Mapping and Analyzing Meltwater Erosion Forms in Bedrock At Bailey’s Ravine, CT.

A report submitted to the department of Environmental Earth Science in conformity with the EES 480 requirements.

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ABSTRACT

This study examines large meltwater erosion marks (up to 3m high) present in garnet-mica-schist (Scotland Fm.) along a ~350m reach of Bailey’s Brook, North Franklin, CT. Similar marks occur on the slopes of several valley sides in Eastern Connecticut and have been used to map the locations of meltwater channels. Current discharge and channel size for Bailey’s Brook, a small first order stream, is grossly undersized when compared with paleoflow associated with meltwater marks. This study relies on survey data collected with total stations and a VX Spatial Station that is capable of terrestrial laser scanning (TLS). This includes ~10 valley cross-sections, a lengthwise profile, and a ~60,000 point cloud collected from 6 instrument positions along the modern channel. In general, the stream flows across ~6 small bedrock escarpments, ~2-4m high, resulting in distinct knickpoints in the long profile. These escarpments constricted meltwater resulting in larger erosion marks where flow incised through the escarpments. TLS data were analyzed using Trimble Real Works Advanced software by segmenting and refining point-clouds to remove vegetation so that bedrock surfaces could be analyzed. TIN based meshes constructed from point clouds were refined, slightly smoothed, and extraneous peaks removed. Meshes were textured with generated VX imagery and in some cases retextured with higher quality DLSR imagery so that individual erosion mark boundaries could be easily recognized. Point-clouds were then segmented to create datasets for each meltwater erosion mark (form). Individual form clouds were analyzed geometrically, defining coordinate systems (frames) based on a best-fit plane to the form-cloud. Form-clouds were exported as object files for analysis using geometric mesh-editing software. Although data analysis presented within is somewhat exploratory, the long-term goal is to quantify these erosion forms to determine whether they can be distinguished from similar looking features developed in modern rivers.
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INTRODUCTION

Water-eroded forms in bedrock occur in Connecticut as a result of both modern fluvial erosion and past meltwater discharge during deglaciation. Distinguishing between these origins requires analysis of the geologic setting and controls on the forms, the size of the features relative to existing flow conditions, and an examination of the shape of erosion marks. This study examines large water-eroded forms that occur along a small stream in North Franklin, CT. that flows over schistose bedrock.

In Connecticut, meltwater has been produced a series of small lakes and ponds within valleys. Stone et al. (2005) has mapped associated deposits throughout the state to reconstruct the chronology of deglaciation. Meltwater channels and glacial spillways are often associated with these deposits. Meltwater forms eroded into bedrock typically occur in small streams along steep side slopes that drain into valley bottoms.

Meltwater erosion forms can vary from millimeters to kilometers in size, although forms examined in this study are typically metres to tens of meters in length. Small forms, like those at Bailey’s Ravine, are referred to as sculpted forms (s-forms). Munro-Stasiuk, et al. (2009) indicate that such forms are classified as convex features, concave features, and conjugate forms which may be oriented parallel, transverse, or not related to prevailing flow. Transverse s-forms are wider than they are long, parallel forms are longer than they are wide, and non-directional do not display a preferred orientation. The majority of the forms at the study site are similar to parallel forms, including cavettos and flutes, as well as non-directional forms such as undulating surfaces and potholes.

Large meltwater forms are also associated with channels that drain glacial meltwater in close proximity to an ice margin. These flows occur in front, beneath, or along the margin of ice sheets. In some cases, water flows though these channels in response to gravitational force or driven by hydrostatic pressure up gradient through ice channels or tunnels near the glacial margin. In places where meltwater flows over bedrock, sculpted forms may develop. Following deglaciation, much smaller modern streams may occupy meltwater channels that contain sculpted forms. As such, in Connecticut, some modern streams occupy channels that also transported meltwater. These modern streams are small first order channels, some occurring along the sides of bedrock cored hills. Bailey’s Brook (Figure 1) is an example.
Within this context, the objectives of this study are to:

1. Characterize aspects of bedrock at Bailey’s Ravine that influenced the development of eroded forms,
2. Utilize total station survey data to compare present and past flow conditions, and

TOPOGRAPHY, BEDROCK, AND SURFICIAL GEOLOGY

The Bailey’s Ravine study site is located just north of Ayer’s Gap in a deep incised valley between Avery Hill (530ft) and Pleasure Hill (530ft) to the north and Ayers Mountain (451ft) to the southeast (Figure 2). Bailey Brook is a small first order stream (≈1.68 km² drainage basin) that drains ≈ 2.07 km southeast down a steep stair-step slope that is underlain by the Devonian Scotland Schist Formation (Snyder, 1964).

