Cosmogenic nuclide evidence for enhanced sensitivity of an East Antarctic ice stream to change during the last deglaciation

Duanne A. White[1], David Fink[2], and Damian B. Gore[1]
[1]Environment and Geography, Macquarie University, Sydney, NSW 2109, Australia
[2]Australian Nuclear Science and Technology Organisation, PMB1, Menai, NSW 2234, Australia

ABSTRACT

Glacial sediments from the Prince Charles Mountains, East Antarctica, record late Pleistocene ice thickness variability in the Lambert Glacier–Amery Ice Shelf system, one of the world's largest ice drainages. A former glacial limit, demarcated by minimally weathered deposits, follows a concave longitudinal profile, indicating a zone of strong ice streaming through the northernmost 500 km of the Lambert Graben. In situ ^{10}Be and ^{26}Al exposure ages from these relatively unweathered deposits indicate that the most recent phase of ice lowering occurred between ca. 18 and 8 ka, preceding by as many as 6 k.y. the deglaciation of adjacent coastal regions. Earlier onset of deglaciation in an area of strong ice streaming suggests a heightened sensitivity of the East Antarctic Ice Sheet to climate and sea-level changes following the Last Glacial Maximum than previously recognized.

INTRODUCTION

The evolution of ice sheets during periods of climate and sea-level variability since the Last Glacial Maximum (LGM) provides important clues to their response to future climate warming. Records of former ice geometries in Antarctica are becoming more comprehensive (Wright et al., 2008), but most focus on the small, coastal ice drainage systems, where ice volume reduction is mainly by low-velocity ice sheet calving into shallow coastal waters, resulting in a slow ice margin retreat. The behavior of the large, fast flowing ice streams that drain much of the modern ice sheet is less certain. Sediments from the continental shelf at the terminus of these large ice streams (Anderson et al., 2002) provide a wealth of glacio-sedimentological information but only partially constrain former ice geometries. Thus, our understanding of the sensitivity of large ice drainage systems to future climate change is currently limited.

The Lambert Glacier–Amery Ice Shelf drainage system (LG-AIS) extends ~1500 km from the Antarctic interior to Prydz Bay (~78°–68°S), draining ~14% by area of the East Antarctic Ice Sheet (Fig. 1). In the northern 500 km of the LG-AIS, major outlet glaciers flow through the Prince Charles Mountains and join to form a single (trunk) stream in a central, overdeepened channel. The mountains flank these ice streams, and act as vertical dipsticks recording former ice elevations, providing a rare opportunity to constrain the former geometry of a large and dynamic ice drainage system. Evidence from Prydz Bay (Domack et al., 1998) suggests that grounded ice was present in Prydz Bay between ca. 20 and 12 ^{14}C kyr B.P. (Fig. 1).

We measured cosmogenic ^{10}Be and ^{26}Al exposure ages of debris deposited by outlet glaciers to reconstruct timing of changes in the height of the LG-AIS following this advance, and compare these results with those from nearby coastal oases and ranges to investigate the relative sensitivity of these systems to late Quaternary climatic events.

