How old are the Pond Ridge and Pineo Ridge moraines?[1]

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Pineo Ridge was first described by George Stone (1899, p. 111-112). Stone noticed till in the vicinity, but he called Pineo a gravel plain not a moraine. Hal Borns (1966) was apparently the first to recognize that Pond Ridge was a moraine and Pineo Ridge was a delta-moraine complex. Their ages have been a topic of study ever since.

A ^{14}C date on seaweed from the Pond Ridge moraine was likely the first date on these moraines: 15.1 ± 0.4 ka (Fig. 1)(Stuiver and Borns, 1975). More recently, Dorion *et al*. (2001) report four dates. At Dennison Point, 3 km outside the Pond Ridge moraine, a *Macoma calcarea* shell closely associated with ice-proximal grounding-line deposits was dated to 16.1 ± 0.1 ka. On the distal side of the Pond Ridge moraine at Turner Brook a *Nucula* sp. shell from glaciomarine sediments interbedded with coarse ice-proximal units was dated to 15.9 ± 0.1 ka. On the proximal side of the Pond Ridge moraine at Sprague Neck a *Portlandia arctica* shell in glaciomarine facies was dated to 15.2 ± 0.1 ka, yielding a minimum age for the moraine. Finally, a date on a *Nucula sp.* shell from basal marine sediment in Marks Lakes, a few kilometers inside the Pineo Ridge moraine, yielded a minimum age for the moraine of 15.1 ± 0.1. Kaplan (1999) reported another date on a *Hyatella arctica* shell from Lily Lake giving another minimum age of 15.2 ± 0.1 ka for Pineo. All of these dates are calibrated (CALIB 7.1). All are shown in Figure 1, color-coded to the moraine.

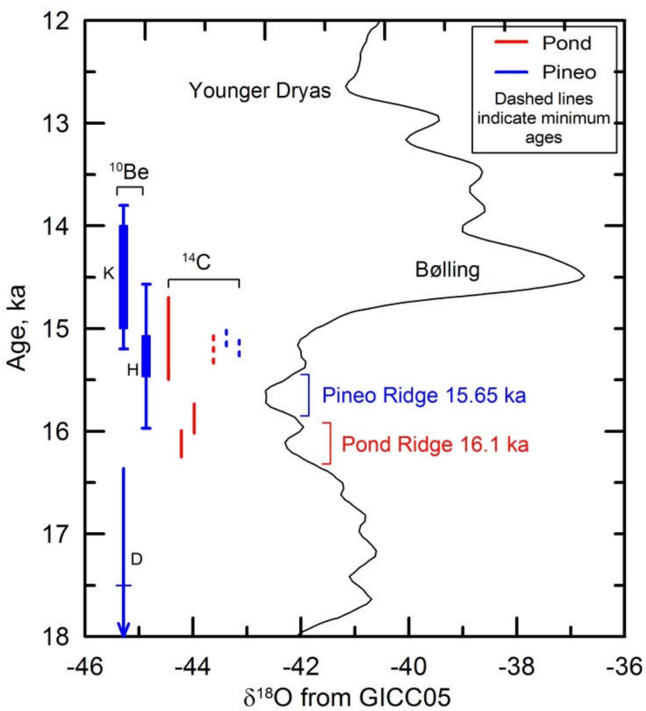

Figure 1. δ^{18}O record from the GRIP ice core and available dates on the Pond Ridge and Pineo Ridge moraines. Boxes and lines on ^{10}Be dates show internal and external uncertainties, respectively. K = Koester; H = Hall; D = Davis.

As all of these ^{14}C dates were on marine organisms, they required a marine reservoir correction. Reservoir corrections vary both spatially and temporally. Along the Atlantic coast from New Jersey to Newfoundland, McNeely *et al*. (2006) report values ranging from 430 to 730 years. By comparing dates on shells and on associated logs in the Presumpscot Formation near Portland, Maine, Thompson *et al*. (2011) found a reservoir age of 1000 years. Following Borns *et al*. (2004) and consistent with a rough estimate of the median value obtained by McNeely *et al*. for the Atlantic coast, I used 600 years when calibrating the above dates.

^{10}Be exposure ages have also been obtained on the Pineo Ridge moraine (Fig. 1). Hall *et al* (2017) dated twelve boulders on the proximal side of Pineo. Three, ranging in age from 16.2 to 17.0 ka, were deemed outliers; the remaining nine yielded a peak age of 15.3 ka on a “camel” plot. Hall *et al*. do not explicitly give an uncertainty in their preferred age for Pineo, but seem to suggest that it is the same as that in the mean age of the population, ±0.2 ky. This is an internal uncertainty. They also imply that the external uncertainty, the one that includes uncertainty in the production rate, is ~±0.7 ky. Koester *et al*. (2017) dated seven boulders on a moraine projecting from beneath the Pineo delta, yielding an age for the moraine of 14.5 ± 0.7 ka. This appears to be too young as it is in the middle of the Bølling warm period. Hall *et al* (2017) think the discrepancy may be attributable to shielding by water, as the moraine would have been below sea level when the Pineo delta formed and for some time thereafter. Davis *et al*. (2015) obtained a significantly older combined ^{10}Be and ^{26}Al date of 17.5 ± 1.1 ka on a single boulder. This boulder was subsequently redated to 15.3 ± 0.4 ka by Koester *et al*..

