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# Cosmogenic exposure age evidence for rapid Laurentide deglaciation of the Katahdin area, west-central Maine, USA, 16 to 15 ka

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ABSTRACT

Katahdin, the highest peak in Maine and part of the second highest mountain range in New England, provides an opportunity to assess the timing and style of continental ice sheet surface lowering during deglaciation. We collected 14 samples from boulders on the adjacent Basin Ponds moraine, from bedrock and boulders on the upper part of the mountain, and from boulders in the surrounding area to estimate the age at which they were exposed by deglaciation of the Laurentide Ice Sheet. Measurements of *in situ* produced $^{10}$Be, which are consistent with measurements of $^{26}$Al, indicate that the Katahdin edifice became exposed from under ice by 15.3 ± 2.1 ka (n = 6), an age indistinguishable from the adjacent Basin Ponds moraine (16.1 ± 1.2 ka, n = 5). A boulder in the lowlands several km south of the moraine dates to 14.5 ± 0.8 ka, and a boulder deposited at Pineo Ridge, about 170 km SE of Katahdin, dates to 17.5 ± 1.1 ka. These data show that samples collected over an elevation range of 1.6 km and a distance of >170 km all have exposure ages that are indistinguishable within uncertainties. Together these data suggest that the Laurentide Ice Sheet surface dropped rapidly and the ice sheet margin retreated quickly across Maine between about 16 and 15 ka, perhaps influenced by calving of the marine-based ice sheet in the St. Lawrence Lowlands to the north and the Penobscot basin to the south.



## 1. Introduction

Until recently, the deglacial chronology of the Laurentide Ice Sheet in New England was primarily constrained by minimum-limiting $^{14}$C ages on organic material deposited in ponds and bogs as well as shells in marine sediments deposited following deglaciation (e.g., Davis and Jacobson, 1985; Thompson et al., 1996, 1999; Dorion et al., 2001). However, an unknown lag time between deglaciation and the deposition of the first datable organic material (Davis and Davis, 1980), the uncertainty of reservoir corrections for marine samples (Kaplan, 1999; Thompson et al., 2011), and the paucity of $^{14}$C datable samples (Balco and Schaefer, 2006) means that in many places the chronologic framework is insufficient to test competing hypotheses for the timing and style of deglaciation. Flint (1929), for example, proposed that large parts of the Laurentide Ice Sheet melted in place, an idea that was adopted by Goldthwait (1938, 1970), and Goldthwait and Mickelson (1982). Then, Antevs (1939) and Lougee (1940) countered that the ice sheet retreated with an active ice margin, a concept later adopted by Koteff and Pessl (1981). Recent work by Ridge et al. (1999, 2012) and Ridge (2004) used $^{14}$C dating to produce a numerical chronology for the glacial Lake Hitchcock varve record of Antevs (1922), which has been used in conjunction with other data to draw glacial retreat isochrones across western New England (Ridge et al., 2012).

Since the first cosmogenic dating of moraine deposits in 1990 ($^{36}$Cl, Phillips et al., 1990), cosmic-ray produced isotopes (e.g., $^{3}$He, $^{10}$Be, and $^{26}$Al) have been used extensively to estimate exposure ages of glacially-related deposits around the world (e.g., Gosse et al., 1995; Bierman et al., 1999; Marsella et al., 2000; Gosse and Phillips, 2001; Briner et al., 2005; Davis et al., 2006; Schaefer et al., 2006, 2009; Kelly et al., 2008; Ivy-Ochs et al., 2009; Owen, 2009). In New England, however, the application of cosmogenic nuclide exposure dating has been limited. Clark et al. (1995) reported $^{10}$Be concentrations of samples collected just inside the Laurentide margin in New Jersey and used these data along with independent $^{14}$C age control to constrain nuclide production rates since 21 ka. Balco et al. (2002) dated coastal moraines in

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Massachusetts and determined that the Laurentide Ice Sheet reached its maximum extent there at about 23 ka (recalculated to 27 ka in reference to modern AMS standards). Balco and Schaefer (2006) used $^{10}$Be to date boulders on moraines in southern Connecticut with high precision and tied those ages to the New England varve chronology (Ridge et al., 1999). Then, Balco et al. (2009) used well-dated sites in New England and the Canadian Arctic to calibrate $^{10}$Be production rates for northeastern North America during deglaciation.

Here, we present measurements of *in situ*-produced cosmogenic $^{10}$Be and $^{26}$Al for 14 samples collected on Katahdin, from the lowland south of Katahdin, and from a $^{14}$C-dated moraine-marine delta complex at Pineo Ridge about 170 km to the southeast, close to the present-day Maine coast (Fig. 1). We consider our data in light of the existing ages generated using other chronometers (Kaplan, 1999, 2007; Dorion et al., 2001; Borns et al., 2004) and the surface processes that can affect cosmogenic exposure ages (Davis et al., 1999; Colgan et al., 2002; Heyman et al., 2011). We use the cosmogenic nuclide data to test several long-standing hypotheses including: continental ice covered summit areas during the late Wisconsinan; continental ice surfaces lowered and cirque glaciers did not reform during deglaciation; and the Basin Ponds moraine and other moraines downslope were formed by a stillstand or re-advance of continental ice in the lowland surrounding Katahdin, and not by cirque glaciers.

