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The sediments of lake on the Ardley Island, Antarctica: Identification of penguin-dropping soil

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Abstract During CHINARE-15 (Dec. 1998 - Mar. 1999), a lake core 67.5 cm in length, was sampled in Y2 lake, which is located on the Ardley Island, Antarctica. The concentrations of some chemical elements in Y2 lake sediments were analyzed. According to comparative research on elementary characters of sediments in Antarctic West Lake, fresh penguin dropping as well as guano soil on the Ardley Island and Pacific Island in South China Sea, it presents that the Y2 lake sediments were ameliorated by penguin dropping. The result of element cluster analysis shows that the type elements in the sediment impacted by penguin dropping include Sr, F, S, P, Ca, Se, Cu, Zn and Ba. This can provide a base for further interpreting the climatic and environmental event recorded in the sediment.

Key words Antarctica, Ardley Island, penguin dropping soil, type element.

1 Introduction

The ice-free area surrounding Antarctica appeared following the climate warming-up and ice regression. The sediment profile of lake formed during this period might completely record the course of the glacial advance and retreat as well as environmental change since Holocene. Therefore, many researchers have made researches on the Holocene lake sediment in Antarctica, especially the lake on the South Sheltland Island (Hodgson and Johnston 1997; Appleby *et al*. 1995; Xie *et al*. 1992; Yu *et al*. 1992; Bjorck *et al*. 1991, 1993; Zhao 1991a, b; Schmidt *et al*. 1990; Zhao 1990; Omoto 1982; Orland 1963). Different researchers used different methods to extract the message of environmental change through Antarctic lake sediment. Zhao (1991c) used biogeochemical method to analyze the sediment of West Lake near Great Wall Station, located on the King George Island of Fildes Peninsula, Antarctica. He quantificationally reconstructed the change of 4000 a precipitation in this area, moreover, and pointed out that the climate of King George Island was impacted by the Antarctic Convergence Zone, comparing with the 16000 a environmental change of South Chile. Appleby *et al*. (1995) used ^{210}Pb and ^{137}Cs dating the sediments of three lakes located on the Signy Island, South Sheltland and calculated the sedimentation rate. Based on the sedimentation rate and the concentration of ^{210}Pb and ^{137}Cs, he demonstrated that climate has been warming up in this region during the past 100 a. In addition, Hodgson and Johnston(1997) estimated the change of 100 a seal populations through hairs remained in the lake sediment on Signy Island and further pointed out that this change was affected by human activity. Here we focused on the elementary geochemistry characters of a 67.5 cm lake core (Y2) sampled on the Ardley Peninsula and identified that the Y2 lake sediment was ameliorated by penguin-droppings. This will provide a base for further illustrating the climatic and environmental event recorded in the sediment.

2 Environmental background, sample collection and analysis

2.1 Environmental background

Ardley Island linking the Fildes Peninsula by a sandy dam is a special ecological protection area (defined by SCAR), located near the Great Wall Station. The area of this island is about 2 km^2. The topography is plainness with a maximum 70 m height above sea level. There are populated with moss and lichen, which were evenly distributed and covered 70% - 80% area of the island. In the Antarctic austral summer (1993 - 1994), the number of penguins in this island is about 9854, major species of which are Gentoo penguins, Adelie penguins and Chintrap penguins. There are other seabirds such as skua and *Macronectes giganteus* living in this area. Krill, fish, shellfish and mollusk make up of the diets of penguin, of which krill occupies of 81.79%, 86.87% and 100% of diets for Adelie penguin, Gentoo penguin and Chinstrap penguin respectively. In the breeding period, it is estimated that penguins on the Ardley Island discharge about 139 t of droppings based on a hypothesis that every day a penguin excretes 84.5 g droppings (dry weight). Droppings were transferred by ice or snowmelt water and at last some of them were deposited in the lake (Wu *et al*. 1998).