Regional topography for the surrounding 220km² reveals numerous asymmetric hillslopes that reflect underlying bedrock control on the landscape. Upon comparison to the contacts in the bedrock, these hillslopes appear to reflect changes in bedrock (Figures 3,4). This is also evident in the detailed topography revealed by the LIDAR data. In general, there is a prevailing steep slope that is trending SSW-NNE, similar to other slopes evident in the topographic map (Figure 2). Ayer’s Gap located to south of the site is steeply incised and serves as another indication of bedrock control on the surface topography. In addition, there are two streams that drain along the steep slopes.

The bedrock geology underlying the study area (Figure 3) indicates that Bailey Brook drains southeast across the Scotland Schist Formation. This rock consists of a silvery-rusty weathered muscovite-biotite-staurolite-garnet schist with minor amounts of granular biotite schist. These rocks have metashale protoliths in close contact with the Hebron Formation to the southeast immediately down gradient from steep slope (Figure 3). Faults and joints have not been mapped in this area, although detailed topographic data described in the results section of this report suggests some brittle fracturing may be present. Regional strike for foliation within the Scotland Schist varies from northeast to north at the study site, with dips (25 to 60°) from the northwest to west.
Surficial deposits underlying the study site include extensive exposures of till in the uplands and alluvium and stratified drift deposits in valley bottoms (Clebnik, 1980). Stratified drift includes large accumulations with the Shetucket River valley deposits but also include some eskers (Figure 4). The streambed of Bailey Brook flows downslope towards alluvium and sediment dammed pond deposits that consist of gravel, sand, and silt. Two meltwater channels occur in this area including Bailey’s Ravine, which is not mapped as a meltwater channel in the CT-DEEP dataset, and a smaller meltwater channel to the southwest (see inset of Figure 2).

The asymmetric bedrock-controlled hills have also been modified by glaciation which abraded at northwestern slopes and pluck, steeper southeast facing slopes. Striations and other glacial lineations from surrounding quadrangles, as well as the orientations of valleys and hills, are indicative of a south-southeast ice flow. Clebnik (1980) suggests that eroded forms in bedrock at a site less than 1 kilometer south of Baily Brook were sculpted by subglacial meltwater draining to the bed of the decaying ice through moulins or flowing in a channel in the front of the retreating ice.

Figure 1. An example of an “escarpment” that has restricted the flow of both the modern and paleo-flow of Bailey Brook. There are nine escarpments similar to this one that cross the studied area of the channel.
Figure 2. A topographic map of the surrounding areas of the study site. Yellow arrows indicate relatively parallel asymmetrical slopes (dark color on map). Inset shows a detailed 1m LiDAR image of the study area.
Figure 3. Bedrock geology for the study site and surrounding region (data from CT DEEP database). Bedrock is part of Iapetos terrain, with inset map (Snyder, 1964) indicating prevalent strike parallel to steep hill slopes with foliations dipping into the hill at many locations.
Figure 4. Surficial map from CT DEEP datasets based in part on Clebnik’s mapping (1980). This site includes exposures of till in the uplands and alluvium and stratified drift deposits in valley bottoms.
**METHODS**

**Data Collection**

Fieldwork included topographic surveying, terrestrial laser scanning, and photography at Bailey’s Ravine with follow up analyses using a variety of computing techniques. Field topographic surveys made use of conventional total stations which involved setting the instruments up by leveling the total station, setting a horizontal angle to local north, and defining an arbitrary occupied point coordinate system for the initial coordinate system. Subsequent total station positions were tied into a common survey coordinate system by resection techniques. This involved surveying 2 or 3 points for the first station setup. After this, the next station was set up, leveled and targeted on the resection points to back-calculate an occupied point for the new total station position. Topographic data were also collected along the stream by placing the prism rod in the stream, surveying the point, and measuring the water depth. These data, when analyzed to define the slope of the water surface. Survey data were also collected across the stream valley and for the highest meltwater forms in each station.

