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Assessment of heavy metal contamination from penguins and anthropogenic activities on Fildes Peninsula and Ardley Island, Antarctic

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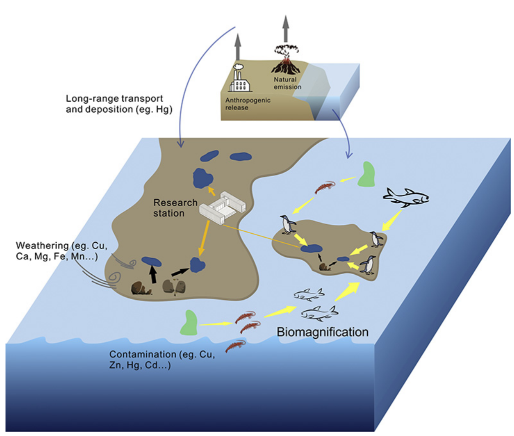
HIGHLIGHTS

- The contamination sources in Antarctica mainly include: penguins transport, human activities and bedrock weathering.
- The impact of penguin-transported contamination on Antarctic environment outweighs human activities in some areas.
- Penguins transport anthropogenic contaminants to Antarctica in the form of penguin droppings through marine food web.

GRAPHICAL ABSTRACT



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ABSTRACT

Fildes Peninsula, with a high density of scientific stations, has been significantly impacted by anthropogenic activities. However, the contamination from penguins, a biovector that transports pollutants from ocean to land, has seldom been assessed. In this study, 32 lacustrine surface sediment samples on Fildes Peninsula and 8 lacustrine surface sediment samples on Ardley Island were collected to determine Cu, Zn, Pb, Ni, Cr, Cd, Co, Sb, Hg and P levels. The results showed that the heavy metal contents of lacustrine sediments on Ardley Island are significantly higher than those on Fildes Peninsula. The contaminants on Fildes Peninsula are mainly derived from anthropogenic activities, while the contaminants on Ardley Island are transported to the lacustrine sediments in the form of penguin guanos after a series of biomagnification in the food chain. The results indicated that the impact of penguin-transported contamination on Antarctic environment outweighs human activities near scientific stations in some areas. Therefore, more attention should be paid to the impacts of Antarctic animals on the Antarctic environment.

1. Introduction

Antarctica, the most remote continent on Earth, is generally recognized as a closed and pristine environment. It plays a vital role in the global climate system and the research of past, present and future

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climate. Despite its geographic isolation, increasing human activities in Antarctica, especially on the Antarctic Peninsula and its offshore islands, have caused numerous environmental problems in recent decades. In Antarctica, only <2% of the continent is ice free, but most human and terrestrial biological activities are concentrated in these areas (Campbell and Claridge, 1987). Madrid Protocol has been signed in 1991 to designate Antarctica as a natural reserve, and the Antarctic Treaty Consultative Meeting (ACTM) has recognized two areas around Fildes Peninsula as Antarctic Specially Protected Areas (ASPAs). Monitoring of contaminants and environmental risk assessment are essential for environmental protection in Antarctica.

Contaminants could reach and impact the Antarctica's pristine environment mainly in three ways: anthropogenic activities, atmosphere circulation and bio-transport. Many countries have established scientific stations on Antarctic, especially in Fildes Peninsula, which has the highest density of scientific stations (Braun and Hock, 2004). Most human and terrestrial biological activity are concentrated in these areas. Besides, an increasing number of tourists visit the Antarctica in recent years (Eckhardt et al., 2013; Madsen et al., 2009). These activities could directly impact the Antarctica's environment. For example, Pongpiachan et al. (2017a, 2017b) discovered Phe is the most abundant congener of PAHs observed in King George terrestrial soils because of the Comandate Ferraz Antarctic Station fire accident, which occurred in February 25th, 2012. The anthropogenic pollution can also reach the Antarctica through atmosphere circulation, e.g., metals (Hg and Pb) (Flegal et al., 1993; Zvěřina et al., 2014) and organochlorines (Risebrough et al., 1990). In addition, as important biovector to transport industrial and agricultural contaminants in polar regions (Blais et al., 2005; Huang et al., 2014; Michelutti et al., 2010), seabirds transport nutrients and contaminants from ocean to land in both Arctic (Blais et al., 2005) and Antarctica (Huang et al., 2014).