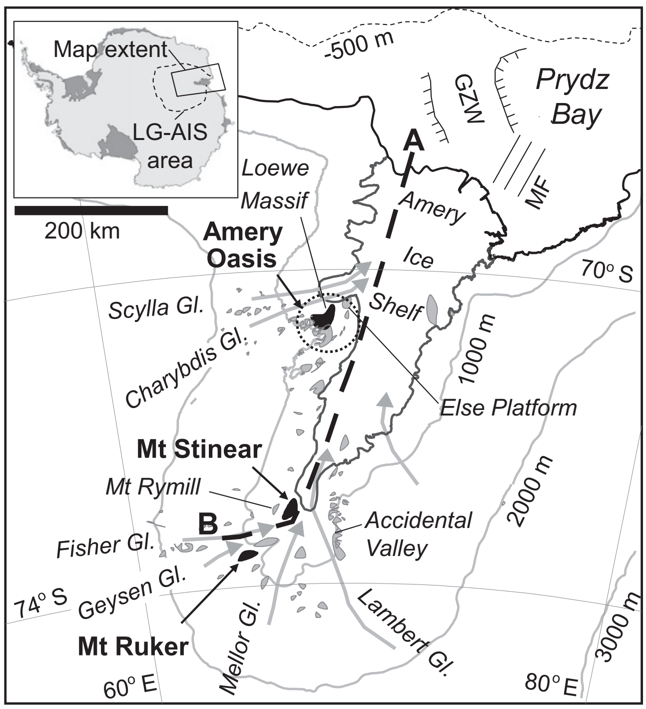

Figure 1. Lower Lambert Glacier–Amery Ice Shelf system (LG-AIS), Antarctica. Ice-free areas are shown in gray; light gray contour lines indicate ice elevation and gray arrows indicate major present-day ice streams. Thick dashed line A–B indicates position of profile in Figure 4. Grounding zone wedges (GZW, hachured lines upglacier) and megaflutes (MF; O'Brien, 1994) indicate extent and flow of LG-AIS ice into Prydz Bay. Thin dashed line indicates shelf edge (–500 m bathymetric contour). Mt—Mount; Gl.—glacier.

GLACIAL GEOMORPHOLOGY

Thin debris drapes and moraine ridges that overlie Cenozoic glaciomarine sediments are present at almost every ice-free area in the Prince Charles Mountains, and were deposited during at least two distinct periods (Bardin, 1982; Fig. 2). Older phase sediments have a subdued surface topography, are strongly weathered, and provide exposure ages ranging from 150 to 1400 ka (Fink et al., 2006; White, 2007; White and Hermichen, 2007). Younger phase sediments are preserved in landforms such as sharp-crested, typically ice-cored moraines, hummocky diamict sheets, and scattered cobbles. Soil formation on these younger deposits is minimal, and weathering on surface clasts is usually restricted to poorly developed iron staining and weathering pits. The lightly weathered debris of the younger phase extends

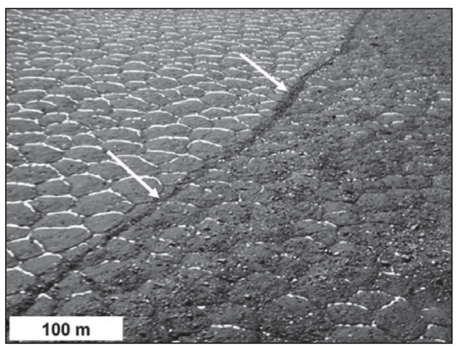

Figure 2. Lightly weathered debris draped over older patterned surface on southern flank of Mount Lanyon. White arrows indicate weathering demarcation line.

from the modern glacier margin to a striking demarcation line, beyond which only heavily weathered bedrock, felsenmeer, and older glacial sediment are preserved. We consider that the highest elevation of unweathered sediments at any one site denotes the local LGM ice surface, and reject the possibility that the demarcation lines are englacial boundaries. Evidence for present-day englacial boundaries above which subglacial debris is not deposited is lacking, as this debris is released from the ice surface at every ablation zone observed in the Prince Charles Mountains. Also, the lightly weathered debris defining the demarcation line was often composed of supraglacial debris derived from local bedrock.

METHODS

Using published reports (Mabin, 1992; Whitehead and McKelvey, 2002), aerial photograph interpretation, field assessment of the degree of weathering, landscape relaxation, and sedimentology of the deposits, we determined the maximum height of the younger debris drapes at 10 ice-free localities along the flanks of the major outlet glaciers, from ~600 km inland adjacent to the current grounding line to near the modern ice shelf edge. At three major ice-free massifs, Mount Ruker, Mount Stinear, and Amery Oasis (Fig. 1), we constrained the timing of deglaciation with 34 in situ ^{10}Be and ^{26}Al exposure ages (Fink and Smith, 2007) on altitudinal transects from the maximum height of the lightly weathered debris down to the modern ice margin. We aimed to minimize the collection of samples with inheritance or a complex exposure history, these being the dominant causes of exposure age uncertainties in Antarctic glacial deposits (Stone et al., 2003). In order of preference, we targeted subglacially abraded cobbles on bedrock, cobbles perched on large blocky boulders on sediment, or the flat uppermost surface of large (>100 cm high) boulders, and intact bedrock surfaces. Where stratigraphic age-altitude reversals occur, the youngest age at a given elevation is considered to provide the best estimate of deglaciation timing (Sugden et al., 2005). Appendix DR1 in the GSA Data Repository[1] presents sample descriptions, analytical methods, and age calculations. Unless stated, exposure ages are reported as the weighted mean of paired ^{10}Be and ^{26}Al ages.

