# Changes in lead concentration in Antarctic penguin droppings during the past 3,000 years

Liguang Sun · Zhonqing Xie

**Abstract** Anthropogenic lead (Pb) has been found in Antarctic seawater, surface snow and ice-cores. Here, we analyzed a 3,000-year record of lead concentration in lake sediments affected by penguin droppings. We found that lead concentration in penguin droppings has significantly increased during the last 200 years, especially in the last 50 years, as compared to low and stable lead levels prior to the Industrial Revolution. This clearly indicates that global environmental pollution has influenced the Antarctic ecological system. Heavy metal (Pb) may find its way into the food web, bioaccumulate, and be passed along the chain to penguins.

**Keywords** Antarctica · Lead · Penguin droppings · Environmental pollution

## Introduction

Despite its remote location Antarctica has been contaminated by human activities (Bonner 1994; Chen and Blume 1995). Many reports exist of soil, water, snow and atmospheric pollution around scientific research stations by heavy metals, organic matter such as polycyclic aromatic hydrocarbons (PAH), sulfur dioxide ($SO_2$) and fluorine compounds (Molski and others 1981; Boutron and Patterson 1983; Batifol 1989; Flegal and others 1993; Green and Nicholas 1995). Radioactive debris including $^{137}$Cs, resulting from nuclear atmospheric tests can also be detected in lake sediments and ice or snow (Koide 1982; Appleby 1995; Sun and others 2001). Organochlorine residues in Antarctic wildlife and snow (e.g., DDT, PCB, PCH) have been found (Sladen 1966; Peel 1975; Risebrough and others 1976; Tanabe and others 1983). Preservation and protection of the Antarctic environment is now becoming an urgent issue (Bonner 1990; Campbell and others 1994). Numerous studies are being carried out to monitor the impact of human activities on the terrestrial or marine ecosystem of Antarctica and are expected to reveal ways to protect this relatively pristine continent. However, little is known about long-term change in the Antarctic ecosystem during the past several 1,000 years. This makes it difficult to distinguish between anthropogenic factors and natural variables causing environmental change.

In this note, we report on changes in lead concentration in Antarctic penguin droppings during the past 3,000 years found in a lake core from Ardley Island, Antarctica. Historically, the fluctuation of lead concentrations will illustrate human activities, which may have affected the Antarctic marine ecosystem in recent years.

Received: 23 February 2001 / Accepted: 8 April 2001
Published online: 17 May 2001


L. Sun (✉) · Z. Xie
Institute of Polar Environment,
University of Science and Technology of China,
Hefei, Anhui, 230026, PR China
E-mail: slg@ustc.edu.cn

## Sample location

Ardley Island (62°13′S, 58°56′W) is 2.0 km in length and 1.5 km in width and was defined as a site of special scientific interest by the Scientific Committee on Antarctic Research (SCAR). It is free of snow- and ice during the summer. Geologically, it consists mainly of Tertiary andesitic and basaltic lavas and tuffs together with raised beach terraces. The island is situated about 500 m east of the coast of Fildes Peninsula, Maxwell Bay, King George Island. The Russian station Bellingshausen and the Chilean station Teniente Marsh are both about 1 km north-west of the island, and the Great Wall Station of China is located about 0.5 km to the west. A German refuge hut near Braillard Point and two other refuge huts are situated near the middle of the northern coast of the island. There is a diverse avifauna with 12 breeding species. It is of particular importance for its breeding colonies of Gentoo penguins (*Pygoscelis papua*), Adélie penguins (*Pygoscelis adeliae*) and chinstrap penguins (*P. antarctica*). Other breeding species of particular importance are southern giant petrels (*Macronectes giganteus*), Wilson's storm petrels (*Oceanites oceanicus*) and black-bellied storm petrels (*Fregatta tropica*). Scientists, especially Chilean and East German scientists, carried out ornithological and botanical studies on Ardley Island for many years. In addition to scientific activities, numerous visitors come to the island every austral Antarctic summer. Thus, anthropogenic contamination is to be expected on the island (Sun and Xie 2001).

## Sample collection and analysis method

A lake sediment core (Y2), 67.5 cm in length, was taken by driving a PVC pipe with 12-cm diameter into the soft substrate of the lake floor on Ardley Island (Fig. 1) during the fifteenth Chinese Antarctic Research Expedition (December 1998–March 1999). The core spanned almost 3,000 radiocarbon years and discharged an "unpleasant smell" (Sun and others 2000a, 2000b, 2000c). The upper 64 cm was sectioned at 1.0-cm intervals. One sample was taken for the bottom section covering 64 to 67.5 cm. Each section was air-dried and placed inside a clean polyethylene plastic bag. Subsamples were pulverized into powder using an agate mortar and pestle, after which the >200-mesh fraction was separated from the powder to be analyzed. The concentrations of Pb in the subsamples were determined using atomic absorption spectrometry (AAS). Total organic carbon (TOC) in the sediment was measured using the carbon analysis instrument CR12 according to the principle SY/T 5117–1996.