More detailed survey data were collected using a Trimble VX Spatial Station (Figure 5 and front cover). This involved setting up and leveling the scanner. The VX was also tied into a common surveyed coordinate system using resection points marked with small white painted crosses on the eroded walls of the streambed. Once in common survey space, the VX was used to scan topography, to collect additional stream profile data, and to survey stream cross-sections in combination with total station results. These data were used to construct triangular irregular network (TIN) models of the forms and to develop a full profile along the stream (Figure 6,7).
Figure 5. View of large forms cut into bedrock in reach that was surveyed using the VX spatial station. (Note person for scale at arrow).

Figure 6. Point clouds are used to construct TIN meshes that represent the three-dimensional character of eroded forms that were retextured with high quality DSLR imagery.
In general, scans were designed to map in detail (typically on 10x10cm grids) the eroded bedrock exposed along the stream-sides (Figure 6). This involved outlining the survey target areas on the instrument controller. The distance to the midpoint of the survey space was measured to determine the typical distance to the target. Once the midpoint distance was established, a survey grid was set at 0.100m point spacing for detailed scans, and 0.500m point spacing for coarser scans. Some sites that were not part of the erosion forms were not measured in great detail. Once the scans were complete, they were evaluated in the field to ensure that survey data had been included for all portions of the eroded bedrock surfaces. In total, six scans were collected from the survey site that consisted of ≈53,000 individual survey points (Figure 7).
In addition to the survey point cloud, the VX was used to collect high quality digital images that are registered in the same survey space. It was also helpful to collect high quality hand held DLSR images of the eroded bedrock walls so that the VX imagery could be replaced if needed when building graphics. Lastly, GPS coordinates were collected for each survey station to give their specific location.

**Computing Methods**

Data were imported from the spatial scanner directly into Trimble Real Works Advanced software. Folders were set up to organize the data into “3D points”, “clouds”, “meshes”, and “textured meshes” in office survey mode (Figure 8). 3D points were then created from targets for each station in registration mode. Point clouds were created from the 3D points using the scan-based sampling tool. The point clouds were then cleaned to remove vegetation so as to create a bare earth cloud. Once cleaned, the bare earth cloud was further segmented to create “East Bank” and “West Bank” clouds for analysis of the forms for erosion marks. The workflow and findings for the additional analyses are described in the results section of this report.

**RESULTS**

Bailey’s Ravine is characteristic of the modern, small, first order channels that occur along the sides of bedrock cored hills. However, this valley likely it was likely also transported meltwater downslope during deglaciation. In addition, the stream channel has clearly been influenced by the underlying geology. Thus, the character and origin of erosion forms along Bailey Brook in North Franklin reflects all of these controls. The following analyses survey, scan, and geologic data prior to examining the forms of the erosion marks.

**Bedrock Control on the Study Site**

Aerial LIDAR data collected for eastern Connecticut separately in November and December 2010 for the USDA Natural Resources Conservation Service (NRCS) was used to generate a 1m bare earth model for the Bailey Brook study site was processed using Global Mapper software. This allowed the 1m bare earth LIDAR data to be processed as a three-dimensional model. This model was used to identify the structural trends in the underlying geology of the site providing a detailed view that could not obtained through areal imagery due to tree cover.
Figure 8. Once extracted (a) individual form clouds were used to construct (b) meshes. (c) Meshes were fit with a plane to define a new coordinate system that is based on the geometry of the form. (d) Resultant forms could then be sliced to define 2 dimensional shapes and to calculate volumes for subsequent analysis.
As noted earlier (Figures 2,3), bedrock conditions in Eastern Connecticut create asymmetrical hillslopes. LIDAR and geologic data for the study site reveals similar trends are present at Bailey Brook. A vertically exaggerated hillslope model (Figure 9) derived from LIDAR data clearly illustrates structural control to the hillslopes crossed by Bailey’s Brook. Note the strike of the steep slope is parallel to smaller lineaments on the hillslope.