RESULTS

Upper Ice Stream: Mount Ruker

Mount Ruker, the southernmost site on Geysen Glacier (Fig. 1), is mantled by three units of unconsolidated debris. In order of decreasing age, these are (1) a spatially widespread, typically ~1-m-thick layer of strongly weathered felsenmeer and glacial debris reworked by active layer processes into unsorted polygonal nets, (2) lightly weathered debris with minor iron staining and preserved glacial polish, as much as 300 m above the modern outlet glacier surface, and (3) an unweathered scatter of erratics <~160 m above the modern outlet glacier surface that displays no iron staining and is visually indistinguishable from debris being released from the modern Geysen Glacier. The two younger units were deposited over the older patterned surface without disrupting either the preexisting polygon morphology or preexisting weathering rinds (see Fig. 2). We infer that the most recent ice advance was dry based, as observed in Marie Byrd Land in West Antarctica (Sugden et al., 2005).

All 11 erratics from Mount Ruker were taken from the 2 younger units. Samples with minor iron staining range from 154 ± 11 ka to 24.9 ± 1.3 ka (Fig. 3; Table DR3 in the Data Repository; excluding Ruk-251, which shows a complex burial history), indicating that unit 2 was deposited prior to the global LGM. Those with little or no visible weathering (Ruk-199A, Ruk-235A, Ruk-261b, Ruk-201) range from 14.3 ± 0.7 ka to 9.0 ± 0.5 ka, recording a period during which ~50 m of the ~160 m of post-LGM ice lowering occurred.

Near the Modern Grounding Line: Mount Stinear, Mount Rymill, and Accidental Valley

The transition from weathered to unweathered debris is poorly defined at Mount Stinear, 100 km downglacier of Mount Ruker. We infer that a local ice dome covered the broad summit and disgorged ice onto the outlet glaciers, precluding the deposition of ice-marginal debris at the LGM limit at Mount Stinear. Thus, the local LGM (at ~1000 m above sea level, asl) was deduced from interpolation of the clear demarcation between highly and lightly weathered glacial deposits at Mount Rymill (to the west) and Accidental Valley (to the east; see Fig. DR6). This is 800 m higher than today's ice surface at Mount Stinear.

Samples of lightly weathered debris dated at Mount Stinear include (1) subrounded cobbles, perched on bedrock ridges on the steep western flank, (2) blocky boulders on an ice-cored diamict sheet that drapes the gentle slopes of the eastern flank, and (3) subrounded cobbles from a scatter of debris and moraines on the low, glacially rounded and striated hills on the north of the massif. As no sufficiently stable or snow-free sites were found above 600 m asl at Mount Stinear, a large blocky boulder (Rym-173) on diamict a few meters below the limit of lightly weathered debris at Mount Rymill was also analyzed.

