Sedimentary architecture and accumulation rate of two lakes in Maine, USA

Ian M. Nesbitt[1†], Seth W. Campbell[1,2], Sean M.C. Smith[1,3], Bess G. Koffman[4], Steven A. Arcone[2]

1. University of Maine School of Earth and Climate Sciences, 2. Cold Regions Research and Engineering Laboratory, US Army Corps of Engineers, 3. Mitchell Center for Sustainability Solutions, University of Maine, 4. Department of Geology, Colby College. †ian.nesbitt@maine.edu

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Abstract

The sedimentary architecture of lakes in previously-glaciated landscapes records geomorphological history that can shed light on the nature of late-glacial, periglacial, postglacial, and anthropogenic landscape change. Unfortunately, the sedimentary architecture of most lakes is not well understood, since they are most often studied using point-source sediment collection. Although coring is a useful way to gain extremely detailed information on sediment columns at specific points in space, coring locations are often sparse and thus not well suited to document change spatially. Reliance on core records for sedimentation rates, for example, assumes that derived rates represent the broader lake basin. Recent ground-penetrating radar (GPR) surveys in Vermont and New Hampshire, in comparison with core data, show that this assumption can be highly erroneous. We conducted ground-penetrating radar (GPR) and two lakes in Maine, USA, representative of different basin types and landscape histories since the retreat of the Laurentide Ice Sheet. Combined with coring, the results suggest very slow (on the order of 0.1 m / kyr) accumulation over the majority of the Holocene, and on the order of 10 m / kyr over the last century in some highly disturbed areas), likely related to agricultural and construction activities, and increased trap efficiency of reservoirs due to dam emplacement. Geophysical results suggest accumulation may also have been faster in the late-glacial and periglacial periods, though the age and duration of these periods are difficult to constrain. Maine's many lakes and ponds likely provide a buffer to sediment and solute transport from inland to coastal areas.

Background

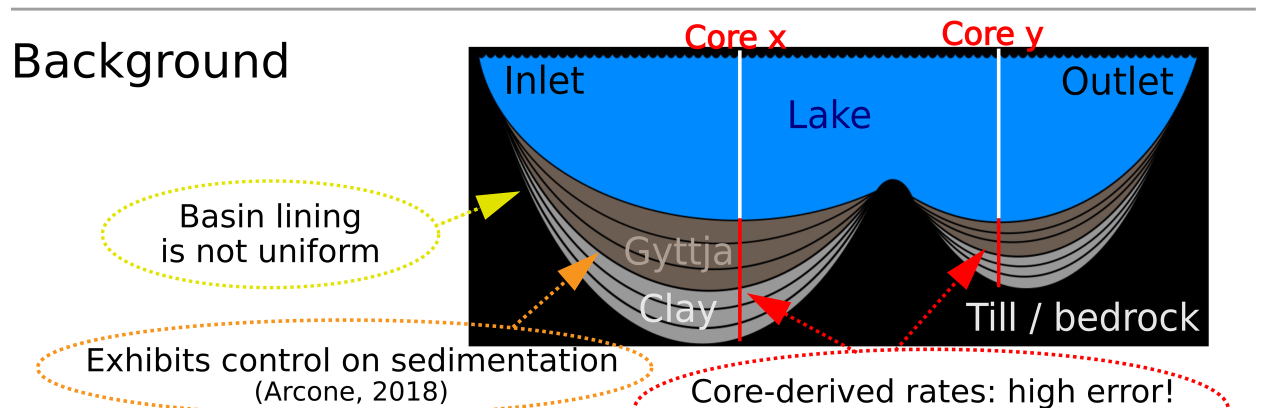


Figure 1. Basins in formerly glaciated areas can have non-uniform spatial sedimentation patterns, which can lead to errors in sedimentation estimates when sampled with coring alone.