**Figure 9:** Slope shade model constructed from 1m LIDAR data. Structural control on the steep slope and several cross-valley transects are also evident in profiles (below) for lines identified in the hill slope model.

**Figure 10:** Cross-sections generated from running a 3D analysis by interpolation perpendicular to strike direction. Profile 6 depicts topography between yellow dots in Figure 9 while Profile 7 is for the magenta dots.
At Bailey’s Ravine, the LIDAR data were imported into ArcMap and explored using the 3D Analyzer to create profiles across the strike of the channel and along the profile of the channel (Figure 10). These cross-sections reveal a "stair-step" pattern for topography when sliced at right angles to the steep slopes. This pattern is also evident for the long profile. This trend is most obvious where the stream cuts through structural escarpments (Figure 2). In general the largest erosion forms occur immediately upstream from locations where the stream flows through an escarpment.

**Paleo-Discharge Estimation and Comparison with Modern Flow:**

The large erosion forms along Bailey’s Brook suggest much greater flow conditions existed in the past. To this end total station survey data were collected lengthwise along a ≈ 400 m reach of the stream, as well 9 valley cross-sections also noting the uppermost elevation of meltwater forms. These data were used to calculate Manning velocities as follows:

$$V_{\text{Manning}} = \frac{1}{n} \cdot R^{0.66} \cdot s^{0.5} \quad (1)$$

The cross-sectional flow for present-day water levels and for past flows were determined from survey data collected for the water level at the time of surveying. Meltwater flow velocities were based on estimation of water level at the tops of meltwater forms at stream cross-section locations. The resulting discharge is the product of the $V_{\text{Manning}}$ (equation 1) and the cross-sectional area of flow (Figure 11). These calculated results are used to compare the modern flows with the paleo-meltwater discharges (Table 1). Slope estimates for the Manning velocities were calculated based on linear trend lines fit to sections of the streams long profile (Figure 12) for modern flow conditions and fit to meltwater elevation for paleoflows.

The large erosion forms along Bailey’s Brook suggest much greater flow conditions existed in the past. Data summarized in Table 1, suggest that meltwater flows were ≈400 times greater (on average) than present day discharge indicating that the modern stream is severely misfit.

**Analysis of Erosion Forms:**

VX scan data were used to characterize individual meltwater forms in Trimble Real Works Advanced software. This involved using a mesh creation tool to select survey points in a cloud
and create triangulated irregular networks (TINs) or “meshes” of the forms. These meshes were created in un-projected mode to produce a triangle faceted surface. Original survey points defined the corners of the triangle surfaces. The resulting meshes were refined by removing unwanted peaks, applying limited smoothing, and removing erroneous triangles. Once the point clouds and meshes for the eroded bedrock banks of the stream were cleaned, it was necessary to isolate individual eroded forms. This involved visualizing points and retextured meshes so as to identify forms, segmenting the data sets, and to create a new coordinate system. This new coordinate “frame” enables analysis of the forms in a consistent manner regardless of their orientation with respect to the flow. Individual meltwater erosion forms were isolated using the segmentation tool (segmented) to create point-clouds for each form. This involved making the retextured mesh layers and point clouds visible so that the form boundaries are readily recognized. Each individual form cloud was then converted to a mesh and cleaned (if necessary) using the “mesh-editing tool”.

For each final mesh, a centroid and best-fit plane was created in the modeling mode of Realworks by selecting survey points along the rim of each form. The best-fit plane was created using a cloud based modeling tool for each rim based on a least squares fit. A coordinate system was developed using the “frame creation tool” with an origin at the centroid, the x-axis running along the base of the fitted plane, the y-axis up the plane, and the z-axis normal to the plane. The Z-axis defined the depth of the forms measured normal to the best-fit plane. This process created a local coordinate system, or frame, which was used when exporting point clouds and meshes. Exporting was completed in both .asc and .dxf formats as these file types were readily imported into Excel and other programs for geometric analyses.