The 14 erratics provide ages from 90.5 ± 6.7 ka to 9.2 ± 0.6 ka, with a strong bias toward the youngest end of this range. Ages for 8 of the 9 subrounded cobble-sized erratics form a tight age cluster from 12.2 to 9.2 ka (excluding Stin-7a) (Fig. 3). We consider these samples to provide the most reliable deglaciation ages at this site. Subangular cobbles (Stin-5a and Stin-148) from northern Mount Stinear have older ages (44 ka and "complex," respectively), which we attribute to inheritance from a prior exposure

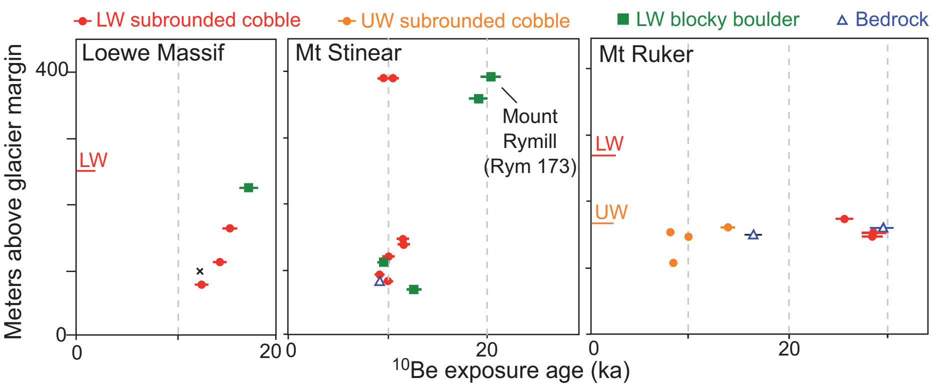

Figure 3. ^{10}Be exposure ages at Mount Ruker, Mounts Stinear and Rymill, and Loewe Massif, Antarctica. Black x at Loewe Massif represents onset of biogenic sedimentation in Lake Terrasovoja (Wagner et al., 2004). Horizontal lines at left axes indicate local Last Glacial Maximum ice elevation deduced from highest observed lightly weathered (LW), and unweathered (UW) debris. LW debris limits at Mount Stinear and Mount Rymill are ~800 m and 400 m, respectively, above modern glacier. Seven samples (3 from Mount Stinear, 4 from Mount Ruker) with ages older than 30 ka are not shown.

[1]GSA Data Repository item 2011026, methods and procedures, weathering demarcation and paleo-ice heights, Tables DR1–DR3 (sample information, accelerator mass spectrometry measurements, and exposure ages), Figures DR1–DR3 (sample site photos and maps), Figure DR4 (^{26}Al/^{10}Be vs. ^{10}Be plot), Figure DR5 (Last Glacial Maximum ice sheet reconstruction), Figure DR6 (local Last Glacial Maximum weathering demarcation lines), and Figure DR7 (Else Platform surficial stratigraphy), is available online at www.geosociety.org/pubs/ft2011.htm, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

and are not discussed further. The remaining four samples are large subangular boulders, most likely supraglacially transported (>2 m^3; Rym-173, Stin-117, Stin-140, Stin-139) with exposure ages of 21.5–10.0 ka. Ages of the two younger subangular boulders are consistent with the cluster of subrounded cobbles, while the oldest have ages as much as 8 k.y. older, suggesting exposure during transport or prior to detachment from the rock wall above. Thus, the 21 ka local LGM exposure age for Rym-173 may overestimate the true deglaciation age by a few thousand years. In summary, the cosmogenic ages indicate that while ice lowering at this site may have begun as early as 21 ka, the final 400 m of lowering occurred between 12 and 9 ka.

Near the Modern Ice Shelf Edge: Amery Oasis

Amery Oasis, 300 km to the north of Mount Stinear, is a large ice-free area flanked by the Amery Ice Shelf to the east and Charybdis Glacier to the north, and is mantled by a complex assortment of Cenozoic glacial deposits (Hambrey et al., 2007). Else Platform, the northern extremity of Amery Oasis, is at the junction of these two ice drainage channels.

Lightly weathered outlet glacier deposits were found only on the northern margins of Amery Oasis at Loewe Massif and Else Platform. Here Charybdis Glacier has deposited a hummocky and partly supraglacially derived debris mantle as much as 1.5 m thick (Figs. DR1, DR6, and DR7). Weathering of these deposits is limited to minor crumbling and iron staining, and shallow (<3 cm) tafoni, providing a strong contrast to the highly weathered bedrock and sediment surfaces across the remainder of Amery Oasis. At numerous locations the debris sheet is shaped into curvilinear ridges, which likely represent ice-contact screes deposited during the retreat of Charybdis Glacier from its most recent advance position.