Methods

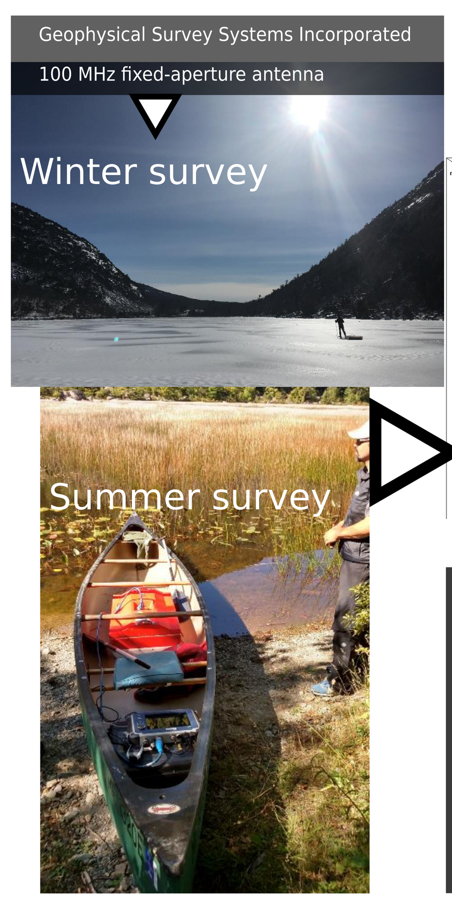
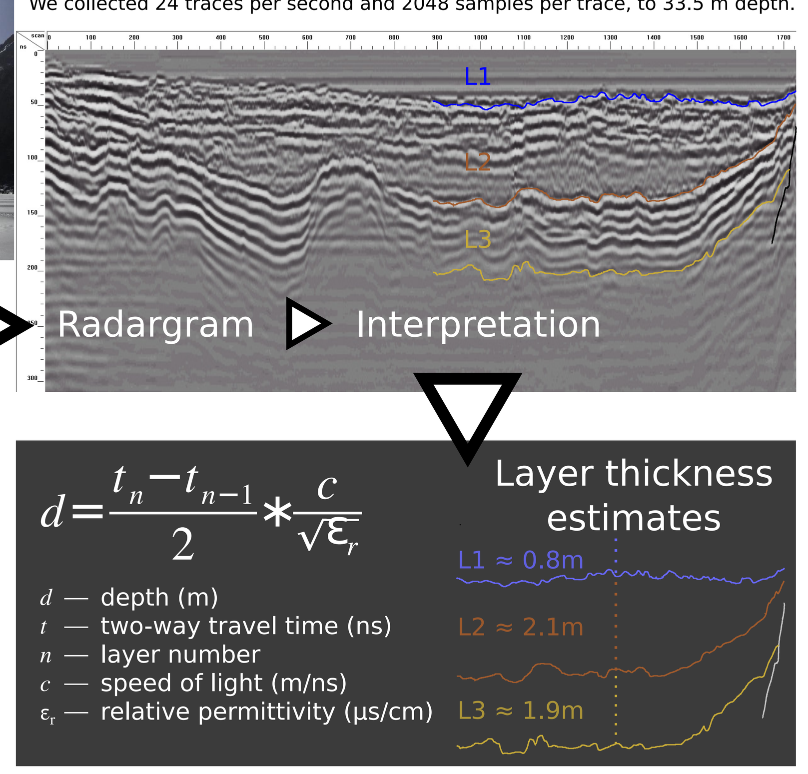


Figure 2. Schematic diagram showing GPR sampling method in shallow (< 30 m) lakes with low salinity (< 50 µs m⁻¹). Surveys can be conducted on open water or ice. In this study we use a Geophysical Survey Systems Incorporated (GSSI) 100 MHz fixed dipole width transceiver antenna with a GSSI SIR-4000 control unit. We collected 24 traces per second and 2048 samples per trace, to 33.5 m depth.



$$d = \frac{t_n - t_{n-1}}{2} * \frac{c}{\sqrt{\varepsilon_r}}$$

d — depth (m)
t — two-way travel time (ns)
n — layer number
c — speed of light (m/ns)
ε_r — relative permittivity (µs/cm)

Sites

Kingsbury Pond Complex

- 1.75 km² lake surface area
- 33.1 km² watershed area
- Lake surface 282.1 m asl
- Deglaciated between 12.8 and 12.0 kya (Borns et al., 2004)
- North of postglacial marine transgression limit
- Dammed in 1835; 3.35 m (11 ft) hydraulic height increase

The Tarn

- 0.076 km² surface area
- 0.716 km² watershed area
- Pond surface 29.1 m asl
- Deglaciated about 13.2 kya (Borns et al., 2004)
- Transgressed by high relative sea level for ~1-1.5 ka (Barnhardt et al., 1995, Borns et al., 2004)
- Wet meadow during Holocene
- Dammed in 1913; ~1 m (3 ft) hydraulic height increase