In order to characterize the form of the erosion marks, the volume, surface area, and planar area were calculated for of each erosion marks. This involved using a volume calculator tool in Real Works. Volume and areas were calculated for 5% depth slices in each form. Results are best presented as plots of volume, planar area, or surface area for individual slice depths. This presents a single curve for each form that can be compared with other forms. See discussion for more development on this idea.
Figure 11. Cross-section profiles of the present day channel complied from total station surveys. These crosssections were used to develop the estimated area of flow and modern discharge.

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Present Day Discharge Estimate

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Figure 12. Lengthwise profile data with best-fit trend lines for present-day flow (yellow and black circles) and paleo-flow based on upper elevations of meltwater forms at valley cross section locations (yellow triangles). Results given in Table 1 indicate much greater discharge associated with erosion forms than those that occur in the modern streams.
DISCUSSION:

Characterizing three-dimensional forms is complex and may be approached in a variety of ways. Because erosion forms are the result of flowing water, the following draws from literature that analyzes the form of water-filled lakes.

The characterization of the form of lake basins has made use of hypsographic curves for many years. Hypsographic curves are graphic representations that compare lake surface area to lake depth (Wetzel, 2001). Another type of hypsographic curve includes depth-volume curves comparing lake volume to depth. Scan data for erosion marks at Bailey’s Brook can be used to develop hypsographic curves using the same technique used for lakes. In lakes, the form of the basin has a direct relationship with lake productivity, biological processes, and the proportion of lake bottom that can be affected by sunlight. Similarly, the form of the erosion marks has direct relationship with the processes that occur within them as well. This may include vortices, erosional patterns, and overall flow magnitude; processes that effect the overall shape of the form. To the best of my knowledge, this method has not been applied to meltwater erosion forms previously. Much research has been undertaken to compare the shape of forms, but this analysis may aid in linking shape to the condition of flow that sculpted these forms.

Hypsographic curves were developed for 9 scanned forms in this study included three varieties of plots. These include a plot comparing form depth to surface area (Figure 13), form depth to planar area (Figure 14), and form depth to volume (Figure 15). For each hypsographic curve, measurements are expressed as m, m², m³, and as relative terms. Relative volumes were calculated as follows:

\[ \text{Relative Value} = \frac{\text{Value Of Form Below Slice Depth}}{\text{Total Form Value}} \]  

(2)

This calculation was performed for depth, volume, surface area, and planar area to achieve values that could be compared to one another regardless of the broad range in size and depth of the forms at the true scale. For each of the calculations, the depth of form was measured beginning at the first z-value in the form’s frame when the first closed polygon in each form
occurs (Figure 16). To determine the range for the hypsographic curve, the depth below zero for each form was broken into 5% intervals.

There appears to be two distinct groups in each of the hypsographic plots. Forms 3EBF4 and 3EB2F4 appeared as outliers in every plot that compares and Form S1F1 often fell between the groupings. As such, hypsographic curves could then be classified into three groups; type one, type two, and intermediate. Examples for each type are given in Figure 17. Type One forms that have a simple curve, or a singular convex shape (Figure 17a). Forms that are more complex and are considered “conjugate”, or made of forms within forms with blurred boundaries (Richardson and Carling, 2005), are Type Two. These were created from the same flow but likely exhibited more than one vortex. An example of this is S3ebF4 (Figure 17b). Type Two forms that fall between these categories can be considered “intermediate” with form S1F1 as an example. Intermediate forms are singular convex forms, but it almost comes to close to a conjugate form (Figure 17c). Classification for all 9 forms are given in Figure 18.

