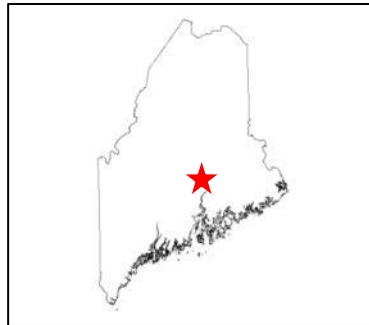


Maine Geologic Facts and Localities  
December, 2008

***Evidence for a calving embayment in the  
Penobscot River Valley, Bangor, Maine***



44° 48' 4.26" N, 68° 46' 40.13" W

Text by  
Kent Syverson and Andrew Thompson



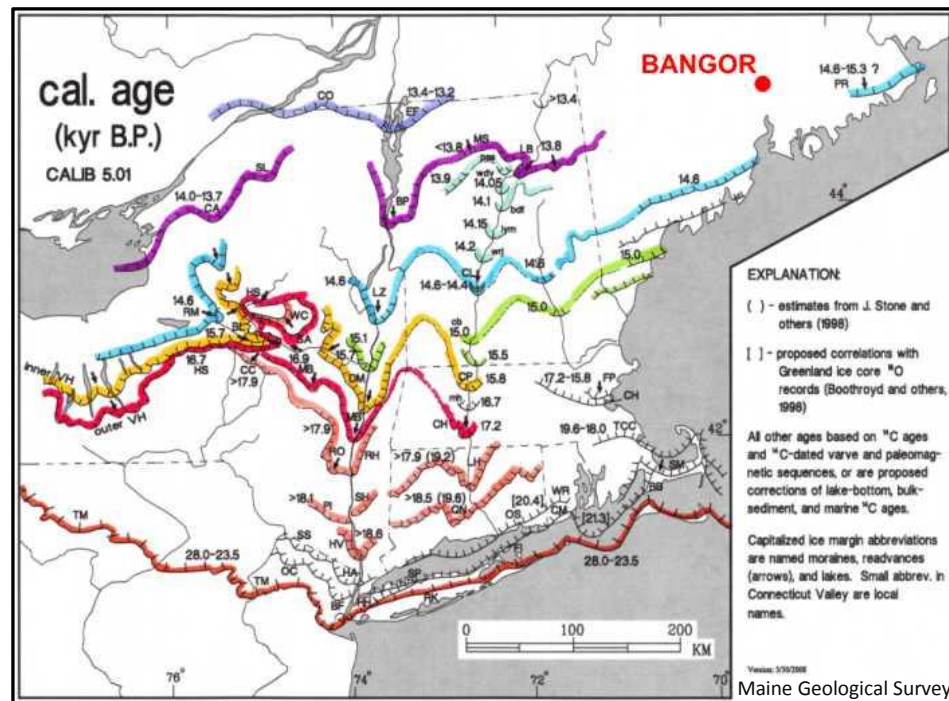
## Introduction

During the summer of 2007, Dr. Kent M. Syverson and field assistant Andrew H. Thompson from the University of Wisconsin - Eau Claire were contracted by the Maine Geological Survey (MGS) to map the surficial geology of the Bangor 7.5-minute topographic quadrangle as a part of the STATEMAP component of the National Cooperative Geologic Mapping Program. The following Geologic Site of the Month is prepared from their map and report, cited below.



### Glacial History

The late Wisconsinan Laurentide Ice Sheet expanded out of Canada and reached its maximum position by 28,000 years ago. The ice sheet was several thousand feet thick during the ice maximum and covered most of the mountains in the state (Figure 1; Ridge, 2008).



From Ridge, 2008

**Figure 1.** Ice-margin position of the Laurentide Ice Sheet during deglaciation from the southernmost position of the glacier on Long Island and offshore of southern New Hampshire (in thousand-years, 13.8 = 13,800). The blue 14.6 line is extended from New Hampshire into Maine by work in the Merrimac River valley and in the Ossipee River valley (Ridge and others, 2001), and is extrapolated from there to the west shore of the Penobscot River valley based on surficial geologic mapping by the Maine Geological Survey.



