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Penguin occupation in the Vestfold Hills

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Abstract: During CHINARE-22 (December 2005–March 2006), we investigated six penguin colonies in the Vestfold Hills, East Antarctica, and collected several penguin ornithogenic sediment cores, samples of fresh guano and modern penguin bone and feather. We selected seven penguin bones and feathers and six sediments from the longest sediment core and performed AMS^{14}C dating. The results indicate that penguins occupied the Vestfold Hills as early as 8500 calibrated years before present (cal. yr BP), following local deglaciation and the formation of the ice free area. This is the first report on the Holocene history of penguins in the Vestfold Hills. As in other areas of Antarctica, penguins occupied this area as soon as local ice retreated and the ice free area formed, and they are very sensitive to climatic and environmental changes. This work provides the foundation for understanding the history of penguins occupation in Vestfold Hills, East Antarctica.

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Introduction

Penguin have their largest populations in Antarctica, account for more than 90% of the Antarctic birds in biomass (Croxall 1987), and play an important role in the Antarctic marine ecosystem as their primary prey are krill and fish. Penguins are sensitive indicators of the Antarctic climate and local environmental parameters (Baroni & Orombelli 1994), and from their palaeoecology past climatic and environmental changes in Antarctica can be inferred (Sun *et al.* 2000, Sun & Xie 2001). So far the primary areas for studying the palaeoecology of penguins have been the Antarctic Peninsula, the Ross Sea area, and the Windmill Islands. In the Antarctic Peninsula, penguins have been present at Hope Bay since 5550 years before present (yr BP) (Zale 1994). Sun *et al.* (2000) reconstructed a 3000 year record of penguin populations on Ardley Island by extracting the assemblage of bio-elements from a penguin ornithogenic sediment core (Y2). Emslie (2001) reported that penguins occupied Lagoon Island around 5990 yr BP following the local deglaciation and its population reached the highest level in 4000–3000 yr BP due to the late Holocene climatic optimum. In the Ross Sea area, penguins were present as early as 13 000 yr BP (Baroni & Orombelli (1991, 1994)). Recently, a 45 000 year record of Adélie penguins was reconstructed (Emslie *et al.* 2007), the oldest penguins record in Antarctica. In the Windmill Islands, penguins were present at 3290 yr BP (Goodwin 1993), and this could extend back to as early as 9000 yr BP immediately after deglaciation (Emslie & Woehler 2005).

The Vestfold Hills is the third largest ice free area in Antarctica after the McMurdo Dry Valleys area of southern Victoria Land and the Bunger Hills of Wilkes Land. More than 80% of the total seabirds in Prydz Bay inhabit these hills, and Adélie penguins (*Pygoscelis acleliae* (Hombron & Jacquinot)) are the major component of the Prydz Bay avifauna that inhabit the western coastal islands (Montague 1988, Woehler *et al.* 1989, Woehler & Johnstone 1991). In the past decades, many palaeoclimatic and palaeoenvironmental records have been reconstructed for the Vestfold Hills (Adamson & Pickard 1986, Bird *et al.* 1991, Fitzsimons & Domack 1993, Roberts & McMinn 1998, 1999, Zwartz *et al.* 1998, Roberts *et al.* 2001, Quilty 2006), but the palaeoecology of penguins in this area remains unknown.

In this paper, we examine the history of penguins on Gardner Island of the Vestfold Hills, using AMS^{14}C dating on the penguin remains and the ornithogenic sediments in different layers of the core.

Study area and methods

The Vestfold Hills are located on the edge of the eastern side of Prydz Bay in the Ingrid Christensen Coast of Princess Elizabeth Land. They are an ice free area of about 400 km^2, bounded by the Sorsdal Glacier in the south, by the steep ice-covered slopes in the east, and by the sea in the north-west. They consist of Long Peninsula, Broad Peninsula and Mule Peninsula and comprise bare, low-lying hilly country deeply indented by sea inlets and studded with lakes and tarns of varying salinity (Zhang & Peterson 1984) with a cold, dry and windy climate. As is typical of continental Antarctic localities, temperatures are below 0°C for most of the year, summer temperature rise as high as +13°C and winter temperatures drop to as low as -40°C (Seppelt *et al.* 1988).