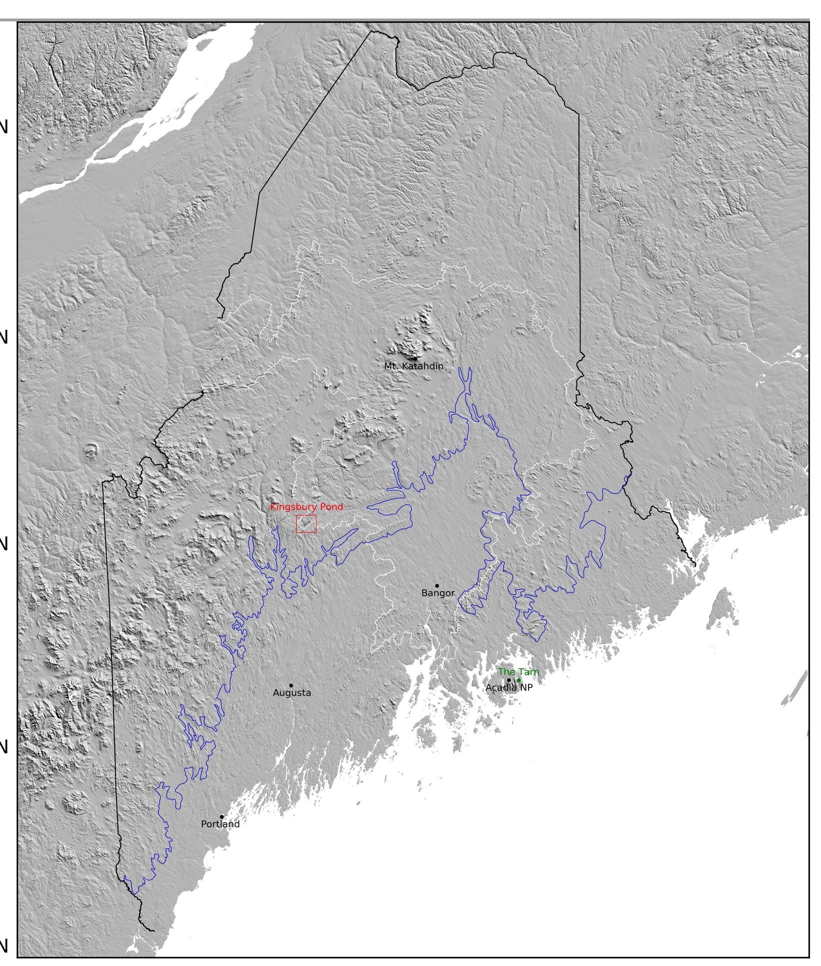


Figure 3. 90 m digital elevation model (DEM) of Maine and surrounding areas. Blue line marks the approximate inland limit of marine transgression. Thin white line marks the Penobscot River watershed boundary.

Kingsbury Pond (Kingsbury Plantation)

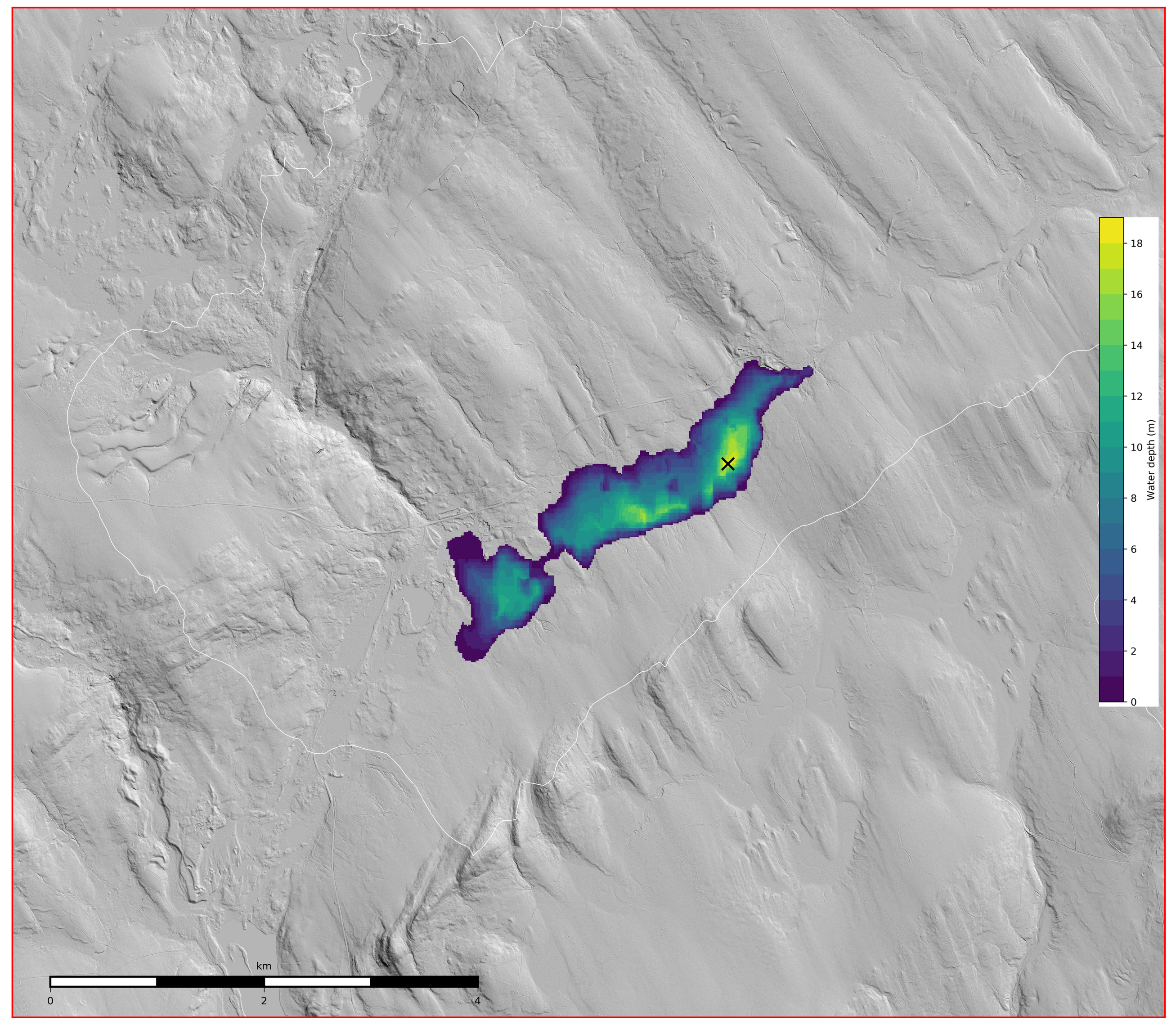


Figure 4. 1 m DEM derived from light detection and ranging (LiDAR) of the Kingsbury Pond complex and its geomorphic setting. Thin white line marks the approximate boundary between the Penobscot and Kennebec watersheds. Kingsbury's depth profile is plotted atop the hillshade. Note glacially streamlined features and multitude of sub- and proglacial landforms. Ground truth core location is marked with black X.

