

RADIOCARBON DATING OF MUMIYO FROM THE VESTFOLD HILLS, EAST ANTARCTICA

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(with one table and one text-figure)

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Accelerator mass spectrometer (AMS) radiocarbon dating of mumiyo deposited by snow petrels at nesting sites in the Vestfold Hills indicates the colonies were established after 4800 yr BP (uncorrected for marine reservoir effect). Sites on the highest hills were probably established first, but colonisation took place long after initial deglaciation, which was well advanced by 12.5k yr BP. The reason for late colonisation is not known. Perhaps older sites exist, but current evidence suggests the main colonisation occurred after the mid-Holocene re-advance of the Sørsdal Glacier. $\delta^{13}\text{C}$ values indicate a diet of krill.

Key Words: Antarctica, Vestfold Hills, mumiyo, AMS radiocarbon dating, snow petrels.

INTRODUCTION

In Antarctica, mumiyo, a waxy accumulation of proventricular oil ejected by nesting snow petrels (*Pagodroma nivea*) (Warham *et al.* 1976), has been radiocarbon-dated to estimate the timing of the initial deglaciation of fringe areas of the continent and establishment of the snow petrel populations. Conventional radiocarbon dating of mumiyo from the Untersee Oasis of central Dronning Maud Land (71°S, 13°E) recorded discontinuous petrel occupation since 34 kyr BP (Hiller *et al.* 1988); two samples from the Robertsoskollen nunatak group, northern Ahlmannryggen, Dronning Maud Land (~71°S, 3°E), suggested that occupation began in about 7 kyr BP (Ryan *et al.* 1992) and in the Bunger Hills, Wilkes Land (66°10'S, 101°45'E), occupation began before 10 kyr BP (Verkulich & Hiller 1994).

This paper reports accelerator mass spectrometer (AMS) radiocarbon dates from snow petrel nesting sites in the Vestfold Hills, East Antarctica (fig. 1). The Vestfold Hills oasis covers an area of about 413 km² and has a maximum altitude of 158 m. Four marine inlets, locally termed 'fjords', penetrate the hills deeply. The East Antarctic Ice Sheet bounds the hills on the east and the Sørsdal Glacier bounds them on the south. The extent to which the hills were submerged by the ice sheet and glacier during the Vestfold Glaciation — considered to represent the last glacial maximum — is debated (Adamson & Pickard 1986, Fitzsimons 1991, Gore 1997). The age of deglaciation is minimally constrained by cosmogenic isotope exposure-age dating of subglacial erratics within 1–2 km of the ice sheet's margin that indicated almost complete deglaciation by 12.5 ± 1.6 kyr BP (Fabel *et al.* 1997). Fitzsimons & Domack (1993) showed that the southern hills had been transgressed by the sea by 9 kyr BP, and that re-advance of the Sørsdal Glacier eroded the marine sediments between 9 and 0.7 kyr BP. Adamson & Pickard (1986) suggested that this re-advance occurred between 3 and 1.5 kyr BP.

METHOD

Mumiyo deposits were obtained by Kevin Kiernan and Anne McConnell during the 1996–97 austral summer with logistical support provided by the Australian Antarctic Division. Field sampling aimed at obtaining the oldest mumiyo deposits. Only basal samples were taken from most accumulations, though at a few sites with thick deposits, additional samples were taken at different levels in the sequence. Care was taken not to disturb nesting birds. The altitudes of the sample sites were recorded (table 1). Few sites had deposits more than 10–20 mm thick. The basal 2 mm were carefully scraped from the deposit to avoid clastic impurities that might contain old carbon. The samples were wrapped in aluminium foil and plastic bags, and refrigerated for transport to Lucas Heights for analysis. The $\delta^{13}\text{C}$ content, per cent modern carbon and conventional radiocarbon age were determined by Ewan Lawson using the ANTARES accelerator mass spectrometer facility at the Australian Nuclear Science and Technology Organisation laboratories at Lucas Heights, NSW, Australia.

RESULTS

The radiocarbon ages obtained from the basal mumiyo samples, uncorrected for marine reservoir effect, range from 4800 ± 60 yr BP (OZD 192) to 500 ± 140 yr BP (OZD 190) (table 1). Radiocarbon measurements of modern marine samples from Antarctica have given ages of 830–1460 yr BP, with a mean of 1180 yr BP (Stuiver *et al.* 1986, Hiller *et al.* 1988, Gordon & Harkness 1992, Ryan *et al.* 1992). Modern samples of marine algae and shells from the Vestfold Hills have given ages of 950–1310 yr BP (Adamson & Pickard 1983, 1986). Using a value of 1300 yr BP for the marine reservoir effect would make the sample from Boulder Hill (OZD 185) close to modern and the sample from Inner Long Peninsula of 500 ± 140 (OZD 190) yet to be deposited. As the appropriate correction factor is uncertain, none has been applied here because to do so would introduce further uncertainty in the age estimates. The earliest dates indicate