2.2 Sample collection and analysis

During the sample collection, there was no water in the lake. We used a 12 cm diameter PVC pipe, which was cleaned firstly, to drill vertically into the Y2 lake bed, 12 m height above the sea level (Fig. 1) and extracted a 67.5 cm length lake core. It gave off a disagreeable smell. The lake core yields (2765 ±60) radiocarbon years. The sample was cold storage in laboratory. Y2 lake core was divided into 64 sections at 1.0 cm interval for the upper 64 cm and one section for the bottom 64 - 67.5 cm.

The concentrations of elements in lake sediments were analyzed by chemical methods including SiO_2(weighted method), Al_2O_3(EDTA VOL), Fe(K_2CrO_4 VOL), S(combustion-KI VOL), F(ISE), Sr, Ba (ICP-AES), P_2O_5, TiO_2, Cr, V, B (UVS), As, Se, Hg (AFS), K_2O, Na_2O, CaO, MgO, MnO, Pb, Ni, Cu, Zn, Ga (AAS).

3 Results and discussion

3.1 Cluster analysis of chemical elements

The concentrations of 26 elements in Y2 lake sediments were listed in Table 1. We

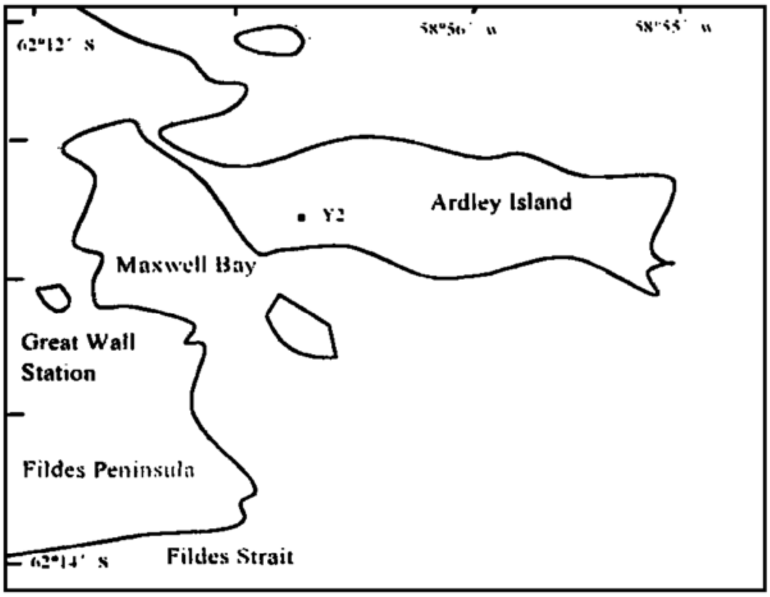

Fig. 1. Map of the Ardley Island and sampling location of Y2.

classified the 25 elements using R-mode cluster analysis according to their similar coefficients (see figure 2). It is clear that these elements were separated into three groups. The first group includes Sr, Cu, P_2O_5, Zn, S, CaO, Se, Ba and the second group includes SiO_2, Al_2O_3, MgO, NaO, TiO_2, Ga, V, Fe_2O_3, MnO, Ni, FeO, As, Cr, B and the elements in the last group are Pb, Hg, K_2O.

Table 1. The mean values and the variance coefficients of 26 elements in Y2 lake sediment