### Glacial History

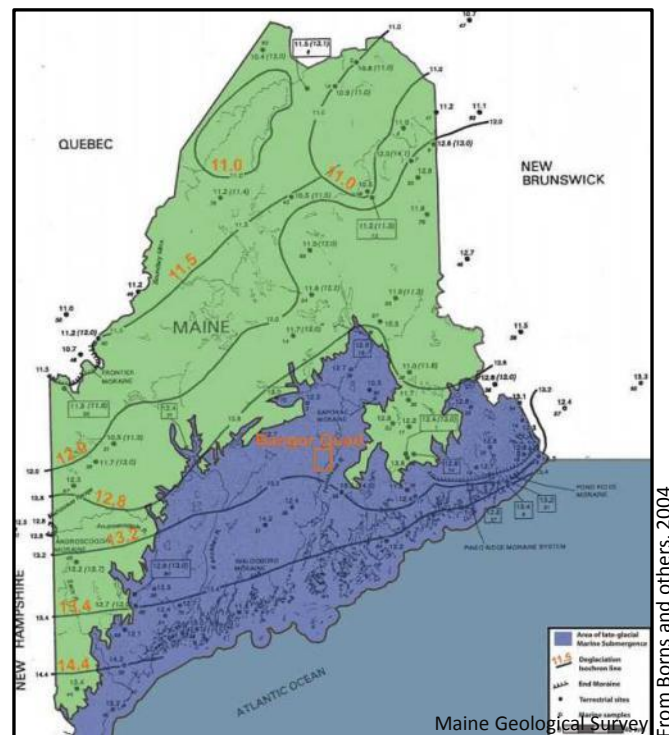
The weight of this ice mass depressed the land-surface elevation. As the glacier flowed across the state for thousands of years, it shaped the surface of the land by eroding, transporting, and depositing tremendous quantities of sediment and rock debris. Ice eroded the Bangor area and smoothed the surface, but little sediment was deposited in the Bangor region (Figure 1; Ridge, 2008).

Climatic warming forced the Laurentide Ice Sheet to start melting and receding prior to 22,000 years ago, and the Bangor area was deglaciated sometime between 14,500 and 14,000 years ago (Figure 1). During the recession of the ice, the Earth's crust was still depressed by the weight of the ice sheet and the sea flooded Maine as the glacier margin retreated to the north-northwest (Figure 2).



## Glacial History

[Glaciomarine deltas](#) deposited into the ocean in the central part of the state (Figure 2) indicate that the sea submerged land to elevations up to 422 feet (129 m) (Thompson and others, 1989). Based on recent studies, the ages of each ice-marginal position line (the orange numbers on heavy black lines) in southwestern Maine are now thought to be significantly younger than as shown on this map (Thompson and others, 2008).



**Figure 2.** Deglaciation chronology for the State of Maine (in thousands of years). Location of the Bangor quadrangle and radiocarbon ages constraining timing are plotted. A reservoir correction of -600 years was applied to ages from marine samples. Areas in dark blue were isostatically depressed and flooded by sea water.

### Glacial History

The Bangor quadrangle shows evidence of the marine submergence caused by the great weight of the Laurentide Ice Sheet. Silt- and clay-rich sediments of the Presumpscot Formation (Figure 3) are found extensively within the quadrangle. Marine sediments are present at elevations up to at least 160 ft (49 m), and seawater up to ~100 m a.s.l. (Thompson and others, 1989) covered the entire Bangor quadrangle except highlands in the Hermon Hill region in the northwestern part of the map.