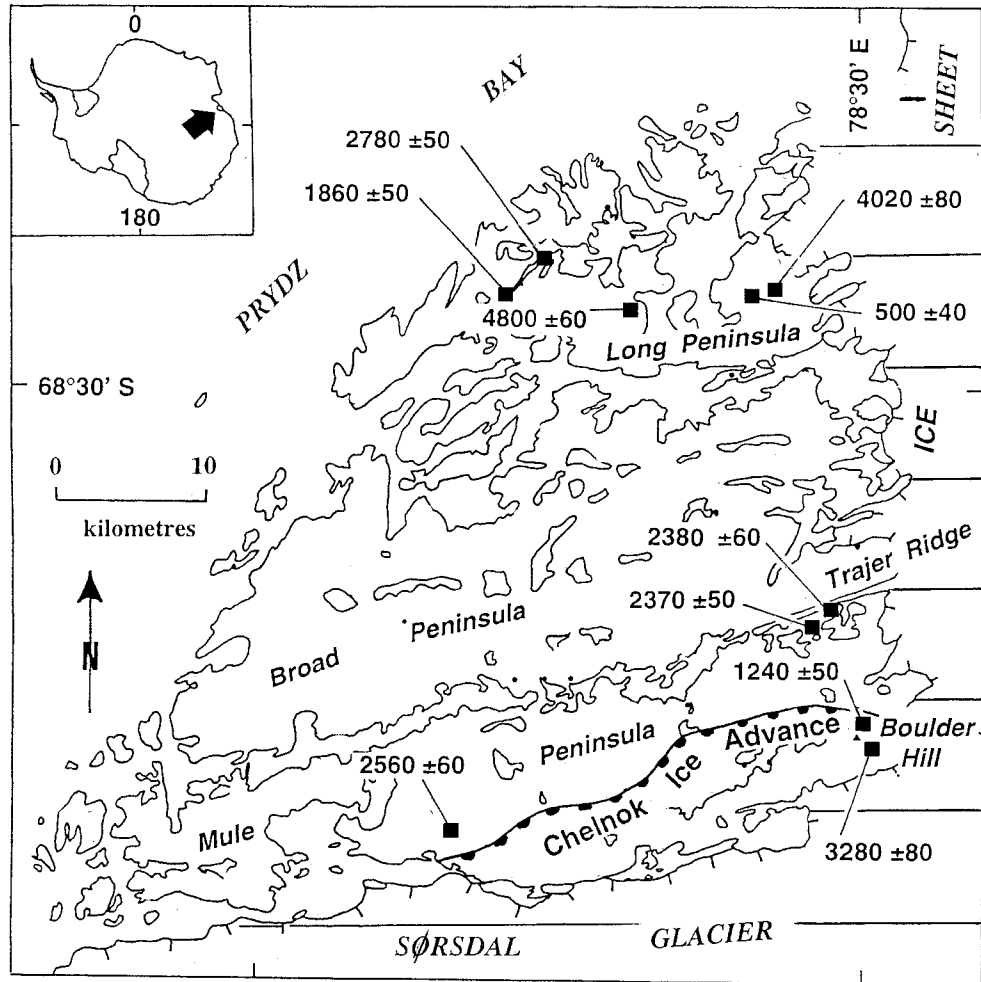


FIG. 1 — Location of dated mumiyo samples from the Vestfold Hills, East Antarctica.

TABLE 1
Location and age of mumiyo samples from the Vestfold Hills

Site	Sample no.	Altitude (metres)	Mumiyo thickness (mm)	$\delta^{13}C$ (‰)	^{14}C age (years, uncorrected)
Boulder Hill	OZD185	110	150	-28.62	1240±50
Boulder Hill	OZD186	80	140	-29.00 *	3280±80
Trajer Ridge	OZD187	80	100	-29.80	2380±60
Trajer Ridge	OZD188	70	140	-30.18	2370±50
Inner Long Peninsula	OZD189	140	<10	-29.94	4020±80
Inner Long Peninsula	OZD190	70	180	-30.95	500±140
Outer Long Peninsula	OZD191	40	<50	-28.25	1860±50
Outer Long Peninsula	OZD192	75	<50	-29.58	4800±60
Outer Long Peninsula	OZD193	30	<50	-30.22	2780±50
Poseidon Plain	OZD194	20	70	-29.99	2560±60

* assumed value

that the Vestfold Hills were probably colonised by snow petrels only as recently as 4800 (uncorrected) years ago and at least 8000 years after the initial deglaciation.

Since only 10 samples have been dated, the age of colonisation may be underestimated. However, as six of the samples were collected within 2–3 km of the ice sheet, the colonisation was probably widespread by 3500 yr BP. There is little pattern in the age distribution of the petrel sites, except that those on high points may be slightly older than those in adjacent low areas, although the reverse occurs at Boulder Hill.

Rates of mumiyo accumulation range from 0.002 mm/yr (OZD 189) to 0.360 mm/yr (OZD 190). The thickest accumulation of mumiyo recorded during this survey was deposited in only 500 years. The rate of accumulation at a site appears to be independent of the basal age of the sample. This suggests that occupation of nesting sites may have been discontinuous in the long term. However, accumulation of 180 mm in only 500 years at Vestfold Hills, giving an average of 0.360 mm/yr, is a much faster rate than any recorded at Bunger Hills (Verkulich & Hiller 1994) or at Robertsoskollen nunataks (Ryan *et al.* 1992).