Element		Sr	Ba	S	P_2O_5	Se	Cu	Zn
Concentration ($\times 10^{-6}$)	Mean	1005.42	227.84	2190	61260	10.15	301.34	343.43
	Range	397 - 2134	144 - 279	140 - 6090	1620 - 150500	1.45 - 40.12	55.20 - 910	39.2 - 870
Variance coefficient (%)		50.95	16.49	66.21	64.61	104.93	74.05	71.79
Element		CaO	K_2O	MnO	Na_2O	MgO	FeO	Fe_2O_3
Concentration ($\times 10^{-6}$)	Mean	85080	6540	940	25090	22950	39030	28300
	Range	6400 - 168800	3800 - 39400	210 - 1430	5500 - 39600	5300 - 45300	13100 - 59100	600 - 60300
Variance coefficient (%)		38.49	107.19	26.60	31.73	45.45	25.98	54.81
Element		SiO_2	Al_2O_3	TiO_2	Pb	Hg	As	Ni
Concentration ($\times 10^{-6}$)	Mean	437870	131880	11670	15.69	0.073	4.993	9.169
	Range	276500 - 591200	70200 - 189300	1800 - 16600	7.20 - 29.20	0.019 - 0.298	2.37 - 13.13	4.8 - 17.6
Variance coefficient (%)		18.78	19.71	28.71	29.38	84.93	47.23	37.13
Variables		Cr	V	B	Ga	F	/	/
Concentration ($\times 10^{-6}$)	Mean	47.78	172.75	6.89	16.65	7700	/	/
	Range	24.80 - 69.80	21.00 - 314	2.20 - 14.31	9.00 - 23.40	2500 - 15200	/	/
Variance coefficient (%)		21.70	44.41	55.00	23.48	97.18	/	/

3.2 Determining the attribution of biogeochemical elements

Cu, Zn, Sr, Ba, Se, S, P and Ca in Y2 lake sediments are significantly correlate although the characteristics of these elements are different in the elemental periodic table. For example, Cu and Zn are generically elements relative to Cu, while Sr, Ba, Se are

