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Holocene and pre-Holocene temporary disappearance of the George VI Ice Shelf, Antarctic Peninsula

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Abstract: We present evidence for the absence of the George VI Ice Shelf during a brief period in the mid-Holocene and during one or more earlier interstadials or interglacials. Barnacle *Bathylasma corolliforme* shells sampled from ice shelf moraines at Two Step Cliffs on Alexander Island have been dated to *c.* 5750–6000 ^{14}C yr BP (*c.* 6550–6850 cal yr BP) and imply seasonally open water in the George VI Sound during this period. Other shells are beyond the range of radiocarbon dating and imply open water during one or more previous interglacial or interstadial period, prior to 40 000 ^{14}C yr BP. Our results show that the ongoing collapse of some Antarctic Peninsula ice shelves is not unprecedented.

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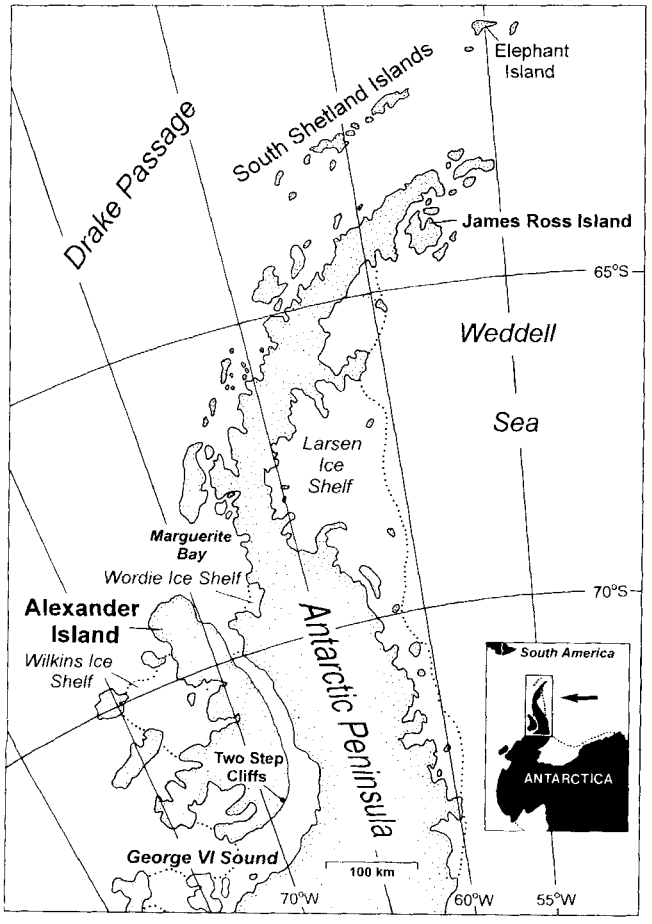

Fig. 1. Antarctic Peninsula area.

Introduction

Recent decades have witnessed the retreat and collapse of some Antarctic Peninsula and Weddell Sea (Fig. 1) ice shelves (e.g. Vaughan & Doake 1996, Rott *et al.* 1998, Skvarca *et al.* 1999, Pudsey & Evans 2001), but it has been difficult to judge the significance of this from a long-term perspective. In particular, it is not clear if such variations are unusual or whether they are a common, or even cyclic feature of the Holocene and pre-Holocene record.

Clapperton & Sugden (1982) dated barnacle shells from an ice shelf moraine (Sugden & Clapperton 1981) deposited by the George VI Ice Shelf at Two Step Cliffs on Alexander Island, southern Antarctic Peninsula (for reference on the ice shelf; see Swithinbank 1988, Reynolds & Hambrey 1988, Luccitta & Rosanova 1998). They obtained an age of *c.* 7200 ^{14}C yr, which corresponds to 5900 ^{14}C yr BP after an Antarctic marine reservoir correction of 1300 yr (e.g. Berkman & Forman 1996) has been applied. A Holocene age for these shells was also suggested by results of amino acid racemization analysis. No modern shells were found in the ice shelf moraines, and even though Hain & Melles (1994) suggested cases where molluscs might have lived under the fringing edges of ice shelves, the Two Step Cliffs area is today about 200 km within the southern and northern margins of the present ice shelf in George VI Sound. Thus the most likely implication of the presence of that benthic community seems to be that George VI Sound was seasonally free of ice around 6000 ^{14}C yr BP. However, due to limitations in the conventional radiocarbon technique used at the time of the Clapperton & Sugden study, when a large sample size including several shells was required, the dating could theoretically have been made on a mixed population, which would have