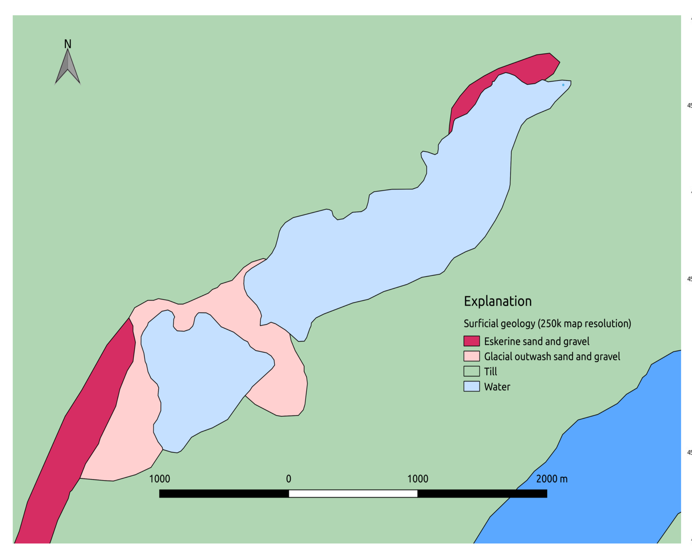


Figure 5. Surficial Geology of the Kingsbury Pond region mapped at 1:250,000 scale (after Thompson & Borns, 1985).

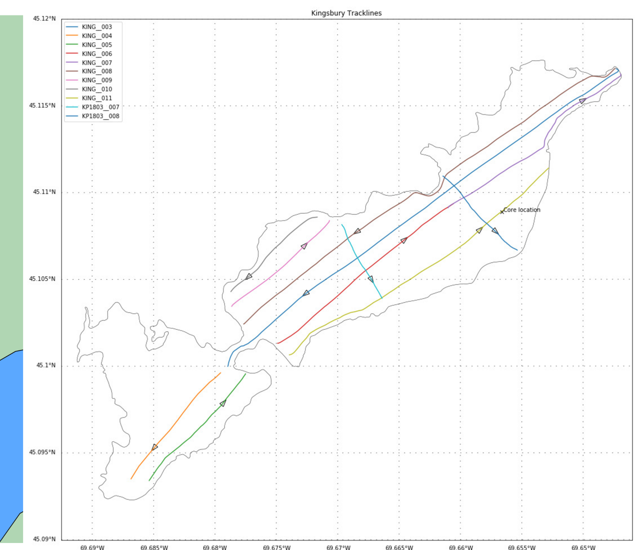


Figure 6. Grid of survey tracklines used to profile Kingsbury Pond. Location of ground truth core is marked. The absence of survey lines in the southwestern basin should be noted, as this is the main inlet area in the complex.

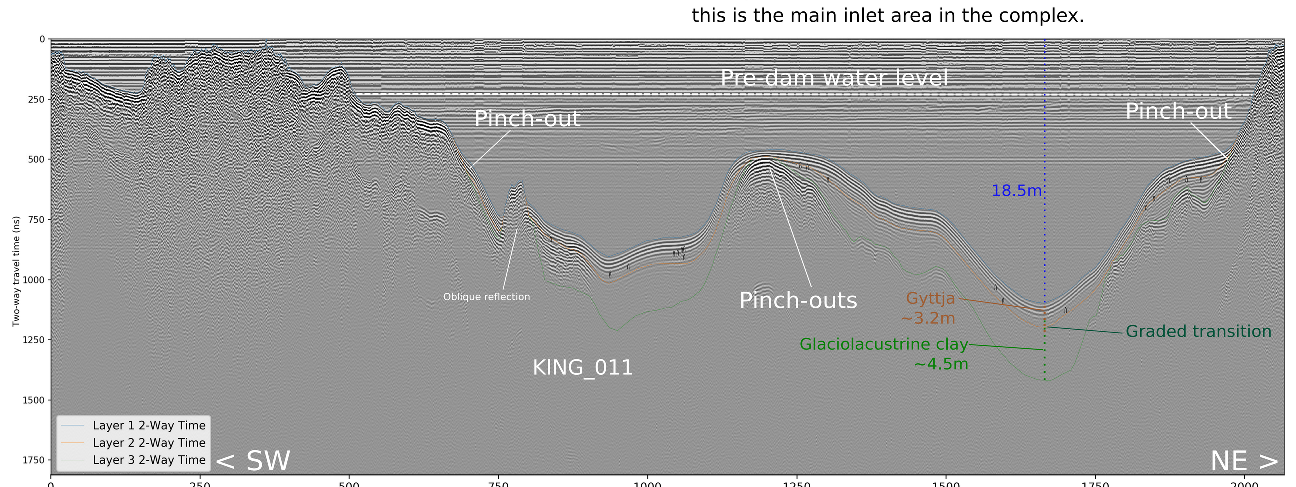


Figure 7. GPR profile across survey line KING__11 in Kingsbury Pond. Coring by B. Koffman at the location of the vertical bars (X on above maps) provided ground truth for geophysical work. Paleosurface controls on sedimentation are evident in layer pinch-out areas. Layer 3 (L3) pinch-outs occur at multiple locations several meters below the proto-lake waterline, which indicates reworking either due to biannual oligotrophic turnover or wave action during significantly lower water levels during the depositional period.