While watching animations of the ice sheet retreat in Maine, produced by the University of Maine Ice Sheet Model (UMISM)(Fastook and Chapman, 1989; Johnson and Fastook, 2007), I noticed that the margin, after retreating rapidly across the Gulf of Maine, hesitated just inland of the present coastline in downeast Maine. It then retreated somewhat more and hesitated again, close to the location of Pineo Ridge. Retreat from this last position was rapid. UMISM is driven by a proxy climate record, the δ^{18}O record in the Greenland Ice Sheet Project (GRIP) ice core (Fig. 1). In that record, there are dips to more negative δ^{18}O values, indicative of a colder climate, at 16.1±0.2 and 15.7±0.2 ka (GICC05 chronology from Anderson *et al*., 2006). These dips were responsible for the pauses in the animations. Such cold events would likely have resulted in pauses in retreat of the actual ice sheet, or possibly slight readvances. I have thus proposed (Hooke and Fastook, 2007; Hooke *et al*., 2016) that they were responsible for the Pond Ridge and Pineo Ridge moraines. As shown in Figure 1, the dates of these cold events are generally consistent with both the relevant ^{14}C and the exposure age dates.

Hall *et al*. raise two objections to correlation of the Pineo and Pond moraines with the cold episodes in the GRIP core: (*i*) the δ^{18}O record in the core reflects winter temperatures, and (*ii*) the ice retreat in Maine was characterized by “rapid ice retreat followed by a (sic) short-lived stillstand/readvance” but the isotope record “shows extremely cold conditions throughout” this time period. In response to this I submit: (*i*) that cold winter temperatures at elevations in excess of 3000 m in Greenland do not preclude summer temperatures capable of significant melting in coastal Maine, and indeed modeling suggests that seasonality increased during this time (Buizert *et al*., 2014); and (*ii*) based on the GRIP δ^{18}O record, the warm-up that likely initiated retreat of the Laurentide Ice Sheet from its LGM position at the edge of the continental shelf and from the Ronkonkoma moraine on Long Island, NY, occurred at ~23.5 ka (Fig. 2). The next 6.5 ky, to ~17 ka, was a period of gradual warming under the influence of increasing insolation (Buizert *et al*., 2014; Koester *et al*., 2017); at 17 ka, when cooling started despite the continued increase in insolation, the ice sheet was not likely to have been fully adjusted to the

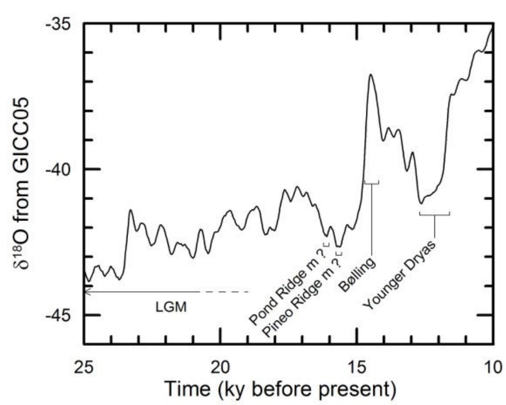

Figure 2. d^{18}O record from GRIP core

prevailing climate. Thus it might well have continued to retreat until ~16.1 ka, but would have been ripe for pauses (or slight readvances) at the times of the *two* cold dips at 16.1 and 15.7 ka.

In short, the 16.1 and 15.7 ka ages for the Pond Ridge and Pineo Ridge moraines based on the Greenland $\delta^{18}O$ record are better supported than either the ^{14}C ages, which are prone to various uncertainties, not the least of which is the marine reservoir correction, or the ^{10}Be exposure ages with their uncertainties.

Davis (1976, 1989) described two parallel lateral moraines on the south flank of Mt. Katahdin and named them the Abol moraines. They are ~50 m apart vertically. Davis *et al*. (2015) associate the Abol moraines with the Basin Pond moraines on the east side of Mt. Katahdin. Their ^{10}Be and ^{26}Al dating suggest an age for the latter of 16.1±2.2 ka. They argue that both were deposited by southeast-flowing continental ice that sent a lobe northeastward along the east side of the mountain. Finally, based on their ages and on the lack of any other significant younger moraines between the Basin Ponds - Abol complex and Pineo Ridge, 170 km to the southeast, they correlate the two. Hooke *et al*. (2016) took this one step further, proposing that the upper and lower Abol moraines were correlative with the Pond and Pineo Ridge moraines, respectively. This implies a reasonable 4m/km surface slope to the ice sheet (Davis *et al*., 2015) and a reasonable amount of margin retreat (9 km) for a ~50 m lowering of the ice sheet surface at Mt Katahdin. (Hall *et al*. (2017, p. 353) incorrectly stated that Hooke *et al* (2016) correlated the Basin Pond moraines, themselves, with Pineo Ridge.)

Hall *et al*. (2017, p. 351) also appear to have erred in their calibration of the Mattaseunk Lake ^{14}C date, inasmuch as they applied a marine reservoir correction. The material dated was from the periostraca of the organism, a part that is composed of terrestrial, not marine carbon (Jenkins and Dorion, 2013). Furthermore, the date was essentially the same, within 50 years, of a date on terrestrial material collected from the same horizon. The calibrated age is 16.2 ka, a date that conflicts with any interpretation of dates at the coast, and therefore must be rejected.

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[1] Reference: Hooke, R. LeB., 2018. How old are the Pond Ridge and Pineo Ridge moraines? *in* Braun, D., Guidebook for the 81st Annual Reunion of the Northeastern Friends of the Pleistocene June 1-3, 2018, Bar Harbor, Maine, p. 31-32.