The droppings of other organisms living on this island were collected. The analysis method was the same as that used for sediments.

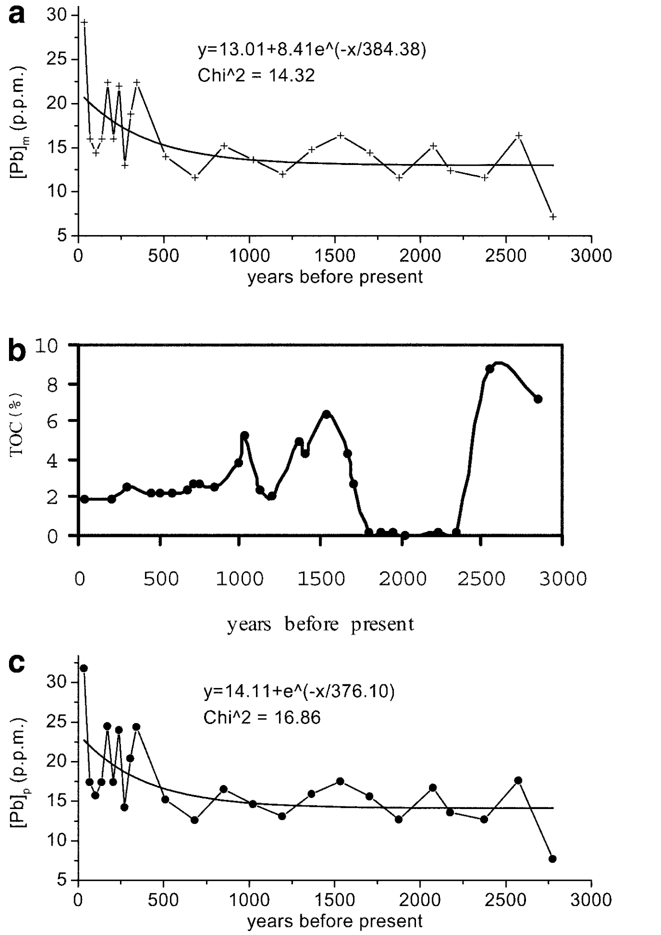


**Fig. 2**
Lead concentrations in penguin droppings. **a** Lead concentration versus depth in Y2 lake sediments. **b** Total organic carbon (TOC%) in Y2 lake sediments. **c** Lead concentration against depth for penguin droppings

## Results and discussion

The concentrations of lead in 24 Y2 lake sediment subsamples, plotted against time in Fig. 2a, are between 7.60 and 29.20 ppm. with a mean value of 15.69 ppm and a standard deviation of 4.61 ppm. As shown in Fig. 2a, there was a significant increase during last 200 years. The average lead concentration for the upper 10 cm of 10 Y2 lake sediment samples is 19.02±4.95 ppm, corresponding to a time span of about 200 years. This is significantly higher than the average concentration of 13.31±2.46 ppm for the bottom 57.5 cm of the 14 Y2 lake sediment samples. Y2 lake received lead from four major sources: (1) lakeside rocks and soils; (2) organic matter including penguin droppings; (3) anthropogenic lead transported over long distances and deposited; and (4) anthropogenic lead from local scientific research stations. The Pb concentrations in the historical penguin droppings are calculated (see equations below) based on the assumptions that: (1) as the organic matter was primarily from penguin droppings, moss and phytoplankton were not included; (2) the ratio of Pb distribution in penguin droppings and soils remains constant with the considered time period; and (3) lead concentrations in penguin droppings in the surface sediment are the same as in fresh penguin droppings.

