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Sensitivity of the Antarctic Ice Sheet to Climate Change over the Last Two Glacial/Interglacial Cycles

Brenda L. Hall

Principal Investigator; University of Maine, Orono, brendah@maine.edu

George H. Denton

Co-Principal Investigator; University of Maine, Orono, [gdenton@maine.edu](mailto:g Denton@maine.edu)

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Cover

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Project Title:	Sensitivity of the Antarctic Ice Sheet to Climate Change over the Last Two Glacial/Interglacial Cycles
PD/PI Name:	Brenda L Hall, Principal Investigator George H Denton, Co-Principal Investigator
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Submission Date:	10/16/2014
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	Brenda L Hall

Accomplishments

* What are the major goals of the project?

This project was designed to develop knowledge of the extent of the Ross Sea ice sheet during the last two glaciations and to develop a chronology for the last glacial maximum and penultimate glaciation. To this end, we had the following

goals:

- 1) Map the extent of the Ross Sea ice sheet along the western coast of McMurdo Sound from Taylor Valley to the southern Royal Society Range.
- 2) Develop a radiocarbon chronology for the last glacial maximum from dates of algal mats within moraines.
- 3) Produce a uranium-thorium chronology to gain information on the timing of the penultimate glaciation.
- 4) Synthesize the data to develop a better understanding not only of the behavior of the Antarctic ice sheet during ice-age cycles, but also of the role of the ice sheet in transmitting or driving climate changes.

*** What was accomplished under these goals (you must provide information for at least one of the 4 categories below)?**

Major Activities: During the course of this project, we carried out the following major activities:

- 1) We produced detailed surficial geologic maps of Miers, Marshall, and Salmon Valleys, including the distribution and elevation of deposits related to the last two glaciations. These maps allowed reconstruction of past ice elevations and flow directions in the McMurdo Sound region.
- 2) We collected hundreds of samples for radiocarbon, uranium-thorium, and surface exposure-age dating. These samples were dated, providing a chronology for glacial and lake-level fluctuations during both the last glacial maximum and the penultimate glaciation.
- 3) We mentored six graduate and five undergraduates. Three graduate theses emerged from this work. All of these students are either continuing with their education or are employed in their field.
- 4) We presented the results of this project at professional meetings, including WAIS, the Comer Abrupt Climate Change Conference, and the International Antarctic Earth Sciences meeting.
- 5) We have published papers incorporating project results, with several more papers in progress, including one aimed at a high-profile (i.e., Nature) journal.
- 6) We have performed outreach activities, including visits and letters to K-12 classrooms and lectures to civic groups.

Specific Objectives: We produced the first well-dated record of the timing of the local last glacial maximum in Antarctica. We found that in the western Ross Sea region, the maximum occurred not during the global LGM, but during the last termination. Although the ice sheet was present in McMurdo Sound perhaps as early as 30,000 years ago, growth to the maximum position did not occur until 18.5 ka. This position was maintained until -13.0 ka. This time range, 13-18.5 ka, overlaps almost perfectly with the last termination in the Southern Hemisphere. While air temperature rose and glaciers north of Antarctica collapsed, the Antarctic Ice Sheet in the Ross Sea region attained its maximum thickness. We infer that this growth was due to increased accumulation resulting from warmer air temperatures. After 13 ka, those glaciers in contact with the ocean began to retreat, likely from a marine mechanism, such as sea-level rise or melt at the grounding lines. This marine effect propagated away from the Ross Embayment, causing later local glacial maxima inland. Those glaciers not in contact with the ocean continued to expand throughout the Holocene, as a result of high accumulation. Our work points to the competing effects of accumulation and marine drawdown in controlling the

extent of the ice sheet. Marine drawdown ultimately overcomes the accumulation effect.

Our work on the penultimate glaciation indicates that the Ross Sea ice sheet reached McMurdo Sound by ~155 ka and remained there until at least 139 ka. Although our work on this time period is not yet definitive, it appears that ice recession may have occurred much earlier in the deglaciation at the stage 6/5 boundary than it did at the end of the last glacial maximum.

Key outcomes or
Other achievements:

*** What opportunities for training and professional development has the project provided?**

This work led to the training and professional development of six graduate students and five undergraduates. These students had opportunities for field work, laboratory research, and preparation of manuscripts. Three students produced graduate theses from this project. All three presented the results of their work at professional meetings. Two undergraduates presented project results at an undergraduate research expo and at the Geological Society of Maine meeting, where they won the best poster award.

*** How have the results been disseminated to communities of interest?**

Results from this project have been presented at numerous professional meetings, including the annual WAIS meeting, Comer Abrupt Climate Change Conference, and the International Antarctic Earth Sciences meeting, among others. Data also have been incorporated in class lectures at the University of Maine, at invited talks at other universities, and to the public in lectures to civic groups. Results also have been published in several papers with others in progress.

