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Radionuclides in ornithogenic sediments as evidence for recent warming in the Ross Sea region, Antarctica

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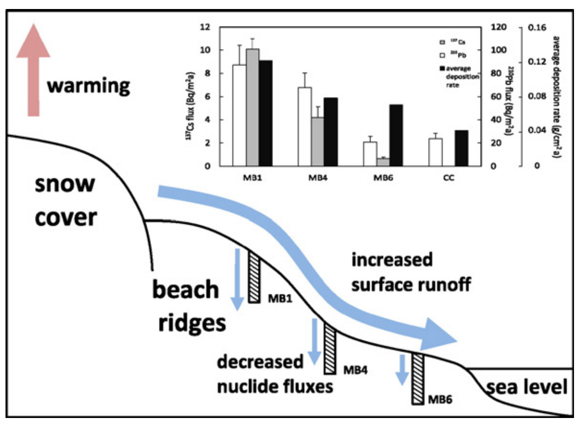
HIGHLIGHTS

- ^{210}Pb, ^{226}Ra and ^{137}Cs were measured in ornithogenic sediment profiles.
- Chronology within 200 years was determined through Constant Rate of Supply model.
- Calculated nuclide fluxes decreased with average deposition rate and locations.
- Deposition rate over time indicated warming which caused the flux gradient.

GRAPHICAL ABSTRACT



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ABSTRACT

Radionuclides including ^{210}Pb, ^{226}Ra and ^{137}Cs were analyzed in eight ornithogenic sediment profiles from McMurdo Sound, Ross Sea region, East Antarctica. Equilibration between ^{210}Pb and ^{226}Ra were reached in all eight profiles, enabling the determination of chronology within the past two centuries through the Constant Rate of Supply (CRS) model. Calculated fluxes of both ^{210}Pb and ^{137}Cs varied drastically among four of the profiles (MB4, MB6, CC and CL2), probably due to differences in their sedimentary environments. In addition, we found the flux data exhibiting a clear decreasing gradient in accordance with their average deposition rate, which was in turn related to the specific location of the profiles. We believe this phenomenon may correspond to global warming of the last century, since warming-induced surface runoff would bring more inflow water and detritus to the coring sites, thus enhancing the difference among the profiles. To verify this hypothesis, the deposition rate against age of the sediments was calculated based on their determined chronology, which showed ascending trends in all four profiles. The significant increase in deposition rates over the last century is probably attributable to recent warming, implying a potential utilization of radionuclides as environmental indicators in this region.

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1. Introduction

The radiometric dating method on shorter time scales (less than 200 years ago) using the natural fallout radionuclide ^{210}Pb was initially introduced by Goldberg (1963), but it was not widely used until after its first application to lake sediments by Krishnaswamy et al. (1971). Later with the development of calculation models of Constant Initial Concentration (CIC, for uniform accumulation rate) and Constant Rate of Supply (CRS, for non-uniform accumulation rate), and corroboration from artificial fallout radionuclides including ^{137}Cs and ^{241}Am for accurate age calibration (Appleby and Oldfield, 1978), the dating method broadened its usage into different geo-carriers such as lake, estuarine and marine sediments, and peat bogs (Appleby, 2008). After decades of application, ^{210}Pb dating has been recognized as one of the most important dating techniques in various paleo studies.

So far, studies on natural and artificial fallout radionuclides in Antarctica serve diverse purposes besides dating. For example, analyses of natural and artificial radionuclides on different materials including ice, sediments, soils, seawater, and biological samples play important roles in establishing baselines from which to estimate the possible impacts of radioactive pollution, to understand marine dynamic processes, and to examine the impacts of anthropogenic activities on this remote area (Schüller et al., 2004; Sanders et al., 2010). Radionuclides in aqueous systems may function as tracers for investigating water circulation and sedimentary processes due to their distinctly different geochemical behaviors (Godoy et al., 1998). Historical records of radionuclides have been used to study the long range water and atmospheric transportation of anthropogenic substances, and for exploring mineral resources (Jia et al., 2000). Snow-firn-ice dynamics based on ^{210}Pb deposition could grant insights into the balance of the Antarctic ice sheet (Goodwin, 1990; Gallée et al., 2001).

Antarctica developed its own unique ecosystem structures due to its isolation from other continents and the absence of anthropogenic influence (Jenouvrier et al., 2005). Its specific location and fragile ecosystems make this land extremely sensitive to climate change (Clarke et al., 2007). In the coastal ice-free areas scattered around Antarctica where migrating birds have the most impact, continuous and well-preserved ornithogenic sediments were formed, and serve as a natural archive for both geochemical dynamics and paleo-environmental conditions, allowing studies on climate change and the corresponding ecological responses in the past, which, in turn, is essential in understanding current and future trends of global warming and its impact on local ecosystems (Parmesan, 2006; McClintock et al., 2008). The Ross Sea is a high latitude embayment with a long history of Adélie penguin (*Pygoscelis adeliae*) occupation (Emslie et al., 2007). Our previous studies focused mainly on the geochemical features and processes based on heavy metal mercury, bio-element assemblage, stable isotope δ^{13}C and δ^{15}N, and rare earth elements in the ornithogenic sediments from this region (Nie et al., 2015). To further decode the information of the past stored in the sediments, accurate chronology of these ornithogenic sediments is crucially required.