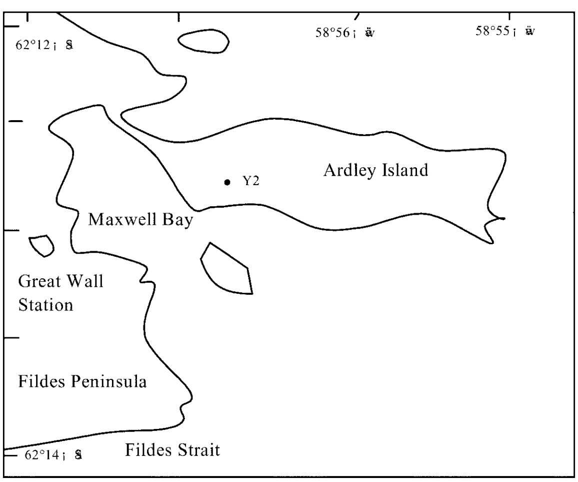


**Fig. 1**
Map of Ardley Island and sampling location of Y2 lake

Based upon these assumptions, the Pb concentrations in penguin droppings were calculated from total organic carbon in the lake sediment ($[TOC\%]_m$) (Fig. 2b) and in the fresh penguin droppings ($[TOC\%]_p$), and the ratio of

Pb concentration in fresh penguin droppings versus that in surface soil according to the methods illustrated below and plotted against depth in Fig. 2c.

$$x\% \times M \times [Pb]_s + y\% \times M \times [Pb]_p = 100\% \times M \times [Pb]_m \quad (1)$$

where

$[Pb]_p$ lead concentration in penguin droppings (p.p.m.);
$[Pb]_s$ lead concentration in sediments except penguin droppings (p.p.m.);
$[Pb]_m$ lead concentration in sediments (ppm);
M total weight of sediment (g);
x% percentage of non-penguin droppings in the lake sediments;
y% percentage of penguin droppings in the lake sediments.

We have measured the TOC% in fresh penguin droppings, which is 22.83%, so

$$y\% = 100[TOC\%]_m/22.83\% \text{ and } X\% = 100\% - y\% \quad (2)$$

$$[Pb]_s/[Pb]_p = 0.91 \quad (3)$$

taken as the ratio of Pb concentration in surface sediment excluding penguin droppings and that in fresh penguin droppings.Combining these equations together, we have

$$[Pb]_p = [Pb]_m/(0.91x\% + y\%) \quad (4)$$

As shown in Fig. 2c, Pb concentration in penguin droppings in the upper 10 cm of the lake sediments is significantly higher than that in the lower 57.5 cm. Penguin droppings from the sediments of the upper 10 cm has an average Pb concentration of 20.72±5.40 ppm ($n$=10), and those from the lower 57.5 cm has an average lead concentration of 14.43±2.63 ppm ($n$=14). A statistical T-test (t: –3.80; P: 9.89E-4; confidence level: 95%) indicates that the difference is significant. The average Pb concentration in non-penguin droppings in the lake sediments is 18.87±4.90 ppm ($n$=10) in the sediments of the upper 10 cm and 13.15±2.40 ppm ($n$=14) for lower 57.5 cm. The difference is also statistically different as seen from T-test (t: –3.74; P: 1.14E-4; confidence level: 95%).

Ten centimeters of Y2 lake sediments corresponds to a time span of about 200 years. Figure 1c indicates that the Pb concentration in penguin droppings has significantly increased during the last 200 years prior to which the Pb concentration in penguin droppings remained at a steady and low level.

One possible explanation may be that Pb produced by human activity was transported to Antarctica via long-distance atmospheric transport and oceanic circulation. Lead has been found to be enriched in krill, with a level of 7.553 ppm (Zhao 1991) and other marine plankton. Thus, high Pb levels in penguins, one of the krill-eating Southern Ocean predators, could be estimated and some of the lead absorbed by penguins will be discharged via droppings. This is demonstrated by the concentrations of lead in the droppings of organisms listed in Table 1. The data show that droppings are enriched in lead in comparison to lake sediments. Especially fresh droppings of giant petrels contain a high level of lead, approximately two times that in other droppings. The behavior of giant petrels differs somewhat from the behavior of other organisms. In austral Antarctic winter, it flies great distances northward from Antarctica. The very high Pb concentrations in giant petrel excreta may be related to extensive environmental pollution in the Northern Hemisphere. During the past 50 years, lead in penguin droppings may also have come from pollution caused by scientific research stations.

**Table 1**
Lead concentrations in fresh penguin droppings and in droppings from other organisms in Antarctica

| Sample numbers[a] | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pb (ppm) | 31.95 | 25.51 | 27.44 | 24.64 | 55.23 |

[a]1, Fresh penguin droppings; 2, fresh seal droppings; 3, fresh skua droppings; 4, fresh gull droppings (*Larus dominicanus*); 5, fresh giant petrels (*Macronectes giganteus*) droppings

## Conclusions

Relics such as droppings may record the impact of human activities. Lead concentration in penguin droppings increased significantly during the last 200 years, and especially during the last 50 years, as compared to the low and stable lead level prior to the Industrial Revolution. This suggests that global environmental pollution has affected the Antarctic ecological system. Heavy metal (Pb) may bioaccumulate in penguin through the food web.