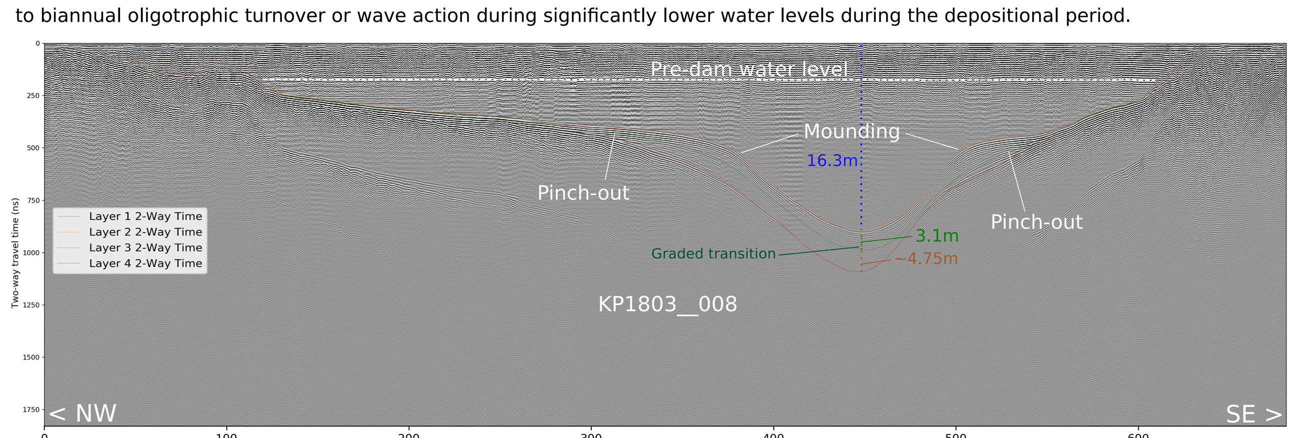


Figure 8. GPR profile transecting Kingsbury Pond from northwest to southeast. Paleosurface controls on sedimentation are less evident. Instead, mounding is visible on the shoulders of the deep basin. Arcone (2018) suggests that this mounding is due to turbidity flows from storms and biannual turnover. The pre-dam waterline is again significantly higher than the pinch-out areas. No L4 sediment is deposited above the shoulder height, perhaps indicating lower water level.

The Tarn (Acadia National Park, Mount Desert Island)