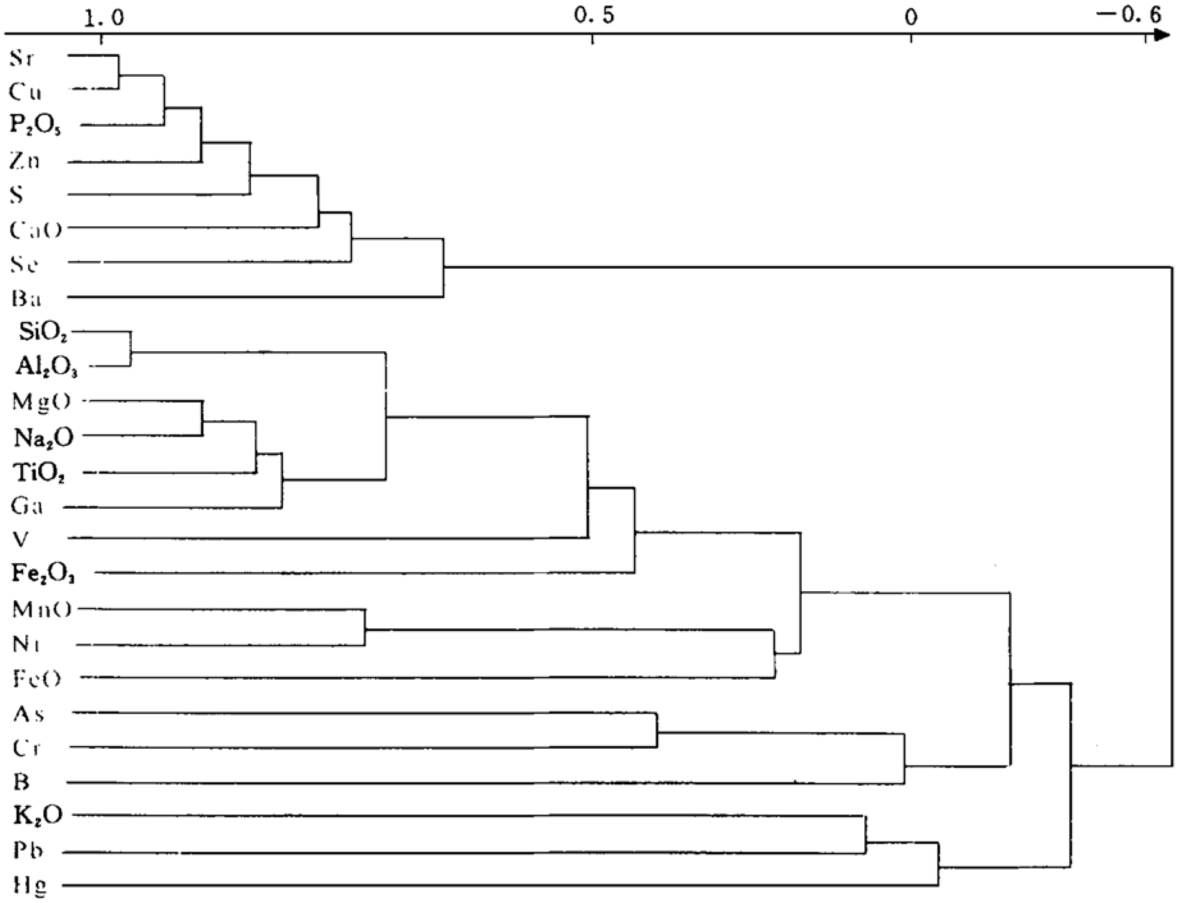

Fig. 2. The R-mode cluster figure for sedimentary sequence of Y2 lake, Antarctica.

generically scattered elements, S, P are generically bio-elements and Ca is generically building-rock element. S and P in sediments predominantly come from the deposition of the material enriched with S and P as well as the enrichment of living plant growing in the lake. The concentrations of S and P in the mother rock and the forming soil are 183.48×10^{-6}, 702.61×10^{-6}, respectively (Zhao 1991c), much less than those in Y2 lake sediments (2190×10^{-6} for S and 61260×10^{-6} for P). Therefore, these materials did not considerably contribute to the S and P in Y2 lake sediments and naturally the source of S and P in Y2 sediments is ascribed to the biological source. Commonly the concentration of Se is higher in plant than in rock, such as the concentrations of Se in igneous rock and sedimentary rock are 7.94×10^{-6}, 11.83×10^{-6}, respectively, while it is high up to 70.46×10^{-6} in the plant fossil in the fossil hill near the Great Wall Station (Zhao 1991c). Se is a bio-element during the course of surface action. The researches on the association of elements of shallow sea sediments of China show that the association of Sr with other elements is of significance as environmental index (Zhao and Yin 1994). Sr and Ba were associated together since chemical weathering action is faint and potassic minerals were relatively enriched in the Bohai Sea and the Yellow Sea, while Sr and Ca were associated in the sediments in the East China Sea because potassic minerals are decomposed by chemical weathering and Sr mainly comes from biological calcareous deposition. The fluctuation and the concentration of K_2O in Y2 sediments were unconspicuous and different from the variation of Sr, Ba, Ca, thus, the association of Sr and Ba in Y2 sediments were not essentially correlated with the content of potassic minerals. Ba in Y2 lake should also come from bio-source. As a result, Sr, Ba and Ca in Y2 sediment association indicate the contribution of bio-source. It can be presumed that Cu and Zn in Y2 sediment were also bio-source since they occur together with Sr, Ca, Ba, S, P and Se. In fact, it is reported that biology and organism are one of significant factors to make Cu enriched in sediment. Many soft tissue of biology were obvious enriched metal such as the average concentrations of Cu, Zn and Pb in oyster are 250×10^{-6}, 8700×10^{-6} and 1.0×10^{-6}, respectively. These trace elements are combined with organic material to form metal-organic matter. After the death of organisms, some of metal-organic matters can resist the bacteria decomposition action and are deposited in the sediment at last. During diagenetic evolution of the sediment, most of these combinations will decompose and metal was discharged. This makes metal to be more enriched in sediment than in original organism. The concentrations of Cu in halobios could be higher up to $(100 - 500) \times 10^{-6}$, comparing with low level Cu concentration in terrestrial organism, which is approximately only 5×10^{-6} (Liu and Cao 1985). The concentrations of Cu in some of plants in Great Wall Station in Antarctica, such as moss and aquatic growth are up to 192×10^{-6} and 557.1×10^{-6}, respectively (Zhao 1991c). It is estimated that these elements in Y2 lake sediments would probably come from the plants enriched with them. However, the concentration of F was also considerably high in the sediment, with the maximum value being about 1.2%. In common the average concentration of F in andesite and basalt, which surround the Y2 lake, are only 361×10^{-6}, 402×10^{-6}, respectively (Liu and Cao 1985). In addition, the concentration of F in plant was low, and the plant will be toxic when F concentration in the soil is up to 0.1% - 0.05%. Whereas the F concentration in penguin dropping could be up to 1.1% . In Table 2, we listed the concentrations of some of elements in fresh penguin droppings, krill and the sediments of Antarctic West Lake. The data in Table 2 shows that the concentration of elements and the fluctuation of concentrations versus depth were similar between the penguin dropping and krill. From the data in Table 1 and Table 2, it is clear that the concentrations of S, P, Cu, Zn and Ca in the sediments of Antarctic West Lake, which are enriched in plant relicts and organic matters, were lower than in Y2 lake sediments, fresh penguin droppings and krill. In summary, the key reason for the nine elements association and their high-concentrations in Y2 lake sediments could not be attributed to plants.