No lightly weathered glacial sediments or landforms produced by the LG-AIS trunk were found at Amery Oasis, so the thickness of the LG-AIS trunk stream during the local LGM at this location is not directly constrained. However, the maximum height of lightly weathered diamicts along the Charybdis and Scylla Glaciers increases from zero near the ice divide in the west to ~200 m above the present ice on Else Platform (Wellman, 1982; Mabin, 1992). This suggests that the Charybdis Glacier was dammed by the trunk stream of the LG-AIS, in a fashion similar to the damming of the Darwin Glacier by the much larger Hatherton Glacier at this time in West Antarctica (Denton and Hughes, 2000). Because the Charybdis moraines at Else Platform have not been overridden, the LG-AIS trunk stream was no higher than the Charybdis Glacier during and following the local LGM. We infer that ice elevations in the lower portions of the drainage system (i.e., at Loewe Massif) were effectively controlled by the LG-AIS trunk stream, and the height of Charybdis Glacier alongside Amery Oasis is a proxy for ice height of the LG-AIS trunk stream at this latitude.

Four samples from the Charybdis Glacier debris sheet on Loewe Massif provide a chronostratigraphic-consistent sequence of ^{10}Be and ^{26}Al ages that decrease from ca. 18 ka near the upper ice limit, to ca. 12 ka near to the modern glacial margin (Fig. 3). These ages correlate with onset of biogenic sedimentation in the then ice-marginal Lake Terrasovoja, ca. 12.4 calibrated (cal) kyr B.P. (Wagner et al., 2004). We consider that these exposure ages directly constrain the timing of retreat of the former margin of the Charybdis Glacier following the local LGM.

DISCUSSION

Exposure ages from Mounts Ruker and Stinear and Loewe Massif (Table DR3), together with constraints from field mapping of weathering demarcation altitudes at these massifs and from seven other sites (see Fig. DR5), enable us to reconstruct a concave local LGM ice profile along the LG-AIS trunk system (black bars in Fig. 4). The elevation of this profile leads us to conclude that prior to ca. 18 ka, ice was grounded across the entire area covered today by the Amery Ice Shelf. This is because the lower sea level (Fleming et al., 1998) and increased ice surface height ca. 18 ka was sufficient to ground ice under hydrostatic balance. Thus, ice was continuously grounded from Mount Stinear to at least as far offshore as the megascale glacial lineations in inner Prydz Bay (O'Brien, 1994); however, based on marine sediment cores, it did not ground all the way to the continental shelf break (Domack et al., 1998). Most important, the low-elevation, low-gradient, concave ice profile north of 72.5ºS (denoted by length of black arrow, Fig. 4) is inconsistent with the parabolic shape of ice undergoing slow ice sheet flow, and instead conforms to that of a rapidly flowing ice stream (Bennett, 2003). Thus, we conclude that the Lambert Graben north of 72.5ºS was occupied by a fast-flowing ice stream during the local LGM.

As a result of this low-gradient ice stream in the LG-AIS, the increase in grounded ice volume during the local LGM was modest. Minimal ice thickening relative to the modern ice surface in areas proximal to other large outlet glaciers has also been observed elsewhere in East Antarctica for this time, such as eastern Larsemann Hills (Hodgson et al., 2001), Lützow-Holm Bay (Miura et al., 1998), and southern Bunger Hills (Gore et al., 2001), suggesting that this may have been a widespread feature of the LGM ice sheet. Based on the difference in ice volume between our reconstructed local LGM and today's ice-surface profiles, we calculate that the LG-AIS contributed 0.4 ± 0.3 m to sea-level rise since the global LGM (for calculations, see the Data Repository).