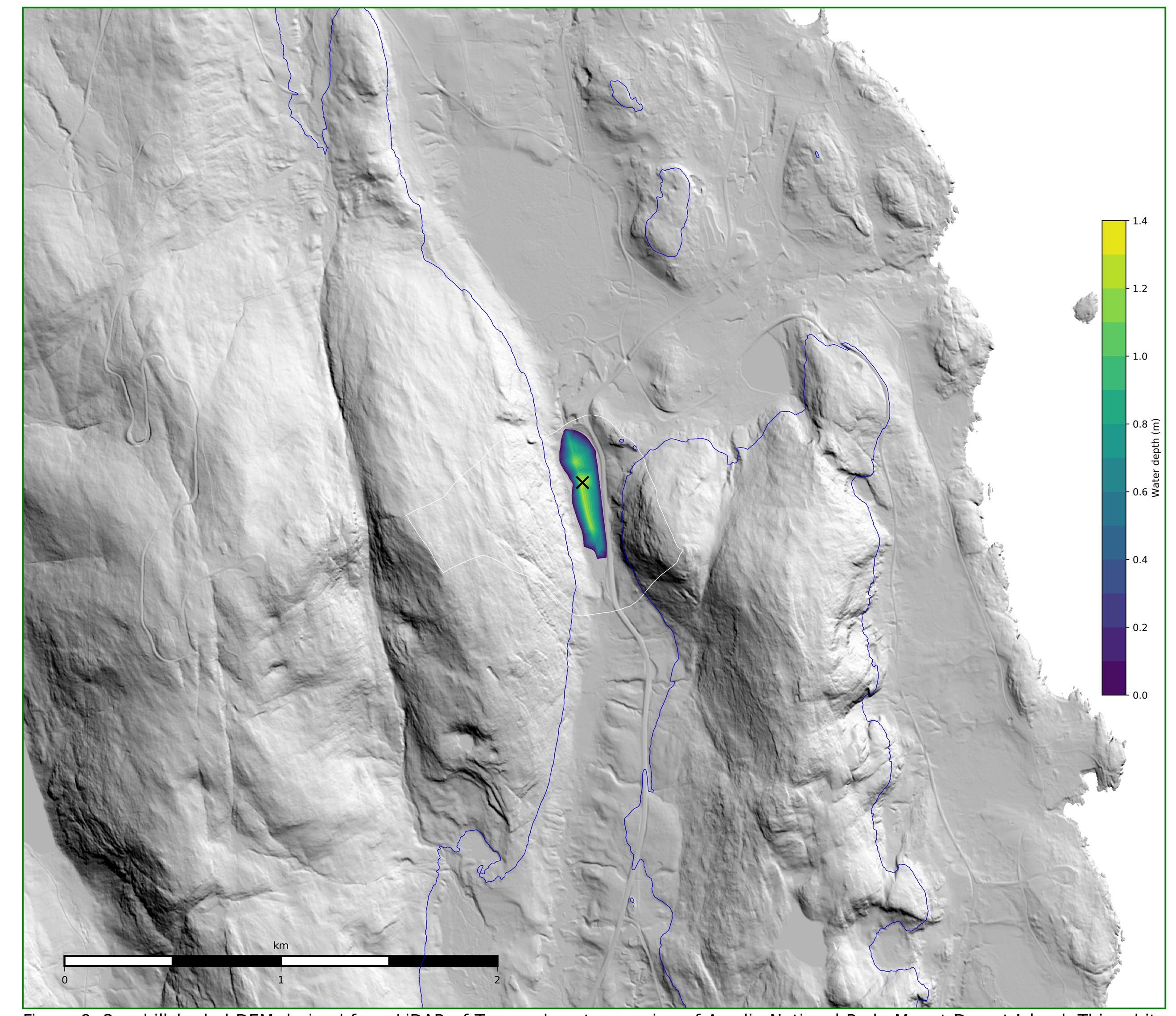


Figure 9. 2 m hillshaded DEM derived from LiDAR of Tarn and eastern region of Acadia National Park, Mount Desert Island. Thin white line marks the approximate watershed boundary. Blue line indicates approximate relative sealevel highstand (73 m above present sealevel Kingsbury's depth profile is plotted atop the hillshade. Approximate pond depth map is plotted atop hillshade. Ground truth core location is marked with black X.

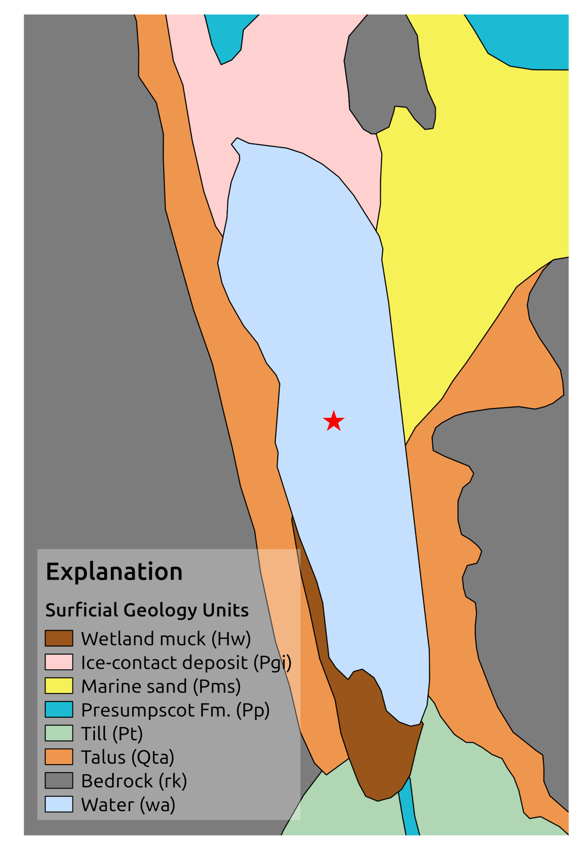


Figure 10. Surficial geology mapped at 1:24,000 scale. Marine and shoreline sand deposits overlie glaciomarine Presumpscot Formation clay. Star indicates approximate core location.

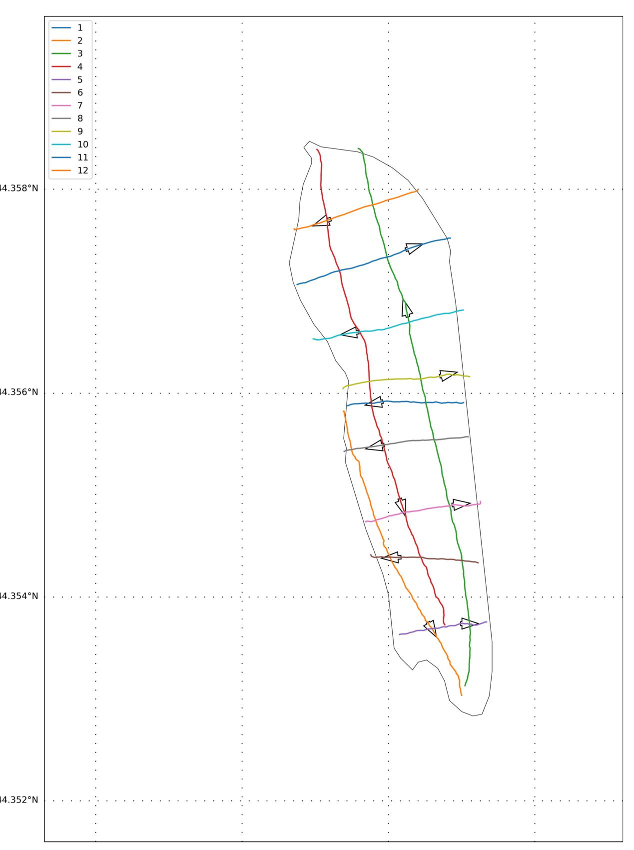


Figure 11. Grid of survey lines used to profile The Tarn. Survey was conducted by canoe (see Fig. 2).