In the past decades, heavy metal pollution in different environmental compartments from different parts of Antarctica has been well studied. For example, on King George Island, Lu et al. (2012) determined the baseline values for 13 trace elements through 30 surface soil samples and assessed the impact of anthropogenic pollution on Fildes Peninsula. Seawater and soil samples were collected to assess the source, distribution and degree of contamination around Maxwell Bay (Padeiro et al., 2016). The bioaccumulation of metals in marine organisms and sediments from Admiralty Bay was evaluated to understand the anthropogenic impacts on the Antarctic environment (Trevizani et al., 2016). On Ross Island, Crockett (1998) reported the background levels of trace elements in soil near McMurdo Station; they also mapped the distribution of organic contaminants and assessed the toxicity of sediments in Winter Quarters Bay (Crockett and White, 2003). In Victoria Land, Malandrino et al. (2009) determined the natural dynamics of several trace elements and the impacts by human activities on sediments from four catchments. Van De Velde et al. (2005) performed Pb isotope analysis in snow from Victoria Land and studied the pollution history over the past century. In East Antarctica, several studies have been undertaken to evaluate deposition of metals (Al, V, Mn, Fe, Cu, As, Cd, Ba, Pb, Bi, U and Zn) in snow (Do Hur et al., 2007; Suttie and Wolff, 1992). In addition, trace elements in moss and lichen samples in Antarctica were also assessed. For example, Culicov et al. (2017) assessed 8 major and 32 trace elements in four species of mosses and two of lichens on Livingston Island, and Amaro et al. (2015) reported the enrichment of contaminants in moss samples due to anthropogenic activities.

However, these studies focused on the baseline values of trace elements and the impacts of anthropogenic activities. Though transport of contaminants from ocean to land by seabirds has been examined (Huang et al., 2014) and several heavy metal records in ornithogenic sediments have been reported (Sun and Xie, 2001; Xie and Sun, 2008; Yin et al., 2006; Yin et al., 2008), the environmental impacts of bio-transported contaminants in Antarctica has rarely been assessed.

In this study, 32 lacustrine surface sediment samples on Fildes Peninsula and 8 lacustrine surface sediment samples on Ardley Island were collected to determine the levels of copper, zinc, lead, nickel, chromium, cadmium, cobalt, antimony, mercury and phosphorus and assess the status of contamination caused by anthropogenic and biological activities on Fildes Peninsula and Ardley Island.

2. Materials and methods

2.1. Study area

Fildes Peninsula and Ardley Island, with an area of ~33 km^2, are located on the southwestern part of King George Island and comprise the largest ice-free area on the King George Island. Fildes Peninsula (62°08′48″–62°14′02″S, 58°53′40″–59°01′50″W) is 10 km long, 2.5–4 km wide, and covers an area of 30 km^2 (Fig. 1). The topography of Fildes Peninsula is flat and the highest altitude is ~70 m. The climate is cold with a mean annual air temperature of −2.2 °C (Wen et al., 1994). Nevertheless, >70–80% of the island is covered with vegetation on Fildes Peninsula, especially lichen and moss. Besides, seabirds and seals are also very common in the coastal areas, and it is important for soil development. In the 20th century, many scientific stations of different countries (Chile, Russia, Uruguay, Germany, and China) have been established on the Peninsula.

Jurassic volcanic rocks near Fildes Strait are exposed unconformably through the outlier of Fildes Peninsula, and the west of Ardley Island rests on the small inliers of Jurassic rocks (Barton, 1965). The rocks of the peninsula are mainly composed of the basaltic-andesitic lavas (Barton, 1965). According to unconformities, the rocks of the Fildes Peninsula could be subdivided into four stratigraphical sub-divisions: predominant andesites, sedimentary rocks, agglomerates and andesites with interbedded tuffs (Barton, 1965). After the last glacial maximum, Fildes Peninsula and Ardley Island are among the first areas to become ice-free in Antarctica. The ice-free areas are shaped by glaciers and most of the lakes in these areas are the glacial basins caused by glacial activity (López-Martínez et al., 2012).

2.2. Sample collection

32 samples of surface sediment (0–2 cm) were collected from 32 lakes of different sizes in Fildes Peninsula, Antarctica (Area B and C; Fig. 1) and 8 samples of surface sediment (0–2 cm) from lakes or pools in Ardley Island (Area A; Fig. 1) using a homemade spade with a long handle of approximately 240 cm in length during the 29th Chinese Antarctic Expedition in the summer of 2012/2013. Group A ($n = 8$) is distributed on Ardley Island, which was inhabited by a large penguin colony, and the number of penguins around the sampling sites varies. Group B ($n = 10$) is located in the southern part of the Fildes Peninsula. Group C ($n = 22$) lies in the eastern coast of the Fildes Peninsula, and it is close to scientific stations. All the samples were frozen in cold storage prior to analysis.

2.3. Analytical methods

Each sample was air-dried in a clean laboratory and homogenized with a mortar and pestle, and then sieved through a 200-mesh sieve. For analysis of trace element Cu, Zn, Pb, Ni, Cr, Cd, Co, Sb and P, ~ 0.25 g of each powdered sample was weighed and digested in Teflon tubes with HNO_3-HCl-HF mix acid. The lids of Teflon tubes were tightened. Then the samples were decomposed with the full automatic microwave and then analyzed by Inductively Coupled Plasma-Optical Emission Spectroscopy (ICP-OES, Perkin Elmer 2100DV).

For analysis of Hg, ~0.25 g of each powdered sample was weighed and digested in Teflon tubes with multi acid (HNO_3-HCl). The lids of Teflon tubes were tightened, decomposed with the full automatic microwave and then analyzed using Atomic Fluorescence Spectrometry (AFS-2202a, Beijing Vital Co., Beijing, China).