Supporting Files

Filename	Description	Uploaded By	Uploaded On
SalmonMap.pdf	Example of a surficial geologic map produced in this study. This shows the surficial deposits in Salmon Valley, Royal Society Range.	Brenda Hall	10/10/2014

Products

Books

Book Chapters

Conference Papers and Presentations

Hall, B., Bromley, G., Conway, H., Dengler, E., Denton, G., Jackson, M., Koffman, T., Stone, J., Spector, P., and Todd, C. (2013). *Chronology of the Ross Sea ice sheet at and since the Last Glacial Maximum [abstract]*. Comer Abrupt Climate Change meeting. Soldiers Grove, Wisconsin. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Hall, B., Denton, G., Allard, S., Bromley, G., Dengler, E., Jackson, M., Koffman, T., Stone, J., Conway, H., and Spector, P. (2012). *History of a grounded ice sheet in the Ross Sea Embayment at and since the Last Glacial Maximum [abstract]*. Comer Abrupt Climate Change meeting. Soldiers Grove, Wisconsin. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Hall, B. (2011). *History of the Antarctic Ice Sheet in the Ross Sea sector at and since the last glacial maximum [abstract]*. 11th International Symposium on Antarctic Earth Sciences. Edinburgh, Scotland. Status = PUBLISHED;

Acknowledgement of Federal Support = Yes

Allard, S., Hall, B., and Denton, G. (2011). *History of the Ross Sea ice sheet based on glacial and lake records from Marshall Valley, Antarctica [abstract]*. 18th West Antarctic Ice Sheet Annual Meeting. Loveland, CO.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Jackson, M., Hall, B., and Denton, G. (2012). *History of the Ross Sea ice sheet in Salmon Valley during the last glaciation. [abstract]*. 19th Annual West Antarctic Ice Sheet Meeting. Pack Forest Park, Washington.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Hall, B., Allard, S., Bromley, G., Conway, H., Dengler, E., Denton, G., Hillebrand, T., Jackson, M., King, C., Koffman, T., Stone, J., Spector, P., and Todd, C. (2014). *Maximum of the last glaciation in the Ross Sea Embayment [abstract]*. Joint Model-Data Workshop. Grenoble, France. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Koffman, T., Hall, B., and Denton, G. (2011). *New radiocarbon dates from glacial deposits in Miers Valley constrain the past behavior of the Antarctic Ice Sheet [abstract]*. 18th Annual West Antarctic Ice Sheet meeting. Loveland, CO. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Hall, B., Denton, G., Stone, J., Allard, S., Bromley, G., Dengler, E., Hillebrand, T., Jackson, C. King, M., Koffman, T., Spector, P., Todd, C. (2014). *The last glacial maximum and deglaciation in the Ross Sea sector of Antarctica [abstract]*. Comer Abrupt Climate Change meeting. Soldiers Grove, Wisconsin. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Inventions

Journals

Anderson, J.B., Conway, H., Bart, P.J., Kirshner, A.E., Greenwood, S.L., McKay, R.M., Hall, B.L., Ackert, R.P., Licht, K., Jakobsson, M., Stone, J.O. (2014). Ross Sea paleodrainage and deglacial history during and since the LGM. *Quaternary Science Reviews*. 100 31. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Golledge, N., Levy, R., McKay, R.M., Fogwill, C.J., White, D.A., Graham, A.G.C., Smith, J.A., Hillenbrand, C-D., Licht, K.J., Denton, G.H., Ackert, R.P., Jr., Maas, S.M., Hall, B.L. (2013). Glaciology and geological signature of the Last Glacial Maximum Antarctic ice sheet.. *Quaternary Science Reviews*. 78 225. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Hall, B., Denton, G., Stone, J., and Conway, H. (2013). History of the grounded ice sheet in the Ross Sea sector of Antarctica during the last glacial maximum and the last termination.. *Geological Society of London*. doi [10.1144/SP381.5](https://doi.org/10.1144/SP381.5). Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI:

Licenses

Other Products

Databases.

Metadata related to radiocarbon dates obtained in this project can be found here:

http://gcmd.nasa.gov/getdif.htm?Royal_Society_Range_Radiocarbon_Data

Databases.