Photo by Syverson and Thompson

Maine Geological Survey

**Figure 3.** Fossil mussel shells washing out of silt and clay of the glaciomarine Presumpscot Formation, East Hampden.



Evidence for Penobscot River valley calving embayment

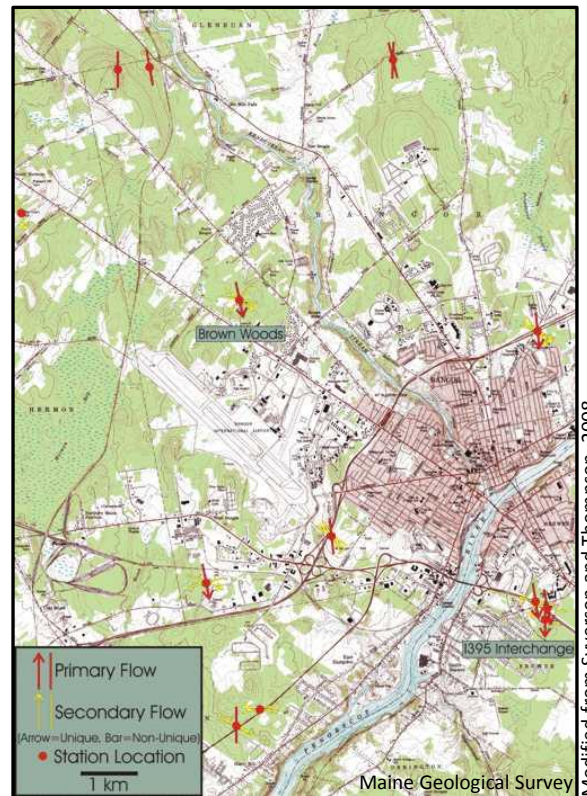
[Glacial calving](#), the spalling of ice from the front of the glacier, removes ice mass rapidly in deep water (Benn and Evans, 1998, p. 277-278). Based on the topset-foreset contact in the Hampden delta, a glaciomarine delta 9 mi (13 km) southwest of the Bangor city center, late Wisconsinan marine water depths ranged from 0 to 317 ft (97 m) in the Penobscot River lowland near Bangor (delta #63, Thompson and others, 1989). However, areas to the west, south, and east rose well above the marine limit. Some workers informally have suggested that the ~100 m difference in sea-water depth caused enhanced calving and a calving embayment in the Penobscot River valley -- a controversial idea.

According to Lowell (1994), an embayment did not form in the Penobscot River lowland because the deep-water area was too narrow. The goal of this part of the study was to examine ice-flow indicators near Bangor and determine if a calving embayment formed in the Penobscot River lowland. If a calving embayment once existed, then ice-flow directions should have changed markedly and converged along the deepest part of the Penobscot River valley during deglaciation.



### Methods

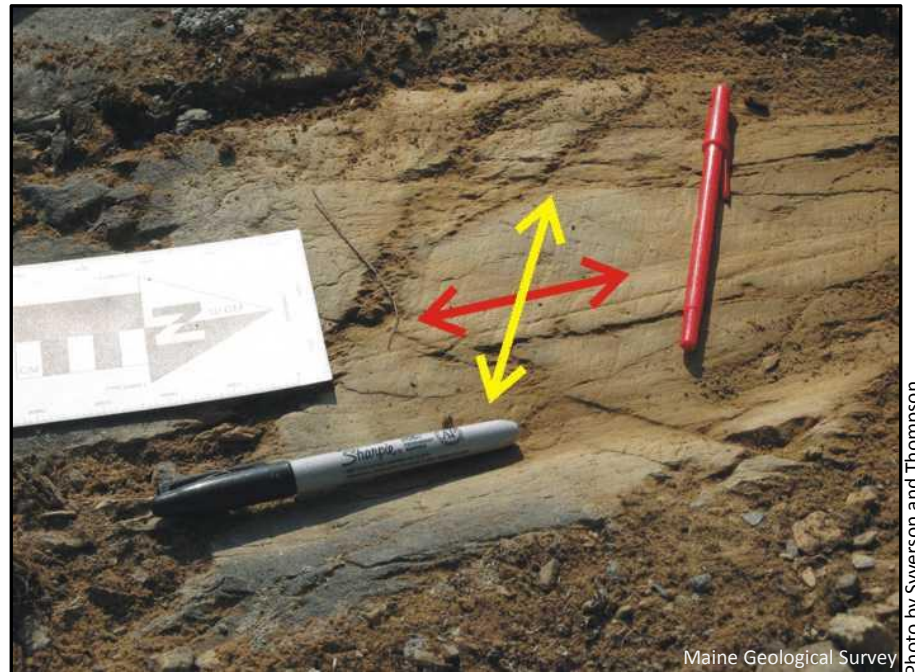
Erosional features were measured at 51 individual sites across the entire quadrangle (Figure 4; Thompson and Syverson, 2008). Southerly ice flow during the late Wisconsinan Glaciation flow maximum (red arrows) became strongly convergent (yellow arrows) along the axis of the Penobscot River valley as deglaciation proceeded.