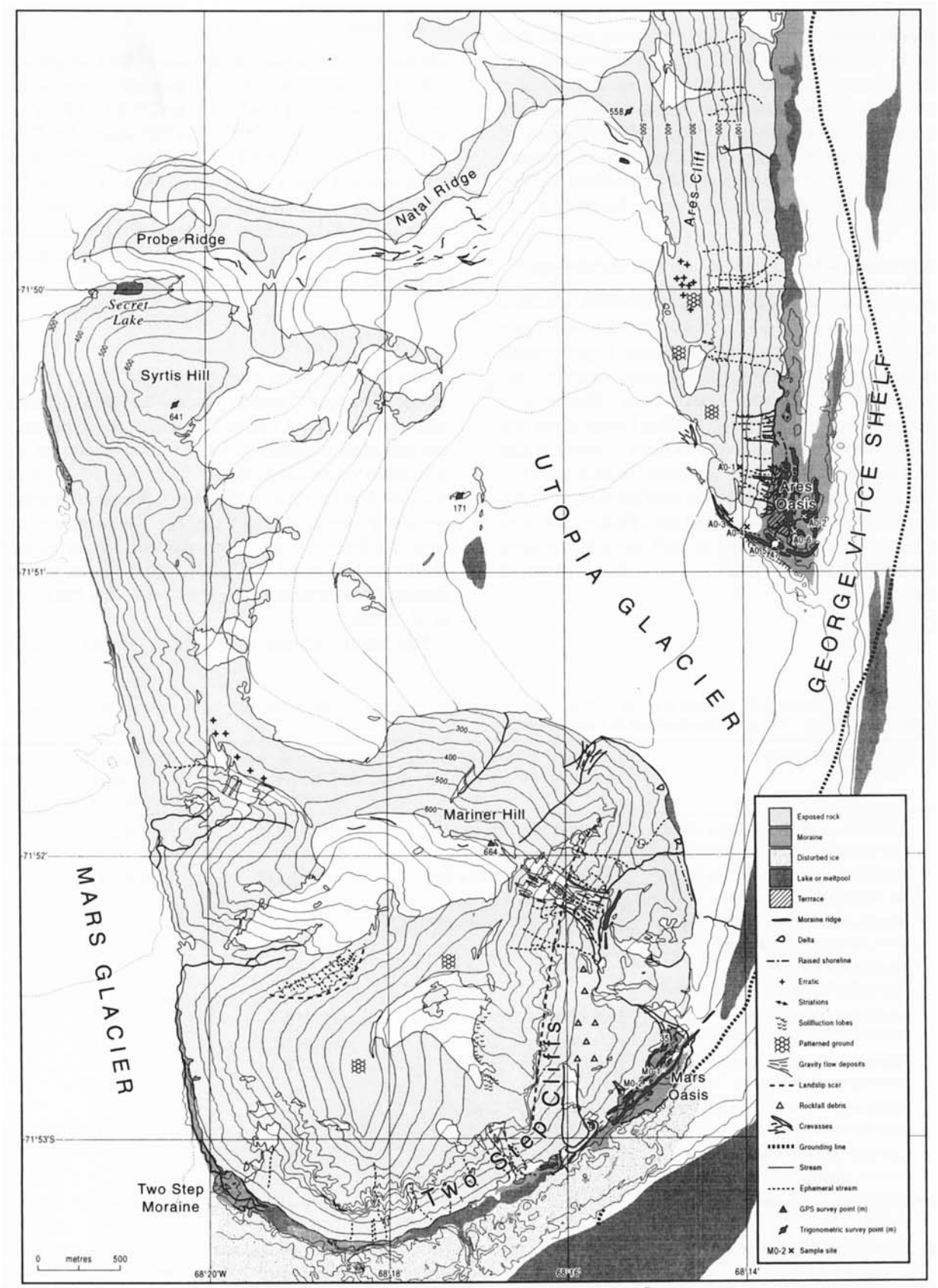

Fig. 2. Two Step Cliffs area, Alexander Island.

given an incorrect age.