Metadata related to this project can be found at:

http://gcmd.nasa.gov/getdif.htm?Royal_Society_Range_Surficial_Maps

These metadata point to surficial maps produced during this project, which can be found here:

<http://umaine.edu/earthclimate/faculty-staff/faculty-and-staff/brenda-hall/glacial-geology-and-geochronology-research-group/data/>

Other Publications

Patents

Technologies or Techniques

Thesis/Dissertations

Tobias Koffman. *Glacial geology of Miers Valley, Antarctica: a record of the western margin of the Ross Sea ice sheet during the local last glacial maximum.* (2013). University of Maine. Acknowledgement of Federal Support = Yes

Margaret Jackson. *Glacial history of Salmon Valley, Royal Society Range, Antarctica.* (2013). University of Maine. Acknowledgement of Federal Support = Yes

Stephanie Allard. *History of the Ross Sea ice sheet based on glacial and lacustrine records from Marshall Valley, Antarctica.* (2012). University of Maine. Acknowledgement of Federal Support = Yes

Websites

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Hall, Brenda	PD/PI	5
Denton, George	Co PD/PI	1
Allard, Stephanie	Graduate Student (research assistant)	12
Braddock, Scott	Graduate Student (research assistant)	3
Dengler, Elizabeth	Graduate Student (research assistant)	1
Jackson, Margaret	Graduate Student (research assistant)	12
King, Courtney	Graduate Student (research assistant)	9
Koffman, Tobias	Graduate Student (research assistant)	12
Arnold, Robin	Undergraduate Student	2
Mako, Calvin	Undergraduate Student	2
McKenney, Glenn	Undergraduate Student	2
Ryan, Patrick	Undergraduate Student	2
Strand, Peter	Undergraduate Student	2

Full details of individuals who have worked on the project:

Brenda L Hall**Email:** BrendaH@Maine.Edu**Most Senior Project Role:** PD/PI**Nearest Person Month Worked:** 5

Contribution to the Project: Dr. Hall conceived and organized the project, managed the logistics, carried out field work, carried out and oversaw the laboratory analyses, mentored students, presented results, and prepared manuscripts.

Funding Support: This grant and institutional support.

International Collaboration: Yes, United Kingdom

International Travel: Yes, Antarctica - 0 years, 3 months, 0 days; United Kingdom - 0 years, 1 months, 0 days; France - 0 years, 0 months, 6 days

George H Denton**Email:** george.denton@umit.maine.edu**Most Senior Project Role:** Co PD/PI**Nearest Person Month Worked:** 1

Contribution to the Project: This person contributed to project design and assisted in data interpretation and preparation of manuscript.

Funding Support: Institutional support

International Collaboration: No

International Travel: No

Stephanie Allard**Email:** stephanielallard@gmail.com**Most Senior Project Role:** Graduate Student (research assistant)**Nearest Person Month Worked:** 12

Contribution to the Project: This person carried out thesis research related to the project, participated in field and lab work, presented results at meetings, and helped with manuscript preparation.

Funding Support: This grant.

International Collaboration: Yes, Antarctica

International Travel: Yes, Antarctica - 0 years, 1 months, 15 days

Scott Braddock**Email:** scott.braddock@maine.edu**Most Senior Project Role:** Graduate Student (research assistant)**Nearest Person Month Worked:** 3

Contribution to the Project: This student was responsible for organizing and maintaining sample collections, as well as clerical tasks associated with this project. He also participated in lab work.

Funding Support: This grant.

International Collaboration: No

International Travel: No

Elizabeth Dengler

Email: liz.dengler@gmail.com

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 1

Contribution to the Project: This person participated in field work and in the processing of radiocarbon samples.

Funding Support: Other NSF funds

International Collaboration: Yes, Antarctica

International Travel: Yes, Antarctica - 0 years, 1 months, 0 days

Margaret Jackson

Email: margaret.s.jackson@maine.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 12

Contribution to the Project: Margaret carried out thesis research related to this project, including field and lab work. She also helped prepare radiocarbon samples.

Funding Support: This grant and other NSF funds

International Collaboration: Yes, Antarctica

International Travel: Yes, Antarctica - 0 years, 1 months, 15 days

Courtney King

Email: courtney.king@maine.edu

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 9

Contribution to the Project: This person carried out laboratory analyses, including preparation of samples for radiocarbon and surface exposure-age dating. She travelled to the University of Washington to receive in-depth training in cosmogenic dating methods.

Funding Support: This grant.

International Collaboration: Yes, Antarctica

International Travel: No

Tobias Koffman

Email: tobykoffman@hotmail.com

Most Senior Project Role: Graduate Student (research assistant)

Nearest Person Month Worked: 12

Contribution to the Project: Toby carried out thesis research related to this project, including field and lab work.

Funding Support: Initially this grant, followed by a NSF graduate fellowship.

International Collaboration: Yes, Antarctica

International Travel: Yes, Antarctica - 0 years, 2 months, 0 days

Robin Arnold

Email: ramold@maine.edu

Most Senior Project Role: Undergraduate Student

Nearest Person Month Worked: 2

Contribution to the Project: This person participated in field work.