Comparative research on the concentrations of elements in Y2 lake sediments, Ardley Island guano soil and Pacific Island guano soil, shows that they are somewhat similar, for all of them are high-P (see Table 3) in spite of many different aspects between Ardley Island and Pacific Island. They are located separately from each other and their mother rocks are different. On Ardley Island there is almost no lime rock. The nutrient characters of soil on Ardley Island are obviously different from that on Pacific Island. For example, soil on Pacific Island is Eutropeptic Rendollsthat while the surface of soil on Ardely Island appeared acid. Gong *et al*. (1999) considered that these similarities and differences among guano soil on Ardely Island and Pacific Island should be contributed to the facts that Aves participated in the course of soil-forming for both of them. The data in Table 3 show that the characteristics between Y2 lake sediments and guano soil on Ardely Island (24D-3-1, 24D-3-2 profile) were almost similar, namely, total P concentrations are both high and similar to that on Pacific Island and total content of K in Y2 lake are also similar, but ten times of that on Pacific Island, the exchange amount of cation (CEC) in Y2 lake is lower than on Ardley Island guano soil but higher than on Pacific Island, pH values in both of Y2 lake and Ardle Island guano soil appeared to be acidic while it shows alkaline on Pacific Island. This suggests that there are Aves relics in Y2 lake sediments. There are two possible approaches or courses for relics deposit in Y2 lake. One is droppings which are transferred to Y2 lake via snowmelt water. Y2 lake is located on a penguin colony. In breeding period, penguin will yield 139×10^3 kg droppings. The other is penguin or other sea birds will directly discharge excreta into the Y2 lake. During the course of deposition, there are different element activities. Classified by the variance coefficients, the activities of these elements from high to low are Se, Cu, Zn, S, P, Sr, Ca and Ba.

Table 2. The concentrations of elements in penguin dropping, krill and West Lake sediment, Antarctica ($\times 10^{-6}$)