**Figure 4.** Bangor quadrangle with ice-flow indicators plotted. Brown Woods and the Interstate 395 interchange are referenced specifically here.

### Methods

These included striations (non-unique flow indicators) and crag-and-tail features (unique flow indicators) (Figure 5). During ice flow, rocks embedded in the base of the glacier were dragged across bedrock, producing striations and grooves parallel to the ice-flow direction. Striations and grooves provide non-unique directional data (i.e. ice flow could have been along the striation or groove in either direction). Using the relative-size criterion, the deep striations and groove (red arrow) represent an older flow event (in this case the flow maximum,  $172^{\circ}/352^{\circ}$  flow azimuth), and the more minor set (yellow arrow) represents younger overprinting ( $111^{\circ}/291^{\circ}$  flow azimuth).



**Figure 5.** Striations and a groove (black marker) on phyllitic bedrock east of the Penobscot River (Interstate 395/ Parkway South interchange in Brewer, see Figure 4 for location).

### Methods

Crag-and-tail features provide unique ice-flow directions (Figure 6). The crag is composed of hard quartz and is surrounded by softer phyllite. The glacier abraded the soft phyllite more easily than the quartz pod. The quartz pod protected phyllite on the lee side and produced a comet-like tail pointing in the direction of ice flow. For this reason, crag-and-tail features are valuable as ice-flow direction indicators.



**Figure 6.** Crag-and-tail feature in phyllitic bedrock at Brown Woods showing unique ice-flow direction.

### Methods

In Figure 7 large crag-and-tail features cut by smaller striations and crag-and-tail features show a major ice-flow direction change east of the Penobscot River valley. Grooves and large crag-and-tail features represent southerly flow during ice-flow maximum (180° azimuth). Small striations and crag-and-tail features (inset photo) reflect younger ice flow to the west-northwest (290° azimuth). This younger flow event was directly toward the Penobscot River valley.