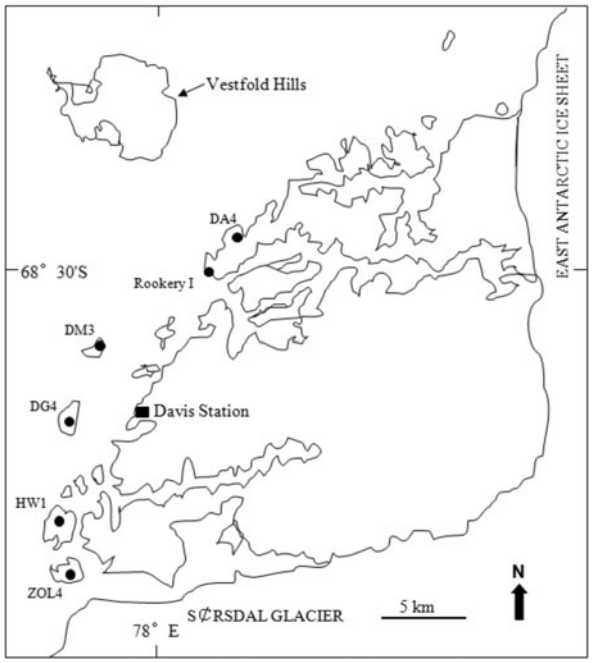

Fig. 1. Map of Vestfold Hills and the sampling sites.

In the summer of 2005–2006, we investigated six penguin colonies on Long Peninsula Island, Rookery Lake Coast, Magnetic Island, Gardner Island, Hawker Island and Zolotov Island of the Vestfold Hills, collecting six ornithogenic sediment cores named as DA4, Rookery I, DM3, DG4, HW1 and ZOL4 (Fig. 1). We also collected the modern penguin bones and feathers from a dead penguin and fresh penguin guano as control samples. DG4 was the longest sediment core at 83 cm, with the highest elevation of 32 m above mean sea level, and was selected for analysis. The core was sectioned at 1 cm intervals; remains such as bone, feather or eggshell were found in every layer from 1 cm to 55 cm except layers at 3 cm, 7 cm, 18 cm, 38 cm and 48 cm in the core, and all the remains were selected. To calculate the age profile of the sediment, five penguin bone/feather samples, two modern penguin bone and feather samples and two uncertain samples (bone or not) from different layers were dated by AMS^{14}C. In addition, we performed AMS^{14}C dating on six ornithogenic sediments from the core and the modern penguin guanos. The conventional dates were corrected and calibrated by using the CALIB 5.1.0 program (Stuiver *et al.* 2005) as well as the dataset of Marine04 (Hughen *et al.* 2004) and SHCal04 (McCormac *et al.* 2004).

Results and discussion

The AMS^{14}C dating results are listed in Table I. The AMS^{14}C dating on DG-1, DG-2, DG-3, DG-31 and DG-32 could not be completed due to their low carbon content. The results from pretreatment of bone and feather indicate that DG-31 and DG-32 are inorganic materials rather than bones. In addition, the dates of DG-5 and DG-26 do not follow the aging trend, probably due to their mixed carbon sources and the potential errors in corrections. In this study, we cautiously reject these two dates, although they are not far from the trend of other dates in the stratigraphic sequence.

Since the total carbon in dating samples has a mixed source, the conventional dates need to be corrected and calibrated. In the Antarctic area different dating materials in different areas usually have a different marine reservoir

Table I. AMS^{14}C dates and calibrated ages using Marine04 and SHCal04 in CALIB 5.1.0

Laboratory number	Sample number	Dated material	Depth (cm)	Conventional ^{14}C age (yr BP)	Marine reservoir (ΔR)	Calibrated age (cal. yr BP)	
						Mean	range (2σ)
*39410	DG-33	feather	modern	860 ± 15	860 ± 15	0	
*39438	DG-34	bone	modern	880 ± 15	880 ± 15	0	
*39435	DG-9	bone	17	6110 ± 20	880 ± 15	5594	5528–5660
*39436	DG-18	bone	28	7090 ± 25	880 ± 15	6650	6560–6741
*39437	DG-26	bone	42	7025 ± 25	880 ± 15	6572	6482–6663
*39408	DG-27	feather	43	7335 ± 15	860 ± 15	6980	6885–7076
*39409	DG-30	feather	55	8865 ± 20	860 ± 15	8463	8392–8535
/	DG-31	bone?	56	/		/	
/	DG-32	bone?	64	/		/	
#BA07029	DG-7	fresh guano	modern	765 ± 45	765 ± 45	0	
#BA07028	DG-6	bulk sediments	7	4070 ± 40	765 ± 45	3508	3323–3693
#BA07027	DG-5	bulk sediments	21	8160 ± 70	765 ± 45	8169	7960–8378
#BA07026	DG-4	bulk sediments	47	7710 ± 45	765 ± 45	7729	7582–7876
/	DG-3	bulk sediments	59	/		/	
/	DG-2	bulk sediments	69	/		/	
/	DG-1	bulk sediments	76	/		/	