Our project aimed at further testing and dating this ice shelf collapse, by obtaining AMS ^{14}C dates on individual shell fragments from several sites and different species. We also, in one case, provide an independent chronological constraint by using amino acid racemization values on shells from a ^{14}C dated sample. The field work was carried out in January–February 2000, and all data presented here are from the Two Step Cliffs area on south-eastern Alexander Island (Fig. 2).

Glacial geomorphology and radiocarbon chronology

We mapped and sampled three ice shelf moraines in each of the Mars and Ares oases (Figs 2, 3 & 4). The moraines, push-moraines formed by ice pressure from the east, largely consist of thrusted, steeply dipping slabs of marine sediments (mainly massive grey–green silts with external salt efflorescence, often shell-bearing), and of folded, bedded fluvial sands and gravels. The moraines are all below 50 m a.s.l., which is also the highest level of still remaining ice-cores. In each of the two oases, the two moraines nearest the ice shelf are sharp-crested, ice-cored and actively slumping along their flanks. The most distal (oldest) ice shelf moraine in each oasis has a more rounded crest with subdued relief and no visible evidence of an ice-core.

Mars Oasis

Barnacle (*Bathylasma corolliforme*) plates sampled from the till of the moraines (Fig. 4) yielded reservoir-corrected radiocarbon ages of 5745 ± 135 and 5980 ± 145 yr BP, which are similar to the date of 5900 ± 110 BP obtained by Clapperton & Sugden (1982) (Table I). These dates suggest a brief period of seasonally open water in George VI Sound around 5750–6000 ^{14}C yr BP (*c.* 6550–6850 cal yr BP; Table I). Growth lines on the shells indicate that some of the barnacles attained ages of more than 50 years, which should thus be the absolute minimum life-time for the benthic community.

Ares Oasis

Dates of shells from Ares Oasis (Fig. 3) all yield infinite radiocarbon ages (Table I). One of these dates is from a shell-bearing (*Hiatella* sp.) till at 150 m altitude on the slope above the ice shelf moraines. This till was deposited during a glaciation over-riding part of Alexander Island some time after the death of these molluscs (Clapperton & Sugden 1982, see also Payne *et al.* 1989, fig. 11). Our amino acid results from this deposit, where the total fraction mean value of three shells is as high as 0.131, indicate that the shells probably date from well before the last interglacial (cf. Miller 1985, Ingólfsson *et al.* 1992).

The other infinite ages (Table I) are from bivalve

Table I. ^{14}C dates from marine shells sampled from ice shelf moraines at Two Step Cliffs (MO = Mars Oasis, AO = Ares Oasis). Antarctic marine reservoir correction of 1300 ± 100 yr is from Berkman & Forman (1996).

Site	Description of sample	Laboratory code	Original ^{14}C date (yr BP) ± 1σ	^{14}C date with marine reservoir correction of 1300±100 yr	Calibrated date 1σ range (calendar yr BP)*	Comment
MO-1	*Bathylasma corolliforme* from till of most proximal ice shelf moraine	LuA-4937	7045 ± 90	5745 ± 135	6717–6421	
MO-2	*Bathylasma corolliforme* from within the middle ice shelf moraine	LuA-4939	7280 ● 105	5980 ± 145	7014–6665	
AO-1	*Hiatella* fragment from till on slope above oasis, *c.* 155m altitude	LuA-4941	> 40 000	n/a		
AO-3	*Adamussium colbecki* from ice thrusted(?) marine silt, *c.* 75m altitude	LuA-4938	> 33 500	n/a		
AO-4	Serpulid worm-tube from reworked material at margin of Utopia Glacier	LuA-4936	> 38 500	n/a		
AO-2	*Adamussium colbecki* from till of most proximal ice shelf moraine	LuA-4940	> 39 000	n/a		
AO-6	*Adamussium colbecki* from till of most distal ice shelf moraine	LuA-4943	> 40 000	n/a		
AO-5	*Laternula elliptica* from reworked material at margin of Utopia Glacier	LuA-4942	> 40 000	n/a		
Mars Oasis	*Bathylasma corolliforme* from ice shelf moraine	SRR-1500	7200 ± 50 (inner fraction)	5900 ± 110 (inner)	6870–6560	Clapperton & Sugden 1982
Ares Oasis	*Hiatella* from till on slope above oasis (same site as AO-1)	SRR-1499	30 600 ± 600 (inner fraction)	amino acid data indicated beyond range of ^{14}C		Clapperton & Sugden 1982