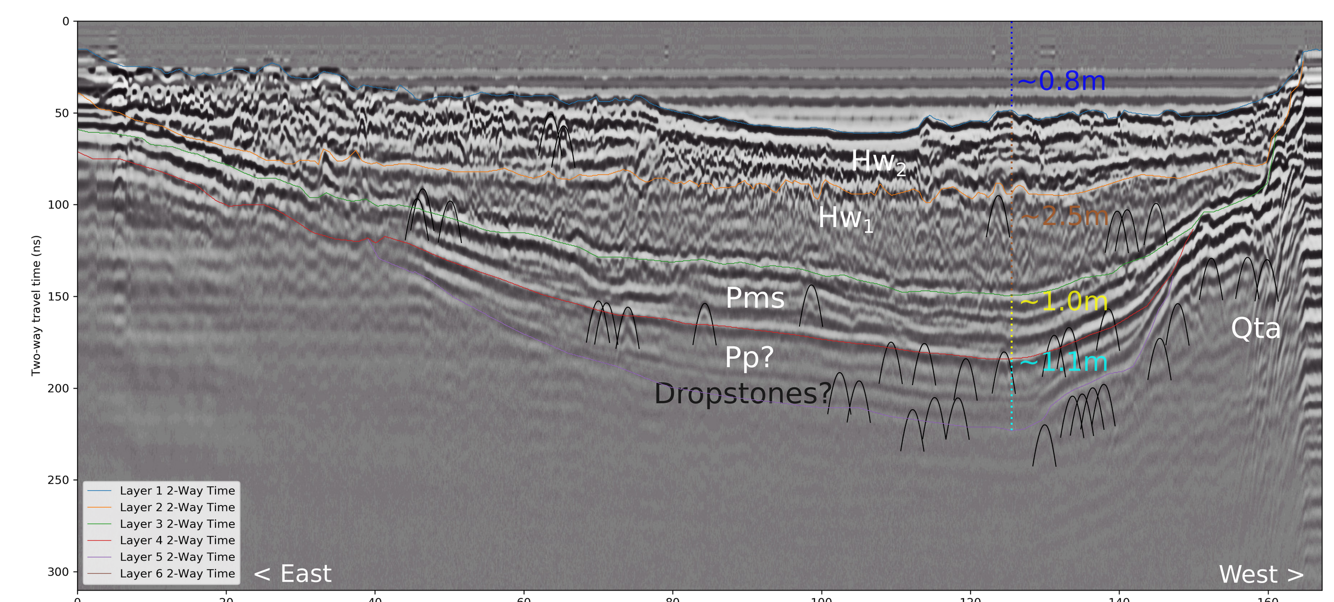


Figure 12. GPR profile transecting The Tarn from east to west. Thin colored lines separate geologic unit interpretations. Hw is broken into two periods, Hw_1 and Hw_2. Hw_2 represents the accumulation since the lake was dammed, while Hw_1 represents the wet meadow stage of the landscape that prevailed for the majority of the Holocene. This interpretation is supported by a shallow ground truth core and ^{210}Pb and ^{136}Cs dating. The unit interpreted as marine sand (Pms), appears to be heavily eroded and contains at least two paleochannels. Below this, a unit with many refractive objects is interpreted as Presumpscot clay. Refractions may indicate large erratic dropstones from stranded ice, since the Tarn was a shallow fjord-like neck during the marine highstand (Fig. 9). Refractions from the talus slope in Fig. 10 is evident on western (righthand) side of profile, descending below more recent onlap.