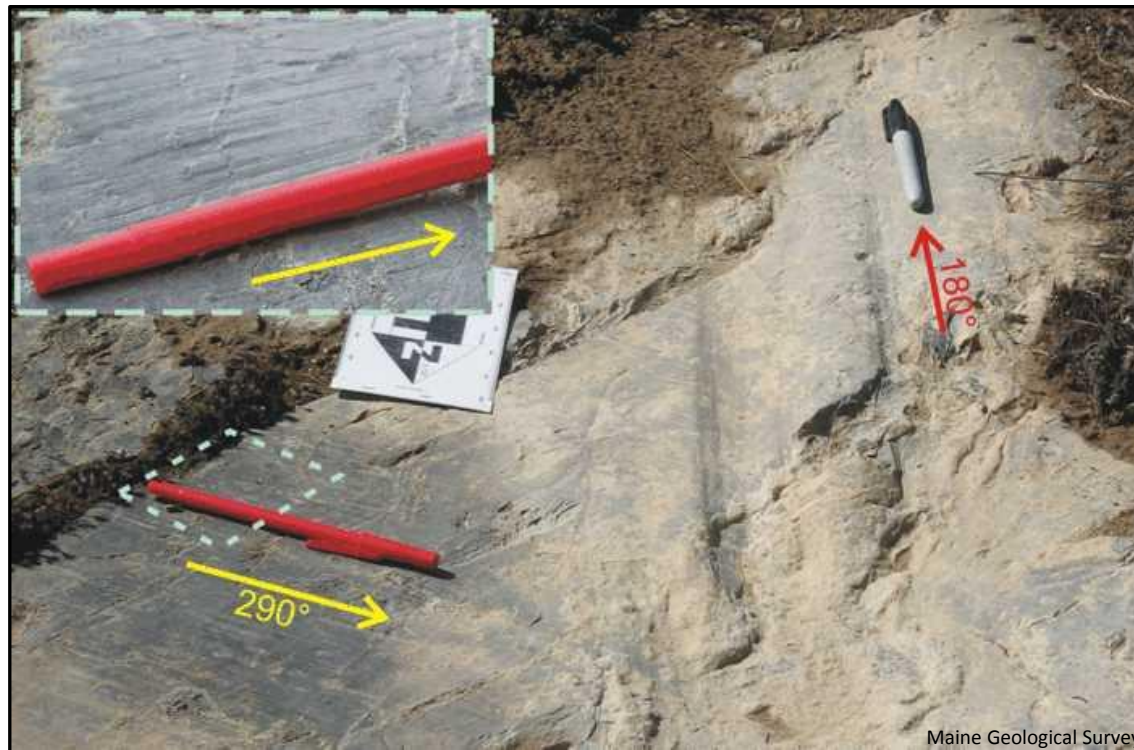


Photo by Swerson and Thompson

**Figure 7.** Large crag-and-tail features cut by smaller striations and crag-and-tail features east of the Penobscot River (Interstate 395/Parkway South interchange).

### Methods

The azimuth and average size of each striation set were recorded, and any cross-cutting relationships and/or unidirectional crag-and-tail features were noted. We assigned relative ages to multiple striation sets whenever possible using the relative-size criterion where deep striations represent older flow events and more subtle sets represent younger overprinting (Syverson, 1995).

Once all field data was collected, flow-indicator data was entered in Microsoft Excel. Azimuth, location (either west or east of Penobscot River), uniqueness, and relative age for each erosional indicator set were coded and then sorted by location. ROCKWORKS 99 software was used to plot rose diagrams and analyze flow trends. Vector means were calculated for the orientations of unique flow indicators (crag-and-tail features). Maps, the relative ages of cross-cutting striation sets, and rose diagrams were evaluated to determine ice-flow direction changes.



### Results

Well-developed striations, grooves, and crag-and-tail features reveal north-south ice flow during the late Wisconsinan flow maximum (vector mean 175°, Figure 8). These abrasion marks represent the flow maximum and are abundant on both sides of the Penobscot River valley. They generally coincide with the north-south orientations of streamlined hills found on the Bangor quadrangle.