Funding Support: This grant.

International Collaboration: Yes, Antarctica

International Travel: Yes, Antarctica - 0 years, 1 months, 15 days

Calvin Mako

Email: calvin.mako@umit.maine.edu

Most Senior Project Role: Undergraduate Student

Nearest Person Month Worked: 2

Contribution to the Project: This person participated in field work.

Funding Support: This grant.

International Collaboration: Yes, Antarctica

International Travel: Yes, Antarctica - 0 years, 1 months, 15 days

Glenn McKenney

Email: Glenn.McKenney@umit.maine.edu

Most Senior Project Role: Undergraduate Student

Nearest Person Month Worked: 2

Contribution to the Project: This person participated in field work.

Funding Support: This grant.

International Collaboration: Yes, Antarctica

International Travel: Yes, Antarctica - 0 years, 1 months, 15 days

Patrick Ryan

Email: patrick.ryan@umit.maine.edu

Most Senior Project Role: Undergraduate Student

Nearest Person Month Worked: 2

Contribution to the Project: This person participated in field work.

Funding Support: This grant.

International Collaboration: Yes, Antarctica

International Travel: Yes, Antarctica - 0 years, 1 months, 15 days

Peter Strand

Email: peter.strand@maine.edu

Most Senior Project Role: Undergraduate Student

Nearest Person Month Worked: 2

Contribution to the Project: This person participated in field work.

Funding Support: This grant.

International Collaboration: Yes, Antarctica

International Travel: Yes, Antarctica - 0 years, 1 months, 15 days

What other organizations have been involved as partners?

Name	Type of Partner Organization	Location
University of Oxford	Academic Institution	Oxford, UK
University of Washington	Academic Institution	Seattle, WA

Full details of organizations that have been involved as partners:

University of Oxford

Organization Type: Academic Institution

Organization Location: Oxford, UK

Partner's Contribution to the Project:

In-Kind Support

Facilities

Collaborative Research

Personnel Exchanges

More Detail on Partner and Contribution: We work collaboratively to produce uranium-thorium chronologies for glaciation.

University of Washington

Organization Type: Academic Institution

Organization Location: Seattle, WA

Partner's Contribution to the Project:

Facilities

More Detail on Partner and Contribution: Project staff received in-depth training in cosmogenic dating at the University of Washington.

What other collaborators or contacts have been involved?

NO

Impacts

What is the impact on the development of the principal discipline(s) of the project?

This project has two principal impacts on the major field of study. The first is the development of one of the most robust chronologies for LGM and Stage 6 ice fluctuations in Antarctica. We produced the first, well-dated record of the maximum ice position in Antarctica at the LGM. Moreover, we now have one of the very few records of Stage 6 ice fluctuations. These precise records are important not only for understanding Antarctic glacial history, but for comparing with records elsewhere in the world to address problems concerning abrupt climate change and ice-age cycles.

Our second major contribution is that we have shown that accumulation plays an important role in causing the Antarctic ice sheet to reach and maintain its maximum position long after glaciers elsewhere in the southern hemisphere have begun to recede. Our record also shows, however, that marine drawdown ultimately overcomes the accumulation effect.

What is the impact on other disciplines?

Our work bears on questions concerning past and future sea-level rise. Our data join a growing body of near-field evidence that suggest that MWP1a did not come from the Antarctic. Our data do not preclude an Antarctic source, but make a Ross Sea sector source very unlikely. Ultimately, an understanding of past sea-level contributions bears on questions concerning the inherent stability of the Antarctic ice sheet in a warming world.

What is the impact on the development of human resources?

This project resulted in the professional development and training of 11 students. All of these students have continued in the field of science.

What is the impact on physical resources that form infrastructure?

Nothing to report.

What is the impact on institutional resources that form infrastructure?

Nothing to report.

What is the impact on information resources that form infrastructure?

Nothing to report.

What is the impact on technology transfer?

Nothing to report.

What is the impact on society beyond science and technology?

Sea-level rise is one of the major concerns with future climate warming. The behavior of the Antarctic ice sheet remains one of the greatest unknowns in predicting future sea level. Our work bears on this problem, because we gained insights into the behavior of the ice sheet during the last episode of major climate warming, the termination of the ice age.

Changes/Problems

Changes in approach and reason for change

Nothing to report.

Actual or Anticipated problems or delays and actions or plans to resolve them

Nothing to report.

Changes that have a significant impact on expenditures

Nothing to report.

Significant changes in use or care of human subjects

Nothing to report.

Significant changes in use or care of vertebrate animals

Nothing to report.

Significant changes in use or care of biohazards

Nothing to report.