DISCUSSION

The establishment of snow petrel colonies at Vestfold Hills appears to be much later than at other coastal nunataks and oases of East Antarctica. To what extent the ages of 34 kyr BP in the Untersee Oasis (Hiller *et al.* 1988) and the >10 kyr BP of the Bunger Hills (Verkulich & Hiller 1994) reflect absence of ice in these areas during the last glacial maximum is difficult to ascertain. At Bunger Hills, intensive colonisation occurred between 8 and 6 kyr BP and after 2 kyr BP. Only the latter phase appears to be temporally related to the late Holocene establishment of snow petrels at Vestfold Hills.

There is considerable evidence in coastal East Antarctica of advancing outlet glaciers during the mid-Holocene. From studies of the Mertz–Ninnis Trough, Dumont d'Urville Trough and Amery Depression, Domack *et al.* (1991), showed that grounding-line advance of outlet glaciers led to deposition of terrigenous sediment on the continental shelf between 7 and 4 kyr BP. Marine biogenic sediments overlie these deposits. They also showed that in Prydz Bay, to the west of Vestfold Hills, open marine conditions existed between 10.7 and 7.3 kyr BP.

A widespread advance of the East Antarctic Ice Sheet margin on the Wilkes Coast during the mid-late Holocene was attributed by Goodwin (1996, 1998) to ice thickening in central-East Antarctica due to 50% higher precipitation in the Holocene than during the last glacial maximum and to slow ice sheet flow response rates. This increased ice volumes in the coastal zone between 4 and 2.5 kyr BP. Modelling suggests that a temperature increase of 5°C is required to cause the ice sheet to recede (Huybrechts & Oerlemans 1990). Ice-core data suggest that temperatures were 0.5°C warmer around 4 kyr BP. Cooling occurred from 2 kyr to 1 kyr BP when there was brief warming before the Little Ice Age. Temperatures during the Little Ice Age were about 0.5°C colder than present (Ciaias *et al.* 1994, Mayewski *et al.* 1995, Morgan *et al.* 1997).

Adamson & Pickard (1986), and Fitzsimons & Domack (1993) showed that the Sørsdal outlet glacier had advanced again recently in the southern part of the Vestfold Hills.

Adamson & Pickard (1986) suggested that this Chelnok Advance occurred between 3 and 1.5 kyr BP. As Boulder Hill lies within this ice limit, the older date for mumiyo of 3280 ± 80 yr BP (uncorrected) is broadly consistent with their estimate. Fitzsimons & Domack (1993) showed that slabs of sheared ice formed the cores of the sediment masses associated with moraine of the Chelnok ice advance, and that the ice limit may have been attained as recently as 710 yr BP (corrected age).

Collectively, this evidence supports the hypothesis that re-advance of outlet glaciers in the peripheral zone of East Antarctica during the mid-late Holocene was associated with climatic conditions less favourable for snow petrels than in the subsequent three or four millenia. Snow petrels apparently colonised the Vestfold Hills during the milder conditions following the last advance of outlet glaciers in coastal East Antarctica. The inferred climatic evidence suggests that average temperatures did not change by more than about 1°C during this period.

The late Holocene colonisation by snow petrels at Vestfold Hills bears comparison with evidence of abandoned penguin rookeries in East Antarctica. Adélie penguins were abundant on the Victoria Land coast between 4 and 3 kyr BP, probably due to abundant open water and reduced snow cover. Many colonies were abandoned ~3 kyr BP, but were re-established about 1.4–0.8 kyr BP (Baroni & Orombelli 1994). Similarly, abandoned rookeries in the Windmill Islands were occupied from 4–3 kyr BP (Goodwin 1998). The open water conditions that facilitated the establishment of penguin rookeries are likely to have been associated with higher air and sea-surface temperatures that promoted greater coastal precipitation (Goodwin 1998). Sea-surface temperatures interpreted from stable oxygen isotope ratios of calcareous marine fauna and diatom transfer functions suggest sea-surface temperatures were 0.5–1.0°C warmer than now at 4 kyr BP (Pichon *et al.* 1992, Goodwin 1998). However, unlike Adélie penguins, snow petrels are not reliant on near-shore food sources. Hence, reduced open water inshore is less likely to affect the viability of colonies than is greater snowfall during warm periods, notwithstanding enhanced summer melt.

The $\delta^{13}\text{C}$ values of mumiyo offer some insight into the likely foods available to snow petrels. Ryan *et al.* (1992) suggested that $\delta^{13}\text{C}$ values for tissues from animals that feed on Antarctic fish are likely to be –24.5‰ or –26 to –27‰ if the diet consists of Antarctic krill. The $\delta^{13}\text{C}$ values reported for mumiyo range from –29 to –31.1‰. Mean values determined from snow petrel body tissue are –28‰ (Ryan *et al.* 1992, Verkulich & Hiller 1994). The values obtained from Vestfold Hills mumiyo range from –28.25‰ to –30.95‰, which is closer to the figures suggesting a diet of krill than of fish.

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