In this study, we analyzed the levels of radionuclides including ^{210}Pb, ^{226}Ra and ^{137}Cs in eight ornithogenic sediment profiles collected from the ice-free areas in McMurdo Sound of the Ross Sea region for the first time. Since no data on radionuclides on a similar geo-carrier was ever reported in this area, we wished to determine whether the sediments with heavy avian influence could be used for ^{210}Pb dating, and exploit the potential of the radionuclides as indicators for environment change.

2. Material and methods

2.1. Study area

Ornithogenic sediments used in this study were collected in ice-free areas of the southern Ross Sea region in January 2010 (Fig. 1). This region is highly sensitive to climate change as it is located at the conjunction of three different air masses from Victoria Land, the Ross Sea, and the Ross Ice Shelf. The weather here is capricious and severe: the mean annual temperature is −18 °C, and the temperature may reach 8 °C in summer and −50 °C in winter. The average wind speed is 22.8 km/h, but may exceed 190 km/h on occasion. Ross Island (~2460 km^2) is of volcanic origin in McMurdo Sound comprising four volcanoes: Mts Terror (elevation: 3262 m,), Terra Nova (2130 m), Erebus (3794 m), and Bird (1800 m), with glacial ice mantles inland, leaving three ice-free areas where Adélie penguins currently breed at Cape Crozier (~18 km^2), Cape Bird (~15 km^2), and Cape Royds (~13 km^2). Beaufort Island (~18.4 km^2) is 21 km north of Ross Island with Adélie penguins breeding on the ice-free areas on the eastern and southern coasts. A long history of penguin occupation has left these areas with numerous abandoned penguin colonies as well as active ones, allowing the study of penguin paleoecology. Surface run-offs are observed in summers, and with the input of nutrients from penguin guano, freshwater algae are widely distributed in the ponds and catchments near the colonies.

2.2. Sample collection

The sampling sites are located in several separate areas on Ross and Beaufort Islands (Fig. 1). Details on depth, location, lithology (see also Supplementary Fig. 1) and catchment description of the eight profiles are provided in Table 1. The site MB4 is close to abandoned penguin colonies in mid Cape Bird. MB4 was collected in a small pond between the fourth and fifth raised beach ridges. According to field observations, the sediment layer below 15 cm was comprised of fine-grained ornithogenic sediments with a dark color and rancid smell; the sediment unit between 5 and 15 cm was mainly composed of dark-colored coarse sands; the surface layer is rich in fine black algae residue. Near MB4, profile CL2 was taken from the northern edge of a pond located on the fifth beach ridge above sea level. CL2 mostly consisted of fairly homogeneous black and grey colored silts, and its uppermost part was comprised of dark green freshwater algae residues. Profile MB6 was collected from a small catchment on the second terrace above sea level in an active penguin colony on the north side of Cape Bird. The sediments below 24 cm were dark-colored ornithogenic soils, and the remainder consisted of brown clay. Seal hairs were found in the sediment layer beneath 32 cm. Profile MB1 with relatively homogeneous lithology was collected from a dried-out catchment on an elevated hillside south of MB4 with traces of penguin activities (bones and feather discovered). Profile CC was collected from a fecal pit in Cape Crozier, Ross Island. Large amounts of penguin guano were deposited here, together with eggshells and downy feathers. The biological remains were concentrated in the layer above 7 cm. Profile MR1 and MR2 were collected near the active penguin colonies at Cape Royds. From bottom to top, both profiles changed from dark-colored weathering products to red-colored ornithogenic sediments with gravels at critical depths of 12 and 15 cm, respectively. Profile BI was excavated from a small peat near the modern penguin colony on the southwest side of Beaufort Island. From the bottom to top, brown clay gradually transitions into black fine-grained ornithogenic sediments. Profile MB4, MB6, MB1, MR1 and MR2 were directly taken in dug pits and sectioned in the field (intervals: 0.8 cm for MB4; 0.6 cm for MB6; 1 cm for MB1, 1 cm for layer above 15 cm, 2 cm for layer below 15 cm in MR1; 1 cm for layer above 15 cm, 2 cm for layer below 15 cm, and the remaining sediments were divided into 2 subsamples in MR2), while CC, BI and CL2 were collected using sediment cores and transported back to the lab and sectioned at the intervals of 0.5 cm. All sediment samples were air dried and homogenized by grinding before radionuclide and chemical analyses. More details about sampling have been reported in Nie et al. (2012, 2015).