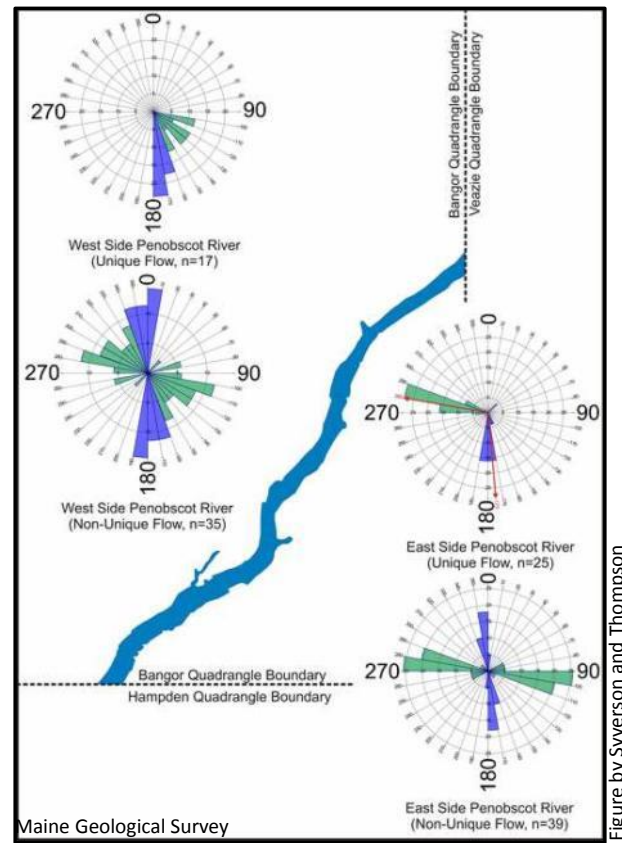


Figure by Syverson and Thompson

**Figure 8.** Rose diagrams of ice-flow indicators west and east of the Penobscot River.

### Results

In Figure 8 ice flow during the flow maximum was approximately north-south (175° azimuth vector mean, lavender petals). West of the river, a continuous suite of striations and crag-and-tail features show how ice flow became more easterly (green petals) as deglaciation proceeded. East of the river, discrete southerly (lavender petals) and younger westerly sets (280° azimuth vector mean, green petals) are present, and intermediate values are not observed. Secondary ice flow (marked by green petals) clearly converged along the axis of the Penobscot River lowland. Unique flow indicators include crag-and-tail features only. Both possible flow directions are plotted for non-unique flow indicators (striations and grooves), hence the perfect petal symmetry. Numbers along cardinal axes are percentages of total data.

A continuous range of abrasion marks is observed west of the Penobscot River. Outcrops at Brown Woods and the Interstate Highway 95/Stillwater Avenue intersection show the relationships most clearly (Figure 8). Robust striation and crag-and-tail features from the flow maximum (175° azimuth) are cut by less well developed striation and crag-and-tail features oriented in a more easterly direction (between 175° and 100° azimuths). Thus, flow became more easterly toward the Penobscot River valley as deglaciation proceeded. These changes in flow direction were observed up to 3 km west of the Penobscot River (Lane Corporation rock quarry on Odlin Road).



### Results

East of the Penobscot River, two major sets of abrasion marks are present. These are well exposed at the intersection of Interstate Highway 395/Parkway South intersection in Brewer (Figure 9). The older set with a vector mean of  $175^\circ$  is well developed in this area, just as it is west of the Penobscot River. However, a younger set of crag-and-tail features with a vector mean of  $280^\circ$ , indicating flow directly toward the Penobscot River valley, is also very well developed. Intermediate values between azimuth  $183^\circ$  and  $241^\circ$  are lacking, indicating a rapid change in flow direction.

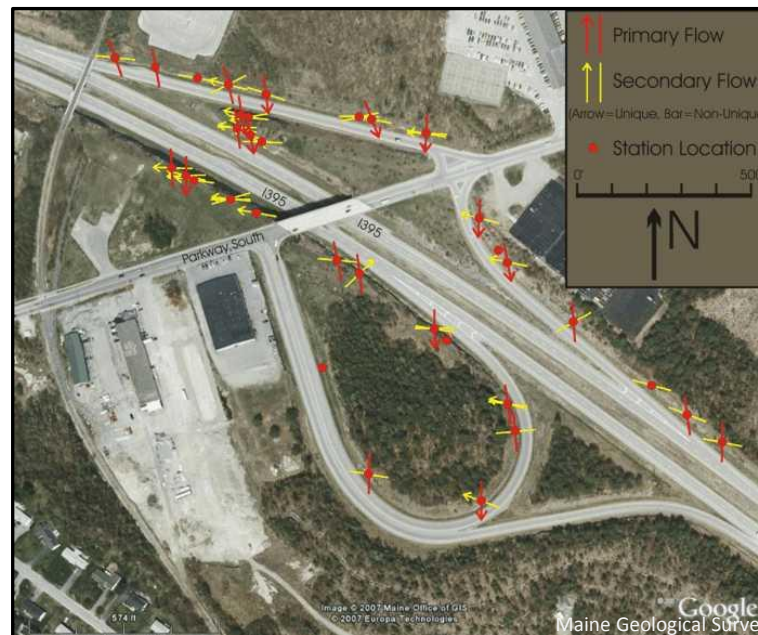


Figure by Syverson and Thompson

**Figure 9.** Ice-flow measurements at the Interstate 395/Parkway South interchange in Brewer. In this area, 64 flow indicators were measured (25 unique). Glacial maximum ice flow was southerly (red arrows). Then ice flow changed to the west-northwest toward the river lowland ( $280^\circ$  azimuth vector mean, yellow arrows).

Base image is from Google Earth.