**Acknowledgements** We thank the Polar Office of the National Oceanic Bureau of China for its support. Dr. Y.H. Wang (Merck Co., USA), Prof. Q.G. Zhao (Institute of Soil Science, the Chinese Academy of Sciences,P R China) and Prof. L.Q. Chen (Polar Office of National Oceanic Bureau of China) made valuable comments about the manuscript. The study was funded by the projects KZCX2-303 (the Chinese Academy of Sciences) and 40076032 (National Natural Science Foundation of China).

## References

Appleby PG, Jones VJ, Ellis-Evans JC (1995) Radiometric dating of lake sediments from Signy Island(maritime Antarctic): evidence of recent climatic change. J Paleolimnol 13:179–191
Batifol F, Boutron C, Martine de Angelis (1989) Changes in copper, zinc and cadmium concentration in Antarctic ice during the past 40,000 years. Nature 337:544–546
Bonner N (1990) International agreements and the conversation of Antarctic systems. In: Kerry KR, Hempel G (eds) Antarctic ecosystem. Ecological change and conversation. Springer, Berlin Heidelberg New York, pp 386–393
Bonner N (1994) Antarctic conservation and management. Polar Biol 14:301–305
Boutron C, Patterson CC (1983) The occurrence of lead in Antarctic recent snow, firn deposited over the last two centuries and prehistoric ice. Geochim Cosmo Acta 47:1335–1368

Campbell IB, Claridge GGC, Balks MR (1994) The effects of human activities on moisture content of soils and underlying permafrost from the McMurdo Sound region, Antarctica. Antarctic Sci 6:307–314

Chen J, Blume HP (1995) Impact of human activities on the terrestrial ecosystem of Antarctica: a review. Polarforschung 65:83–92

Flegal AR, Maring H, Niemeyer (1993) Anthropogenic lead in Antarctic sea water. Nature 365:242–244

Green G, Nicholas PD (1995) Hydrocarbons and sterols in marine environments and soils at Davis Station, Antarctica: a survey for human-derived contaminants. Antarct Sci 7:137–144

Koide M, Michel R, Goldberg ED, Herron MM, Langway CC (1982) Characterization of radioactive fallout from pre- and post-moratorium tests to polar ice caps. Nature 296:544–547

Molski B, Bytnerowicz A, Dmuchowski W (1981) Air pollution with sulphur dioxide and fluorine compounds in the vicinity of the Arctowski Station, King George Island, South Shetland Islands. Polish Polar Res 2:87–93

Peel DA (1975) Organochlorine residues in Antarctic snow. Nature 254:324–325

Risebrough RW, Walker W, Schmidt TT, De Lappe BW, Connors CW (1976) Transfer of chlorinated biphenyls to Antarctic. Nature 264:738–739

Sladen WJL, Menzie GM, Reichel WL (1966) DDT residues in Adelie penguins and a crabeater seal from Antarctica. Nature 210:670–673

Sun LG, Xie ZQ, Zhao JL (2000a) A 3,000-year record of penguin populations. Nature 407:858

Sun LG, Xie ZQ, Zhao JL (2000b) The characteristics of Sr/Ba and B/Ga in Lake sediments on the Ardley Peninsula, maritime Antarctic (in Chinese with English Abstracts). Mar Geol Quat Geol 4:44–46

Sun LG, Xie ZQ, Zhao JL (2000c) The lake sediment of Ardley Peninsula, Antarctica: identification of penguin-dropping amended soil (in Chinese with English Abstracts). Chin J Polar Res 2:106–112

Sun LG, Xie ZQ, Zhao JL, Xiang L (2001) $^{210}Pb$,$^{137}Cs$ dating of lake sediments from Ardley Island (maritime Antarctic) and their environmental implication (in Chinese with English Abstract). J Lake Sci 13:93–96

Sun LG, Xie ZQ (2001) Relics: penguin poop scoop. Sci Prog (in press)

Tanabe S, Hidaka H, Tatsukawa R (1983) PCBs and chlorinated hydrocarbon pesticides in Antarctic atmosphere and hydrosphere. Chemosphere 12:277–288

Zhao JL (1991) The characteristics of the modern environmental evolution in the region of Antarctic Great Wall station (in Chinese with English Abstracts). Science Press, Beijing