

Signature of the Last Termination in Maine

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Principal Investigator:

Dr. Brenda Hall, Professor
School of Earth and Climate Sciences
The Climate Change Institute
University of Maine
Orono, ME 04469
(207) 581-2191
BrendaH@maine.edu

Co-Investigators:

Dr. Thomas Lowell, Professor
Department of Geology
University of Cincinnati
Cincinnati, OH

Dr. Gordon Bromley, Research Assistant Professor
School of Earth and Climate Sciences
The Climate Change Institute
University of Maine
Orono, ME 04469



Introduction and Statement of Problem

The origin of Pleistocene ice ages remains a major unsolved problem of earth sciences. The glacial/interglacial transition at the end of the last ice age, known as a termination, is particularly important, because it represents the greatest natural warming of recent geological history. Yet, the mechanisms by which the earth exits an ice age are not fully understood.

The current consensus is that terminations are characterized by out-of-phase climate behavior between the Northern and Southern Hemispheres. Intense winter cooling and spread of sea ice in the North Atlantic is thought to be key in rapidly propagating the effects of North Atlantic cold periods, such as Heinrich Stadial I (HS-1; 14.5-18 ka), into the Southern Hemisphere by causing southward shift of the Intertropical Convergence Zone. This shift at the start of HS-1 may have caused Southern Hemisphere oceanic fronts and westerly winds to migrate poleward, producing rapid warming of southern latitudes and release of carbon dioxide from the Southern Ocean that set in motion the termination. By this hypothesis, a variety of 'bipolar seesaw', cold periods in the North Atlantic region lead to warming in the south, which kick starts the end of the ice age.

Recent work, however, has begun to cast doubt on this simple conception of a bipolar seesaw in climate during the termination. Emerging glacial chronologic data seem to indicate that the timing and pattern of climate change during the termination may have been identical in both hemispheres, at least during summer, and that deglaciation (summer warming) in the north occurred during what are traditionally thought of as Northern Hemisphere cold periods. For example, recent data from the Alps suggest rapid deglaciation during HS-1, similar to that seen in the Southern Hemisphere. In addition, new work suggests that glacier fluctuations in later stages of the termination, during the late-glacial period (11.7-14.5 ka) also may be the same in both hemispheres. Thus, a limited amount of emerging data hints at the possibility that significant Northern Hemisphere deglaciation may have occurred during what is traditionally thought of as a cold period, HS-1. One explanation for this apparent paradox is that the termination of the ice age in the Northern Hemisphere was characterized by warming summers, which caused ice melt, but extremely cold winters, which produced the cold mean-annual temperatures seen in the majority of North Atlantic region climate proxies. Resolving the timing of Northern Hemisphere deglaciation during the beginning of the termination and, in particular, whether any of it occurred during HS-1, is key for assessing the mechanisms that ended the ice age.

Results of this Study

In 2015 and 2016, we collected samples for surface exposure-age dating from vertical transects on Mt. Desert Island and Isle au Haut, with the goal being to determine the timing of ice thinning during the termination. We collected 18 samples from Sargent, Penobscot, and Cadillac Mts. on Mt. Desert Island and from Jerusalem Mt. on Isle au Haut. All samples were collected above the local marine limit and thus were never covered by the ocean during deglaciation. We crushed and sieved the samples, isolating the 250-500 micron fraction for ^{10}Be analysis. We purified the quartz using a combination of froth floatation and etching in 2% HF acid. Purity was confirmed by ICP-OES analysis. Approximately 15 g of pure quartz was dissolved in concentrated HF,

and the sample chemistry to isolate beryllium followed standard methods. All samples were run at Lawrence Livermore National Laboratory. One sample, IAH-16-2, did not have enough pure quartz.

Table 1. Sample locations and ages.

Sample	Lat.	Long.	Elev.	Age	error
SM-15-1	44.34244	-68.2738	417	13,050	300
SM-15-2	44.33977	-68.2715	401	14,600	400
SM-15-3	44.33187	-68.2659	362	15,120	260
SM-15-4	44.32912	-68.2649	332	14,580	260
SM-15-5	44.32609	-68.2638	281	14,770	330
SM-15-6	44.32350	-68.2636	246	15,810	310
CM-15-1	44.34793	-68.2285	441	15,410	560
CM-15-2	44.34132	-68.2295	370	14,470	310
CM-15-3	44.33298	-68.2237	309	15,810	280
CM-15-4	44.32991	-68.2211	261	14,920	380
CM-15-5	44.32537	-68.2205	215	14,560	320
CM-15-6	44.32323	-68.2189	147	14,920	400
IAH-16-1	44.05530	-68.6237	140	14,310	650
IAH-16-2	44.05493	-68.6228	148	No data	
IAH-16-3	44.05473	-68.6213	153	18,890	420
IAH-16-4	44.05342	-68.6215	141	16,963	400
IAH-16-5	44.04878	-68.6249	133	17,230	450
IAH-16-6	44.04520	-68.6271	105	23,890	490

On Mt. Desert Island, sample ages ranged from ~15,800 to 14,600 yr BP. We consider one sample, dating to 13,050 yr BP, to be an outlier, because it is considerably younger than the other samples. This sample comes from the summit of Sargent Mt. and would be expected to be one of the oldest samples, rather than the youngest. One possibility is that erosion early in deglaciation exhumed the boulder. Overall, the ages, when plotted vs. elevation (Fig. 1), show that there is little difference between the ages of rocks near the summit vs. those lower on the mountain. We conclude that deglaciation had begun by ~15,800 yr BP and proceeded rapidly, faster than our ability to resolve with our dating technique. The mountains were free of ice within a thousand years.