Note: *Measured at W.M. Keck Carbon Cycle Accelerator Mass Spectrometry Laboratory, University of California Irvine (KCCAMS UCI).
Measured at Institutes of Heavy Ion Physics, School of Physics, Peking University.
/ Not measured.

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effect (ΔR). Adamson & Pickard (1986) reported that the marine reservoir effect for marine sediments and molluscs in the Vestfold Hills is 1300 years, and Verkulich & Hiller (1994) reported a similar result in East Antarctica. Baroni & Orombelli (1991) suggested a marine reservoir effect of 915–1760 yr in Victoria Land, Antarctica. Penguin bones in Antarctica generally have a marine reservoir effect of 700–750 yr (Emslie *et al.* 1998, Emslie 2001, Emslie & McDaniel 2002). In this paper we have chosen to use the dates of modern penguin bone, modern feather and fresh penguin guano from the local area as the corresponding ΔR. Conventional dates of penguin bone and feather were corrected and calibrated for the marine carbon reservoir effect by using the Marine04 database (Hughen *et al.* 2004), giving ΔRs of 880 ± 15 and 860 ± 15 yr, respectively and for bulk sediment samples using the SHCal04 database (McCormac *et al.* 2004) giving ΔR of 765 ± 45 yr. The results in Table I show that the oldest mean calibrated date from the feather sample in the 55 cm layer is 8463 cal. yr BP, and thus penguins have occupied in Vestfold Hills as early as 8500 cal. yr BP but we cannot make any inferences about continuity at this stage since the sparse data from the Vestfold Hills are insufficient to indicate continuous occupation.

There was a widespread early Holocene climatic optimum (HCO) in Antarctic at 11 500–9000 cal. yr BP (Masson *et al.* 2000). For the Vestfold Hills, the oldest documented lacustrine radiocarbon age was 8400–8600 yr BP (Adamson & Pickard 1986, Zwartz *et al.* 1998), whilst a shell sample in a moraine, close to the present-day ice margin, has a radiocarbon age of 9920 yr BP (Fitzsimons 1991), and a cosmogenic isotope exposure age from an erratic two kilometres from the present ice edge was 12500 ± 1600 yr BP (Fabel *et al.* 1997).

The deglaciation of the Vestfold Hills seemed to take place prior to or in the early Holocene climatic optimum period after the Last Glacier Maximum (LGM). In the Antarctic Peninsula, southern Ross Sea, and Windmill Islands, penguins occupied land immediately after local deglaciation and the formation of ice free areas (Baroni & Orombelli 1994, Emslie 2001, Emslie *et al.* 2003, Emslie & Woehler 2005). In the Vestfold Hills, the oldest penguin occupation date of 8500 cal. yr BP from this study is consistent with the time of local deglaciation and ice free area formation. Penguins are opportunists, colonizing suitable ice free nesting habitat close to the coast as the areas deglaciated, and thus responding to environmental change at local scales but providing signals about climatic change at regional scales. Further research on the spatial-temporal patterns of penguin occupation in this region is currently in progress.

Conclusions

The results of AMS ^{14}C dating on ornithogenic sediments and penguin relics indicate that penguins occupied Gardner Island of the Vestfold Hills as early as 8500 cal. yr BP following local deglaciation and the formation of an ice free area. These results are consistent with data from the Antarctic Peninsula, southern Ross Sea area and Windmill Islands, and they support the hypothesis that penguins are good proxies for determining climatic and environmental changes. This is the first report for the Vestfold Hills on Holocene penguin occupation and it provides the foundation for understanding the ecological history of penguins in this region.

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