenic to total metal contents of some surface sediments (Concentrations in ppm except Fe in %)

Metal	Concentration in sediment				Anth./Total metal ratio		
	Lake Michigan [#]	Palace Moat Tokyo	Kunming Lake Beijing	Calif. Basin [*]	Lake Michigan	Palace Moat Tokyo	Kunming Lake Beijing
Zn(A)	300	900	28	0.29	0.85	0.64	0.41
Zn(T)	350	1400	68				
Cu(A)	35	100	9	0.45	0.63	0.33	0.33
Cu(T)	55	300	27				
Ni(A)	10	15	8.1	0	0.33	0.33	0.8
Ni(T)	30	45	10				
Co(A)	3	6	4.3	0	0.25	0.33	0.69
Co(T)	12	18	6.2				
Fe(A)	2	0.5	0.8	0	0.47	0.11	0.38
Fe(T)	4.3	4.7	2.1				
Mn(A)	1000	0	60	0	0.63	0	0.25
Mn(T)	1600	800	240				
Pb(A)	120	150	17.6	0.7	0.92	0.47	0.65
Pb(T)	130	320	27				

*Bruland *et al.*, 1974; #Goldberg *et al.*, 1976.

dependent of coal burning primarily in Tokyo and Beijing as well as industrial activity in southern California. Lead, to a significant extent, comes from its use as an antiknock agent in gasoline.

OVERVIEW

It is estimated that by the year 2000 annual coal burning in China will be doubled from the 1982 annual usage of 666 million tons (Heise, 1988). Without improving emission controls, the anthropogenic metal fluxes to the Kunming Lake can also be expected to be doubled. Still, they will not attain the values of those of Tokyo and U.S. lakes.

These Beijing results are not in compliance with the urban air quality values of the Global Environment Monitoring System (UNEP, 1987) where Tokyo had suspended particulate matter and sulfur dioxide air burdens far less than Beijing did. Both of these measurements do reflect the intensity of coal burning.

This discrepancy may result from the large variations found in cities due to the type, number and location of pollutant sources, the type of air pollution control employed and the general meteorological and topographical features that govern atmospheric dispersion.

Acknowledgements—These researches were supported by a Research Grant from the National Geographic Society to the Regents of the University of California at San Diego. The Pb-210 actives were measured in the laboratory of Professor Kenneth Bruland, University of California at Santa Cruz. The instrumentation for measuring the magnetic susceptibilities was provided by Professor Liza Tauxe of the University of California at San Diego. We are grateful for the assistance of these colleagues.

REFERENCES

- Bruland, K.W., Bertine, K., Koide, M. and Goldberg, E.D., *Environ. Sci. Technol.*, 1974, 8:425
Bertine, K.K., Mendeck, M.F., *Environ. Sci. Technol.*, 1978, 12:201
Goldberg, E.D., Hodge, V.F., Koide, M. and Griffin, J.J., *Geochem. J.*, 1979, 10:165
Goldberg, E.D., Hodge, V.F., Griffin, J.J., Koide, M. *et al.*, *Environ. Sci. Technol.*, 1981, 15:466
Heise, L., *World Watch*, 1988, 1:12
Klein, D. *et al.* *Environ. Sci. Technol.*, 1975, 9:973
Locke, G., Bertine, K.K., *Appl. Geochem.*, 1986, 1:345
UNEP, *Global Pollution and Health*, 1987, 4