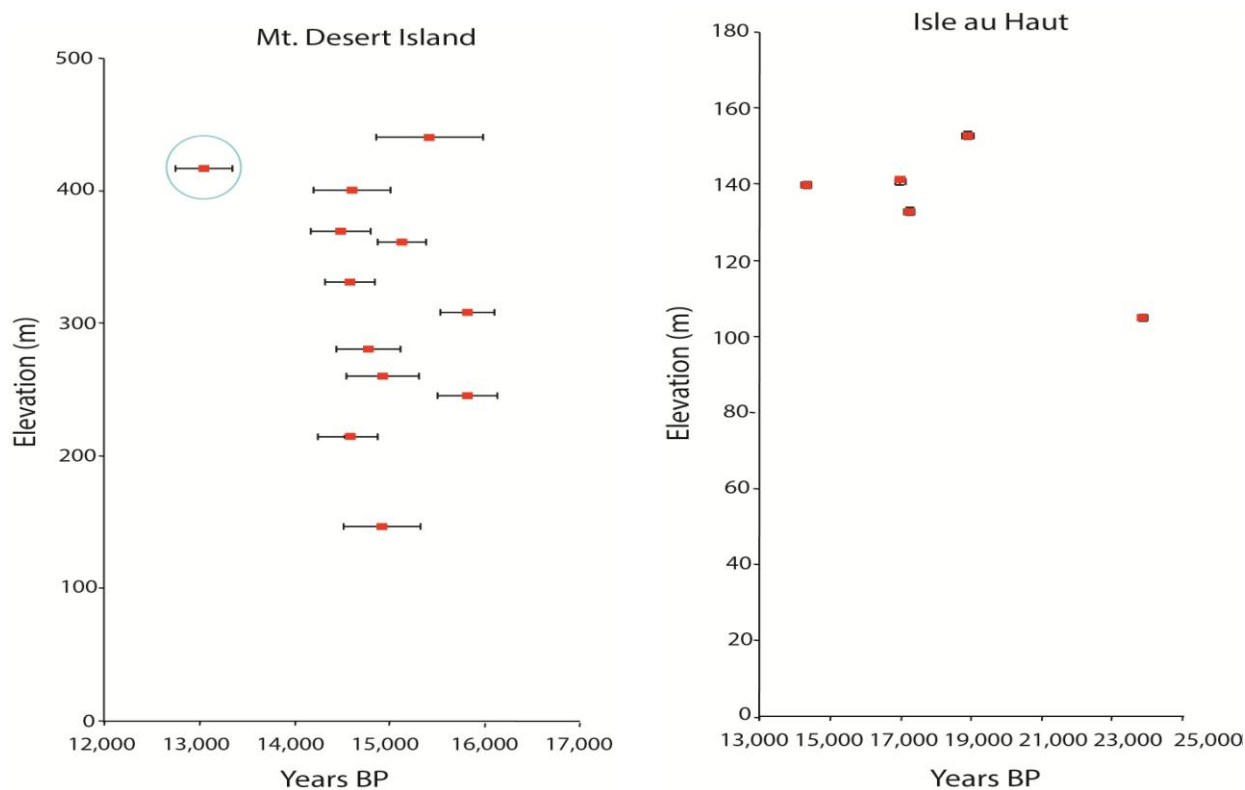


Fig. 1. Age vs. Elevation plots for cosmogenic surface exposure-age dates from Mt. Desert Island and Isle au Haut. Error bars are 1-sigma and for the Isle au Haut data, are smaller than the symbol. The blue circle on the Mt. Desert Island plot identifies an outlier in the dataset.

Data from Isle au Haut are less straightforward to interpret. In general, the dates are older than those at Mt. Desert Island. One sample is 23,890 yr BP, which seems improbable, given that ice is thought to have covered the Gulf of Maine at that time. Other samples cluster at ~17,000-19,000 yr BP. It is possible that these samples may actually reflect the emergence of the summit. Ages just offshore from marine cores suggest that deglaciation was already underway by 17,000 yr BP. This deglaciation and drawdown may have been faster in the deeper Penobscot Bay area (close to Isle au Haut) as opposed to farther east near Mt. Desert Island. Testing this hypothesis awaits further data. An alternate explanation is that these rocks have some degree of prior exposure and thus do not accurately reflect the timing of deglaciation.

Conclusions

Our data indicate very rapid deglaciation of Mt. Desert Island beginning shortly after 16,000 yr BP. Isle au Haut data are difficult to interpret, possibly because of prior exposure of the boulders. One interpretation is that deglaciation was underway there by at least 17,000 yr BP. The Mt. Desert Island data (and possibly those from Isle au Haut) are consistent with the idea that deglaciation of the Gulf of Maine and coastal areas was well underway during HS-1. This deglaciation gives support to recent data that suggest

warming summers in the North Atlantic region during HS-1, despite the fact that winters remained bitterly cold. This revelation that strong seasonality characterized HS-1 is important for understanding the mechanisms of the last termination.