Exposure ages from the northern LG-AIS sector (i.e., Loewe Massif) indicate that ice lowering commenced as early as ca. 18 ka, reaching the modern ice margin by ca. 12 ka. Further inland at Mounts Stinear and Ruker, ice lowering occurred from 14 to 8 ka, the delay most likely being due to the time required to propagate the deglaciation response upglacier. The timing of ice lowering in the ice stream–affected region of the LG-AIS is roughly coeval with the recession of ice streams in the western Ross Sea (Anderson et al., 2002). In contrast, deglaciation at Loewe Massif preceded by a few thousand years the phase of post-global LGM ice loss in Mac.Robertson Land (Mackintosh et al., 2007; Leventer et al., 2006) and Wilkes Land (Goodwin and Zweck, 2000), both of which are characterized by slow ice sheet flow.

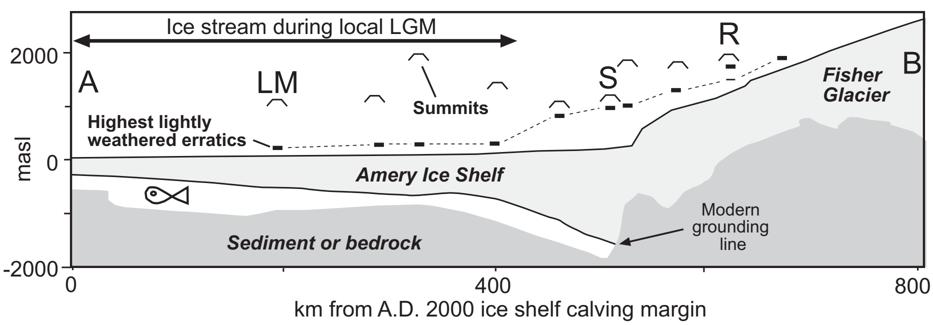

Figure 4. Vertical section of ice sheet along transect A–B (shown in Fig. 1; masl—meters above sea level). Thin dotted line indicates maximum height of outlet glaciers along this profile since local Last Glacial Maximum (LGM) (ca. 18 ka) based on exposure ages and field observations (of weathering demarcation altitudes). Thick solid line indicates zone of ice streaming at this time. Modern ice sheet and bedrock elevation were extracted from BEDMAP folio (Lythe et al., 2001). Mount Ruker, Mount Stinear, and Loewe Massif are labeled as R, S, and LM, respectively. Thick horizontal bars indicate maximum elevation of lightly weathered erratics, while thin bar at Mount Ruker indicates maximum elevation of unweathered debris.

The earlier deglaciation in areas of Antarctica with large ice streams indicates that they were more responsive to changes in climate and sea level at the end of the global LGM than areas dominated by slower, more diffuse ice flow. This sensitivity is not currently captured in ice sheet models used to predict Antarctic-wide contribution to sea-level rise over the next few centuries (Gregory and Huybrechts, 2006). Thus, such simulations should be regarded as minimum estimates of deglaciation, particularly given that dynamic thinning is currently occurring at most major Antarctic ice stream outlets (Pritchard et al., 2009).

ACKNOWLEDGMENTS

We thank the Australian Antarctic Division (grants 1071 and 1215), Australian Research Council (grant DP0556728), and Australian Institute of Nuclear Science and Engineering (grants 03-048 and 04-062) for financial support; A. Cianchi, R. Ferguson, D. Gardner, W.-D. Hermichen, A. Hull, M. Jenkin, and T. Pickard for field assistance; C. Mifsud for assistance at the Australian Nuclear Science and Technology Organisation; and D. Zwartz, B. Wagner, and M. Bentley for comments on the manuscript.

REFERENCES CITED

Anderson, J., Shipp, S., Lowe, A., Wellner, J., and Mosola, A., 2002, The Antarctic Ice Sheet during the Last Glacial Maximum and its subsequent retreat history: A review: Quaternary Science Reviews, v. 21, p. 49–70, doi: 10.1016/S0277-3791(01)00083-X.

Bardin, V.I., 1982, Composition of East Antarctic moraines and some problems of Cenozoic history, *in* Craddock, C., ed., Antarctic geoscience: Madison, University of Wisconsin Press, p. 1069–1076.