*Calibration to calendar years with CALIB 4.2 (Stuiver & Reimer 1993) using regional offset for marine reservoir correction, ΔR = 900 ± 100, based on a global ocean R_g-value of 400 (Stuiver *et al.* 1998).

Fig. 3. George VI Ice Shelf and the ice shelf moraines (here *c.* 250 m across) at Ares Oasis. Photo C. Hjort.

Fig. 4. Upthrusted marine sediments with upthrusted ice shelf margin in the background and geologist for scale, at Mars Oasis. Photo Ó. Ingólfsson.

(*Adamussium colbecki* Smith) shells and serpulid worm-tubes, sampled from the tills of the Ares Oasis ice shelf moraines (Fig. 3) and in a nearby lateral moraine along the Utopia Glacier. On the basis of the similarities in geomorphology between Ares and Mars oases and the unweathered state of the moraines at both sites we suggest that the ice shelf moraines and the Utopia Glacier moraine are all Holocene in age, and that the older shells have been reworked from interglacial or interstadial deposits that survived the glaciation(s) of George VI Sound.

Comparison with other climate proxies

Our evidence of Holocene seasonally ice free conditions around 6000 ^{14}C BP in George VI Sound, indicating warmer than present conditions at that time, should be compared to other proxies. However, the geological picture of Holocene climatic change around the Antarctic Peninsula is complex and differs significantly depending on whether it is based on marine or terrestrial data (e.g. Domack *et al.* 2001 vs Ingólfsson *et al.* 1998), or whether the marine data come from shelf or fjord areas (e.g. Domack *et al.* 2001 vs Shevenell *et al.* 1996). Neither is any straightforward correlation obvious between these geological data and Antarctic ice-core data (e.g. Ciasis *et al.* 1994, Masson *et al.* 2000). The period when the barnacles lived in George VI Sound falls within the marine Holocene climatic optimum defined from inner-shelf data by Domack *et al.* (2001) to about 8000–3000 ^{14}C yr BP, but predates the terrestrial optimum, dated through lake sediments by Björck *et al.* (1996) to between 4000–3000 ^{14}C BP.

Kennedy & Anderson (1989) and Bentley & Anderson (1998) suggested that the Clapperton & Sugden (1982) original dates were minimum dates for the deglaciation of Marguerite Bay at the northern entrance to George VI Sound. This roughly coincides with the end of the deglaciation process further north (e.g. Ingolfsson *et al.* 1998). The narrow "window" of our younger ^{14}C dates from Two Step Cliffs may indicate that the Holocene period with seasonally open water in George VI Sound lasted only a short time, perhaps not much longer than 300–600 years. In that case the formation of the present ice shelf may have coincided with the mid-Holocene Bahia Bonita glacial readvance further north along the Antarctic Peninsula (Rabassa 1983, Hjort *et al.* 1997).

Conclusions

- ^{14}C dates and amino acid data on shells incorporated in till at 150 m altitude document a glaciation overriding the east coast of Alexander Island and reworking marine shells originally deposited well before 40 000 ^{14}C yr BP.
- A sequence of low level (< 50 m a.s.l.) ice shelf moraines on the west side of George VI Sound contain shell fragments that imply a mid-Holocene period of ice shelf absence around 6000 ^{14}C yr BP, and also ice shelf absence during one or more previous interstadial or interglacial periods >40 000 years ago.

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