Element	S	P	Zn	Cu	Se	Ca	Al	K
Penguin droppings in Zhongshan Station	6900	19954	275	77.1	12.54	39800	13579	5311
Penguin droppings in Great Wall Station	7200	61900	314	316	13.87	108900		
Krill in Great Wall Station	2820	34154	417.4	232.8	/	80287	301.9	941.6
Sediment in Antarctic West Lake	1297	568	65	102	/	28801	69974	4659
Element	Na	Mg	Ti	Cr	V	F	Fe	Mn
Penguin droppings in Zhongshan Station	10758	15900	1020	17.5	82	1757.2	12300	199
Penguin droppings in Great Wall Station						14725		
Krill in Great Wall Station	281.4	15164	10.54	9.477	2.645	/	375.7	16.66
Sediment in Antarctic West Lake	18370	14346	6324	35	180	/	49389	783
Element	Ni	Pb	Hg	As	Sr	Ba		
Penguin droppings in Zhongshan Station	5.67	21.5	0.11	7.04	/	/		
Penguin droppings in Great Wall Station	/	/	/	/	1696	58.8		
Krill in Great Wall Station	2.016	7.553	/	/				
Sediment in Antarctic West Lake	19	20	/	/	/	/		

Note: (1) Data for krill and Antarctic West Lake sediments (cited from reference Zhao 1991c); (2) Concentrations refer to dry weight (drying temperature 105 ℃, 24 h).

Table 3. Comparaison of chemical and nutrient characters between guano soil of Pacific Island in South China Sea and guano soil of Ardley Island and Y2 lake sediments, Antarctica

Profile		Depth /cm	pH(water extracted)	TOC/%	TP_2O_5 /%	TK/%	[CEC/ cmol(+)/kg]
Ardley Island, Antarctica	Y2	14-15	5.55	15.34	6.07	0.54	28.21
		24-25	6.01	13.61	7.41	0.57	24.21
		34-35	6.30	10.39	4.98	0.58	27.48
		64.5-67.5	6.10	36.14	16.17	0.38	40.57
	24D-3-1*	0-4	4.89	19.89	13.19	0.48	39.19
	24D-3-2*	4-8	7.19	11.55	14.11	0.36	83.43
Pacific Island*	AG-8	10-20	8.46	7.5	17.53	0.042	20.63
		20-45	8.47	6.4	23.00	0.057	13.15
	AG-9	0-10	8.40	55.6	14.50	0.048	1.82
	AG-13	7-20	8.50	46.2	24.98	0.024	20.52
		20-35	8.47	15.3	8.36	0.051	8.68

Note: (1) Data of 24D-3-1 and 24D-3-2 profiles cited from Chen (1994); (2) Data of Pacific Island cited from Gong(1999).

3.3 Determined the attributions of chemical elements of the other two groups

SiO_2 and Al_2O_3 in the second group were related to the mother rock weathering action. They reflect the characters of the chemical composition of mother rock and the course of weathering. The variance coefficients of these elements from low to high are Si, Al, Cr, Ga, FeO, Mn, Ti, Na, Ni, V, Mg, As, Fe_2O_3 and B. The attributions of Si and Al belong to building rock elements. The low level of variance coefficients of Si and Al suggest that the chemical weathering action in this region was not strong. In addition, the variance coefficient of FeO was lower than that of Fe_2O_3, indicating that the sedimentation environment was mainly reductive. Furthermore, the variance coefficient of Na and Mg, the activity of which should be strong, were small and the variance coefficient of Mg being lower than Na demonstrated that in polar environment the course of de-alkali of weathering crust of mother rock was not significant and Na could not be completely eluviated. In contract, the variance coefficient of B was much high. It is known that the transference of B in weathering crust was related to the degree of mother rock weathering and the content of clay mineral in the weathering crust. Thus the concentration of B in the sediments can illustrate these two aspects. We presumed that the high variance coefficient of B in the Y2 lake sediment implicated the significant distinction of the content of clay mineral versus depth in Y2 lake sediments. The last group including Pb and Hg may reflect the impact of human activity on the polar environment.

4 Conclusion

The Y2 lake sediments were ameliorated by penguin droppings, which were transferred into the lake by ice or snowmelt water or directly discharged into the lake. The type elements of this sediment ameliorated by penguin droppings are Sr, F, S, P, Se, Ca, Cu, Zn and Ba.

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