Bennett, M.R., 2003, Ice streams as the arteries of an ice sheet: Their mechanics, stability and significance: Earth-Science Reviews, v. 61, p. 309–339, doi: 10.1016/S0012-8252(02)00130-7.

Denton, G., and Hughes, T., 2000, Reconstruction of the Ross ice drainage system, Antarctica, at the last glacial maximum: Geografiska Annaler, v. 82A, p. 143–166.

Domack, E., O'Brien, P., Harris, P., Taylor, F., Quilty, P.G., De Santis, L., and Raker, B., 1998, Late Quaternary sediment facies in Prydz Bay, East Antarctica and their relationship to glacial advance onto the continental shelf: Antarctic Science, v. 10, p. 236–246, doi: 10.1017/S0954102098000339.

Fink, D., and Smith, A., 2007, An inter-comparison of ^{10}Be and ^{26}Al AMS reference standards and the ^{10}Be half-life: Nuclear Instruments and Methods B, v. 259, p. 600–609, doi: 10.1016/j.nimb.2007.01.299.

Fink, D., McKelvey, B., Hambrey, M., Fabel, D., and Brown, R., 2006, Pleistocene deglaciation chronology of the Radok Lake basin, Amery Oasis, northern Prince Charles Mountains, Antarctica: Earth and Planetary Science Letters, v. 243, p. 229–243, doi: 10.1016/j.epsl.2005.12.006.

Fleming, K., Johnston, P., Zwartz, D., Yokoyama, Y., Lambeck, K., and Chappell, J., 1998, Refining the eustatic sea-level curve since the Last Glacial Maximum using far- and intermediate-field sites: Earth and Planetary Science Letters, v. 163, p. 327–342, doi: 10.1016/S0012-821X(98)00198-8.

Goodwin, I., and Zweck, C., 2000, Glacio-isostasy and Glacial Ice Load at Law Dome, Wilkes Land, East Antarctica: Quaternary Research, v. 53, p. 285–293, doi: 10.1006/qres.1999.2125.

Gore, D., Rhodes, E., Augustinus, P., Leishman, M., Colhoun, E., and Rees-Jones, J., 2001, Bunger Hills, East Antarctica: Ice free at the Last Glacial Maximum: Geology, v. 29, p. 1103–1106, doi: 10.1130/0091-7613(2001)029<1103:BHEAIF>2.0.CO;2.

Gregory, J., and Huybrechts, P., 2006, Ice-sheet contributions to future sea-level change: Royal Society of London Philosophical Transactions, ser. A, v. 364, p. 1709–1731, doi: 10.1098/rsta.2006.1796.

Hambrey, M., Glasser, N., McKelvey, B., Sugden, D., and Fink, D., 2007, Cenozoic landscape evolution of an East Antarctic oasis (Radok Lake area, northern Prince Charles Mountains), and its implications for the glacial and climatic history of Antarctica: Quaternary Science Reviews, v. 26, p. 598–626, doi: 10.1016/j.quascirev.2006.11.014.

Hodgson, D., Noon, P., Vyverman, W., Bryant, C., Gore, D., Appleby, P., Gilmour, M., Verleyen, E., Sabbe, K., Jones, V., Ellis-Evans, J., and Wood, P., 2001, Were the Larsemann Hills ice-free through the last glacial maximum?: Antarctic Science, v. 13, p. 440–454, doi: 10.1017/S0954102001000608.

Leventer, A., Domack, E., Dunbar, R., Pike, J., Stickley, C., Maddison, E., Brachfeld, S., Manley, P., and McClennen, C., 2006, Marine sediment record from the East Antarctic margin reveals dynamics of ice sheet recession: GSA Today, v. 16, no. 12, p. 4–10, doi: 10.1130/GSAT01612A.1.

Lythe, M., Vaughan, D., and the BEDMAP Consortium, 2001, BEDMAP: A new ice thickness and subglacial topographic model of Antarctica: Journal of Geophysical Research, v. 106, p. 11,335–11,351, doi: 10.1029/2000JB900449.