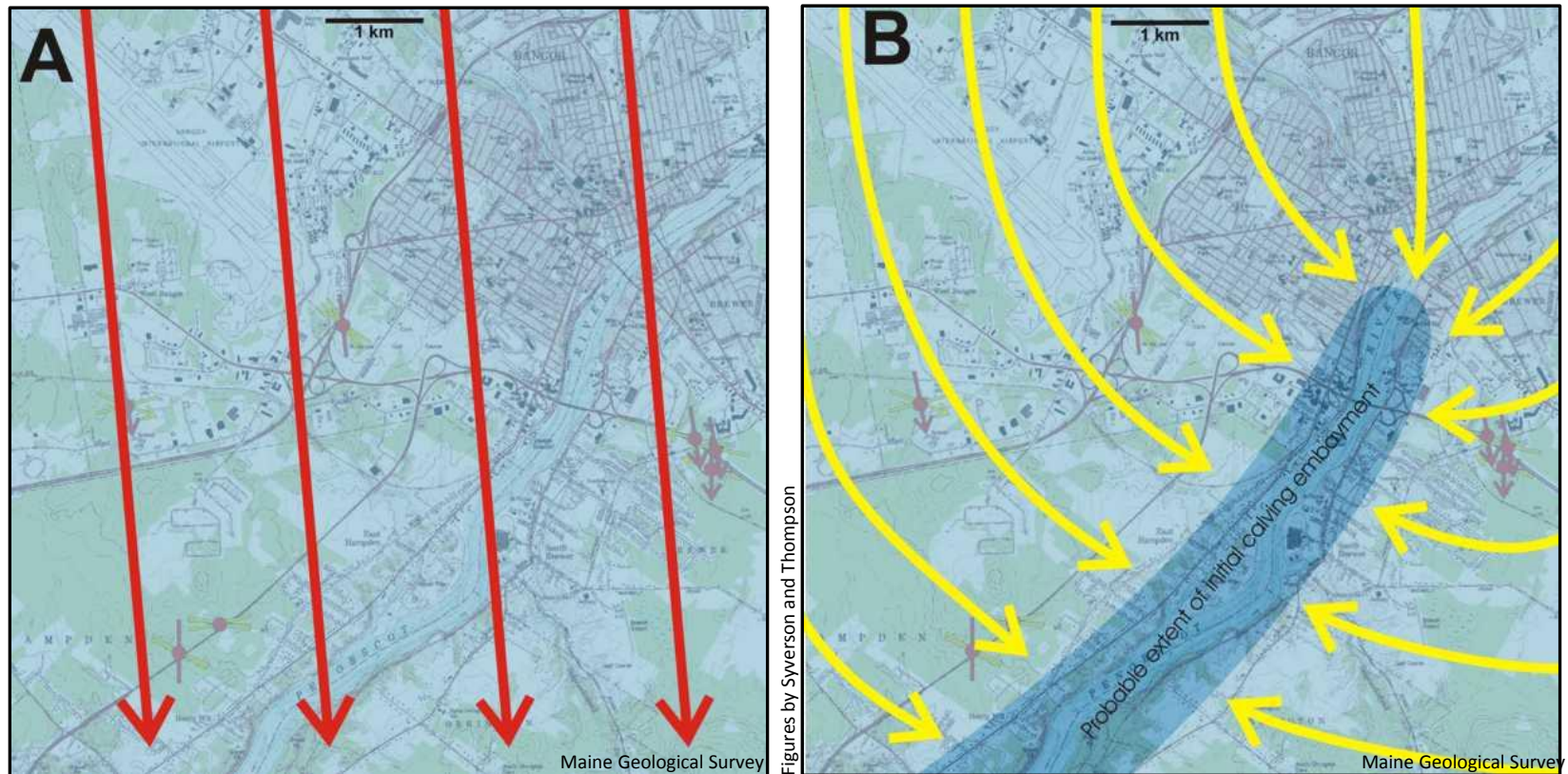
### Discussion

Ice-flow directions changed markedly in the Bangor area during deglaciation. Flow patterns west of the Penobscot River changed from southerly (175° azimuth vector mean) to easterly (100° azimuth) as deglaciation proceeded - a 75° flow change (Figure 6). The continuous range of striations and crag-and-tail features suggests a progressive easterly shift in the ice-flow direction. The change in flow direction is even more pronounced east of the Penobscot River - a 105° change from southerly (175° azimuth vector mean) to westerly (280° azimuth vector mean, Figure 9). Intermediate values between these two sets are lacking in this area suggesting a rapid change in flow direction from southerly to the west-northwest.