## 2. Background, study site, and previous work

Katahdin (meaning “greatest mountain” in Penobscot) is the highest peak in Maine (1605 m), with a local relief of about 1450 m, only surpassed in height in the northeastern United States by the Presidential Range in New Hampshire (Figs. 1 and 2). The mountain is composed of a large Devonian pluton (Katahdin granite) that intrudes lower and middle Paleozoic sedimentary and volcanic rocks, which underlie the surrounding lowlands (Caldwell, 1972; Hon, 1980; Rankin and Caldwell, 2010). Most workers agree that Katahdin was covered by ice at some time in the Pleistocene. Erratics found by Tarr (1900) and Antevs (1932) near the summit of Katahdin, and by Caldwell (1972) on other mountains in the Katahdin region, support this view. Non-weathered erratic cobbles and weakly developed soil profiles on the summit areas, as well as modeled ice profiles, suggested to Davis (1976, 1989) that the summit areas of Katahdin were glaciated during the late Wisconsinan. A general model for deglaciation in northern New England calls for thinning of the Laurentide Ice Sheet that exposed the higher mountains as nunataks (Borns, 1985). This concept is incorporated in a numerical model for the deglaciation of northern New England and adjacent maritime Canada by Hughes et al. (1985).

Katahdin is unusual in New England because it has several distinct cirques. The three largest cirques lie on the east side of Katahdin and have headwall heights that range between about 345 and 720 m. Although the three great east-side cirques have flat to concave floors and steep headwalls composed largely of bedrock (Figs. 1 and 2), postglacial rockfall and avalanche debris mask the lower slopes of the cirque headwalls and sidewalls. These cirques are remarkably steep, especially when compared with other cirque-like features in northeastern United States, believed by some (Wagner, 1970; Craft, 1979; Bradley, 1981; Fowler, 2010), but not others (Borns and Calkin, 1977; Gerath and Fowler, 1982; Fowler,

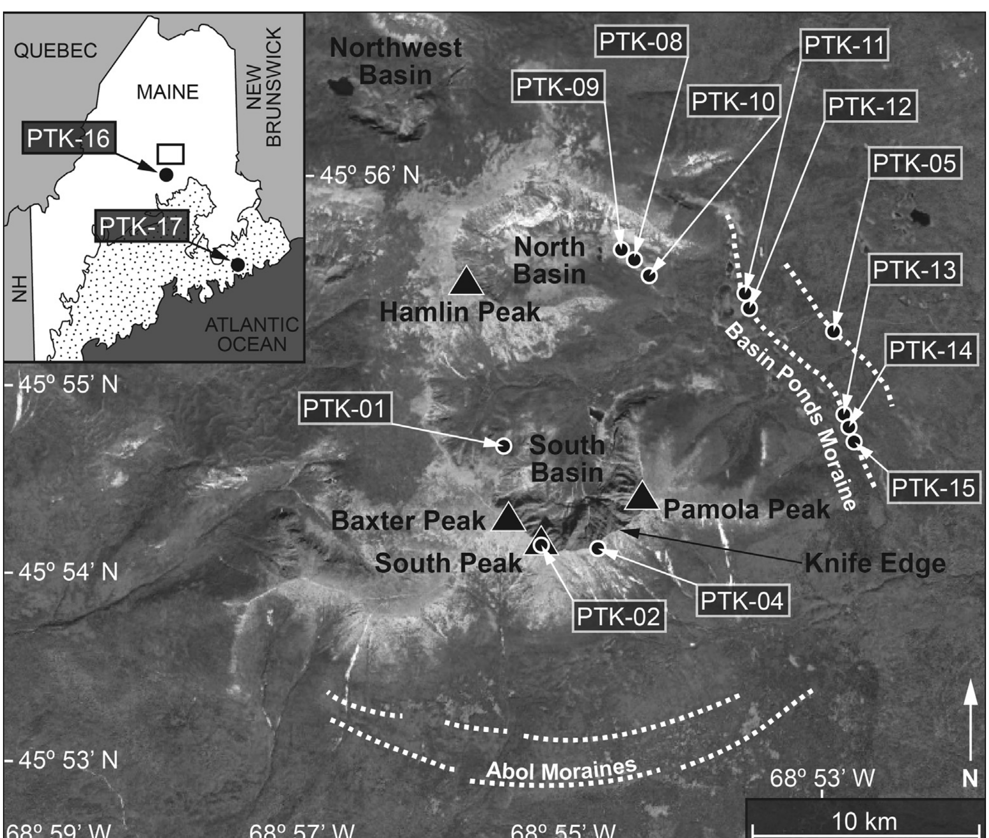


**Fig. 1.** Map of the study area. Main panel shows Google Earth satellite imagery of the Katahdin area, with relevant features labeled. Black and white circles denote the location of cosmogenic samples and white dashed lines show the location of moraines described in the text. Inset map shows the location of Katahdin in Maine, as well as two additional cosmogenic samples. Stippled pattern shows the region of post-glacial marine submergence.