Mabin, M., 1992, Late Quaternary ice-surface fluctuations of the lower Lambert Glacier, northern Prince Charles Mountains, *in* Yoshida, Y., ed., Recent progress in Antarctic earth science: Tokyo, Terra Scientific Publishing Company, p. 683–687.

Mackintosh, A., White, D., Fink, D., and Gore, D., 2007, Exposure ages from mountain dipsticks in Mac. Robertson Land, East Antarctica, indicate little change in ice sheet thickness since the Last Glacial Maximum: Geology, v. 35, p. 551–554, doi: 10.1130/G23503A.1.

Miura, H., Maemoku, H., Seto, K., and Moirwaka, M., 1998, Late Quaternary East Antarctic melting event in the Soya Coast region based on stratigraphy and oxygen isotopic ratio of fossil molluscs: Polar Geoscience, v. 11, p. 260–274.

O'Brien, P.E., 1994, Morphology and Late Glacial history of Prydz Bay, Antarctica, based on echo sounder data, *in* Cooper, A., et al., eds., The Antarctic continental margin: Geophysical and geological stratigraphic records of Cenozoic glaciation, paleoenvironments and sea-level change: Terra Antartica, v. 1, p. 403–405.

Pritchard, H., Athern, R., Vaughan, D., and Edwards, L., 2009, Extensive dynamic thinning on the margins of the Greenland and Antarctic ice sheets: Nature, v. 461, p. 971–975, doi: 10.1038/nature08471.

Stone, J., Balco, G., Sugden, D., Caffee, M., Sass, L., Cowdery, S., and Siddoway, C., 2003, Holocene deglaciation of Marie Byrd Land, West Antarctica: Science, v. 299, p. 99–102, doi: 10.1126/science.1077998.

Sugden, D., Balco, G., Cowdery, S.G., Stone, J., and Sass, L., 2005, Selective glacial erosion and weathering zones in the coastal mountains of Marie Byrd Land, Antarctica: Geomorphology, v. 67, p. 317–334, doi: 10.1016/j.geomorph.2004.10.007.

Wagner, B., Cremer, H., Hultzsch, N., Gore, D., and Melles, M., 2004, Late Pleistocene and Holocene history of Lake Terrasovoje, Amery Oasis, East Antarctica, and its climatic and environmental implications: Journal of Paleolimnology, v. 32, p. 321–339, doi: 10.1007/s10933-004-0143-8.

Wellman, P., 1982, Surging of Fisher Glacier, eastern Antarctica: Evidence from geomorphology: Journal of Glaciology, v. 28, p. 23–28.

White, D., 2007, Cenozoic glacial history and landscape evolution of Mac. Robertson Land and the Lambert Glacier–Amery Ice Shelf System, East Antarctica [Ph.D. thesis]: Sydney, Macquarie University Department of Physical Geography, 166 p.

White, D., and Hermichen, W., 2007, Glacial and periglacial history of the Southern Prince Charles Mountains: East Antarctica: Terra Antartica, v. 14, p. 5–12.

Whitehead, J., and McKelvey, B., 2002, Cenozoic glacigene sedimentation and erosion at the Menzies Range, southern Prince Charles Mountains, Antarctica: Journal of Glaciology, v. 48, p. 226–236, doi: 10.3189/172756502781831340.

Wright, A., White, D., Gore, D., and Siegert, M., 2008, Antarctica at the Last Glacial Maximum, deglaciation and the Holocene, *in* Florindo, F., and Siegert, M., eds., Antarctic climate evolution: Developments in Earth and Environmental Sciences 8: Amsterdam, Elsevier, p. 531–570.

Manuscript received 19 July 2010
Revised manuscript received 28 July 2010
Manuscript accepted 30 July 2010

Printed in USA

Geology

Cosmogenic nuclide evidence for enhanced sensitivity of an East Antarctic ice stream to change during the last deglaciation

Duanne A. White, David Fink and Damian B. Gore

Geology 2011;39;23-26
doi: 10.1130/G31591.1

Notes

THE GEOLOGICAL SOCIETY OF AMERICA