Discussion

In both cases, flow became more convergent along the axis of the Penobscot River during deglaciation (Figure 10).



**Figure 10.** Formation of calving embayment in the Bangor quadrangle area. A) Ice flow was southerly (175° azimuth vector mean) during glacial maximum. B) More rapid calving in deep water within the Penobscot River lowland formed a calving embayment.

### Discussion

This is what would be expected if a calving embayment was present in the Penobscot River lowland during deglaciation. A calving embayment acts as an ice "drain" and pulls in ice from the surrounding area, similar to what has been described in Scandinavia (e.g. Strömberg, 1981) and observed in Glacier Bay, Alaska (Mickelson, 1971; Syverson, 1995). Thompson (2007a,b) also observed convergent ice-flow patterns along the Kennebec River in Gardiner and Augusta, ME, and he interpreted these as evidence for a calving embayment in that area. The evidence for widespread, robust convergent ice flow has not been recognized previously in coastal Maine, and this is strong evidence for a narrow calving embayment in the Penobscot River lowland.

Although the convergent ice-flow pattern is distinctive along the Penobscot River, other non-calving explanations must be considered. First, the changing flow patterns could have occurred during a separate readvance of the ice margin. This seems unlikely from a glaciological standpoint, and evidence for such an event is lacking in the literature (Thompson and Borns, 1985; Borns and others, 2004). Secondly, ice flow toward the Penobscot River valley could have occurred as ice slid directly down the bedrock slope during the latest stages of deglaciation, as observed by Mickelson (1971). This seems unlikely in the Bangor region because (1) the Penobscot valley walls generally rise ~90 ft (27 m) within ~1600 ft (0.5 km) of the river up to a rather gently sloping bedrock platform; secondary flow indicators from this study are found on the gently sloping bedrock platform more than ~1600 ft (0.5 km) from the steep valley walls, (2) the abrasion marks associated with the secondary flow directions are extremely robust in many places, especially at the Interstate 395/Parkway South intersection in Brewer, and (3) the secondary striation patterns are very consistent; variations in bedrock slope direction would produce disparate striation orientations.



### Conclusions

We conclude that a narrow calving embayment is the most reasonable explanation for convergent ice-flow patterns along the Penobscot River lowland near Bangor (Figure 10). The Penobscot valley is quite narrow, and water depths would have varied by ~98 ft (30 m) within a distance of 3280 ft (1 km) on either side of the river. Based on this, we think the calving embayment was <1.2 mi (2 km) wide when it formed. Impacts of this calving embayment have been observed up to 1.8 mi (3 km) west and 0.9 mi (1.5 km) east of the Penobscot River.



### Conclusions

- Ice flowed roughly north-south (175° azimuth vector mean) over the Bangor area during the late Wisconsinan Glaciation flow maximum.
- This ice abraded the bedrock and deposited sandy till (generally quite thin) across the Bangor region. Subglacial streams deposited glacial marine sediment in low-lying areas as the ocean flooded the isostatically depressed land surface.
- West of the river, a continuous set of striation and crag-and-tail features formed between 180° and 100° azimuths as flow became more easterly toward the Penobscot River lowland (Figure 8).
- East of the river, a rapid change from southerly flow to west-northwesterly flow (280° azimuth vector mean) is suggested by the lack of intermediate flow indicators (Figure 8 and Figure 9). Evidence for robust ice flow directly away from the Atlantic coastline has not been recognized previously in coastal Maine.
- Major ice-flow direction changes and convergent, robust ice flow toward the Penobscot River lowland are the first strong field evidence reported for a calving embayment near Bangor. The calving embayment initially was <2 km wide based on erosional indicators and the width of the deepest part of the Penobscot River valley.



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