Discussion

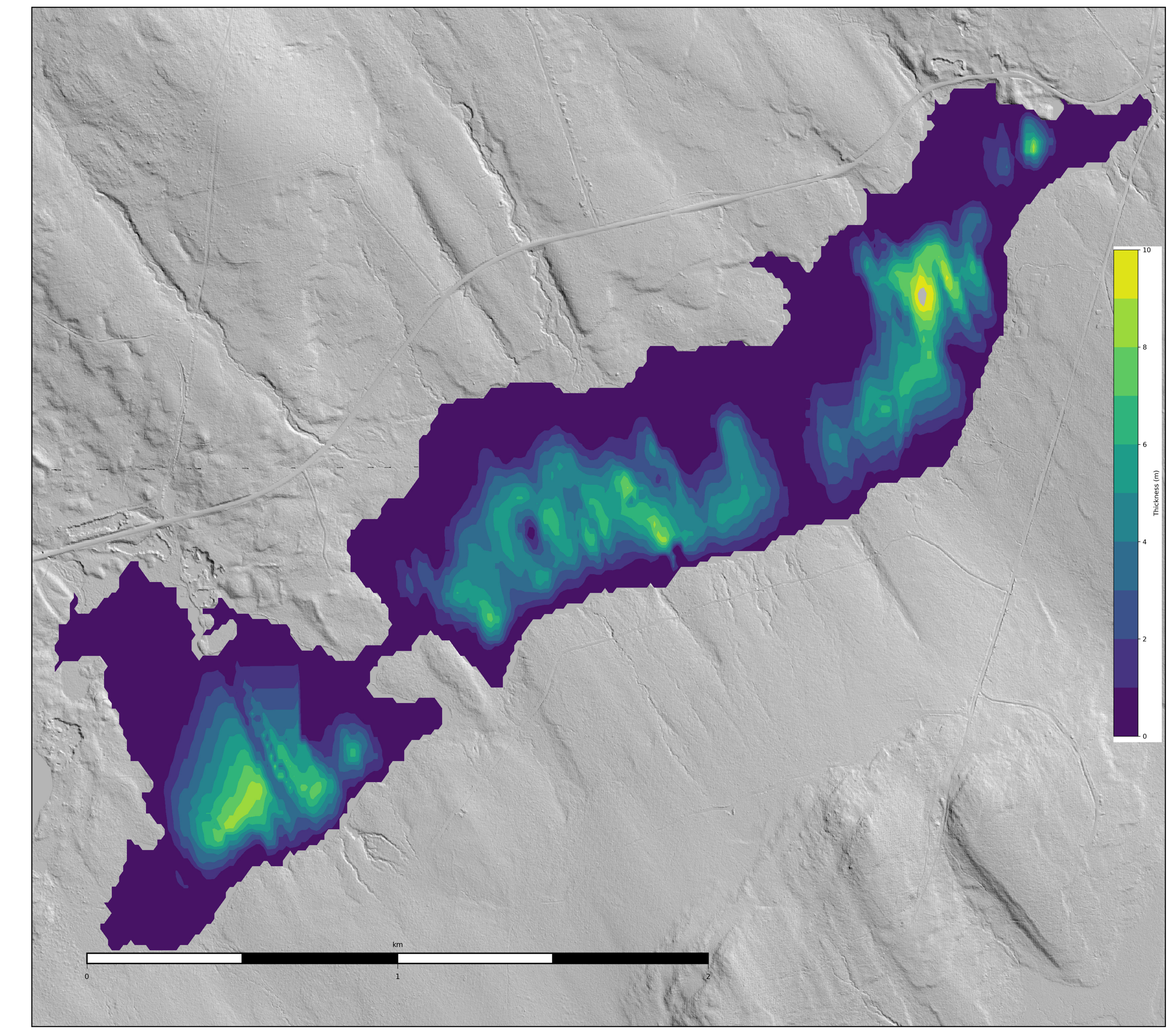


Figure 13. 1 m hillshaded DEM of the Kingsbury Pond complex derived from LiDAR, with an overlay of inorganic sediment thickness (Glaciolacustrine clay; Layer 3 shown in Fig. 7, or Layer 4 shown in Fig. 8). Orientation of sediment thickness banding appears to follow subglacial paleosurface also reflected in subaerial topography.

Sub-basin paleobathymetric features at Kingsbury Pond appear to act as sediment traps for the duration of inorganic sediment deposition. Core analysis (in progress) and GPR profiles of the sediment in these troughs indicate that the transition from inorganic to organic-dominant sedimentation was gradual enough that the ice was coeval with terrestrial and/or marine plant life for a brief period (~tens of years) while the ice sheet retreated from the watershed. Proglacial meltwater erosional features near the watershed boundary to the west of the lake complex give some clue to ice dynamics as it retreated over the Kennebec/ Penobscot watershed divide. Meltwater in a proglacial pond may have raised water above the present drainage divide height to create a spillway across the divide, bringing sediment to the lake for several years or tens of years. Indeed, evidence of such a channel exists in LiDAR (Fig. 4). The volume of inorganic sediment below gyttja in GPR profiles suggests that the sedimentation rate during these years was orders of magnitude higher than present (0.1 m kyr⁻¹ or less based on calculations using a total sediment thickness mesh as above), depending on the duration of years in which flow was able to reach the spillway. Towards the top of the clay-gyttja transition, sediment in the core appears to have couplet-like varves, a possible indication that as the ice sheet receded further down into the Kennebec drainage, the proglacial pond was only high enough to breach the spillway during ever more intense melt events.

Stratigraphic interpretation of GPR profiles collected at the Tarn reveals that, unsurprisingly, the pond has been very shallow for the entirety of the past century since being dammed. Preliminary 210Pb dates reveal that the sedimentation rate has averaged 0.5 cm yr⁻¹, since the dam was installed in 1913, an astoundingly high rate for such a small watershed. Previous studies by the Park Service have concluded that the wetland grass species began to the pond during several consecutive dry years during the 1990s, but given the sedimentation rate, this colonization was nearly inevitable anyway.
Beneath the more recent sediment likely lie interesting clues into iceberg dynamics in the Gulf of Maine during the highstand. The presence of many refractions likely indicates dropstones and from stranded ice in the narrow gorge between Dorr and Champlain mountains where the Tarn lies.

Conclusions and Future Work

- Sedimentation rates per unit area vary widely across northern New England watersheds.
- Paleosurfaces control sedimentation patterns beneath lakes, especially in formerly glaciated areas with sub-ice streamlining.
- GPR is an effective and efficient tool for studying sediment heterogeneity beneath shallow freshwater lakes.
- Planning to develop decisionmaking tools to select optimal coring locations based on stratigraphy and sub-basin landscape geomorphology.
- Planning further research on inlet fan from major drainage on west side of Kingsbury Pond to study ice behavior and biological succession as the ice sheet retreated from the watershed.
- Planning search for reliable radiocarbon material to determine approximate Kingsbury deglaciation age.

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Acknowledgments

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