One form that was especially unique to this study area. Although S4F1 is classified as Type One, its shape is not a simple convex curve. Rather it is a pothole on its side (perpendicular to what one would expect). Richardson and Carling might classify this as a “lateral pothole” in their report, A Typology of Sculpted Forms in Open Bedrock Channels (Figure 19). Richardson and Carling (2005) discuss a type of form that they classify as “lateral potholes”. Lateral potholes are evidence in a breach of the bedform walls. They describe lateral potholes as having rounded surfaces, that indicate that a large percentage of rock has been removed. The axis of these lateral potholes must be nearly perpendicular to the channel of flow. Form S4F1 (Figure 19, 20) is likely the most predominate form at this site to be classified as a lateral pothole as it meets these criteria. Its sharp rims are not a rare occurrence for lateral potholes. Another signature characteristic for S4F1 is that it narrows with depth (almost forming a "cone" shape) and tapers upwards; also a very common occurrence in lateral potholes. This forms a “teardrop” shape (Richardson and Carling, 2005), or the “Cornucopia” as we casually named it in the field. Another defining characteristic of S4F1 as a lateral pothole is that it does not form a complete circle at its rim.
Figure 13. Hypsographic curves representing the relationship between form depth and volume.

Figure 14. Hypsographic curves representing the relationship between form depth and surface area. See legend in Figure 12.

Figure 15. Hypsographic curves representing the relationship between form depth and projected planar area. See legend in Figure 12.
Figure 16. Each of the forms were broken into increments of 5%. Volume depths and surface areas were taken for each of these "slices" and used to generate the hypsographic curves. (a) Side view of 5% increments, used for finding surface area and volumes. (b) Polygons that are formed and measured. Each polygon defined planar area, like contours on a topography map, in 5% increments.
A) **TYPE ONE**: Simple convex forms. Form S6F1 (person for scale).

B) **TYPE TWO**: Simple convex forms. “Conjugate” forms with “burred” boundaries. Form S3ebF4.

C) **INTERMEDIATE TYPE**: Forms that are not completely simple “type one” forms that exhibit some minor “conjugate” traits. Total station for scale.

**Figure 17.** The three classifications of forms in this study. (a) Form S6F1 is an example of a simple type one form, exhibiting just a singular convex shape. (b) Form S3ebF4 is an example of type two forms, exhibiting “conjugate” behavior. (c) Form S1F1 is an example of an intermediate form exhibiting traits that are dominantly singular but could be considered conjugate.
Figure 18. Mesh plots for all 9 scanned forms including their hypsometric classification.
Figure 19. A photograph of the lateral pothole nicknamed “The Cornucopia”, formally referred to as S4F1.
Figure 20. The digital model of S4F1 developed using the techniques in this report. Note how it does not have a circular rim, it is perpendicular to the channel, it narrows with depth, and tapers upward; identifying characteristics of a lateral pothole. (a) Look straight into the form, (b) Side view; both at same scale.
Glacial Interpretation:

Meltwater released during the Wisconsinian deglaciation has been fundamentally important to Connecticut’s landscape and has been integral in sculpting forms at Bailey’s Brook. As such, it is useful to briefly compare DEEP mapped positions of ice margin retreat to the location of meltwater forms at Bailey Brook. Such a comparison provides some insight into the timing and conditions in which the Bailey forms may have developed. Figure 21 shows the positions of related glacial features, deposits, and ice margins near the study site.

The topography of this site suggests that the forms were sculpted by glacial meltwater. Given paleo-discharges (Table 1), it seems necessary that a large amount of water had to flow along the brook. However, the present-day size of the Bailey’s Brook drainage basin would only provide a small amount of water. This suggests that meltwater from the decaying ice flowed through Bailey’s Ravine before the site was ice-free and therefore could tap into the large volume of glacial meltwater. Also this would provide a means by which water could be delivered to the topographically high location of Bailey Brook. The meltwater had to be delivered to the high elevation of the till-covered hill. Hydrostatic pressure from the overlying ice would enable meltwater to be fed to this high elevation position. The orientation of the eskers downstream from the channel also serve as evidence that subglacial flow did occur in this area.

It seems most likely that these forms at Bailey Brook were sculpted at the time that ice was at ice-margin “A” in Figure 21. By the time that the ice had retreated to margin “B”, the hill that drove Bailey Brook drains would have been exposed and there would no longer be a hydrostatic method of delivering large quantities of meltwater to this site. This suggests that the forms had to have been sculpted any time that the ice was south of position “B”.
Figure 21. A quaternary map of the study region. Since approximate ages were not available for the ice margins, they have been labeled chronologically A-B. Colors for the surficial material match those in Figure 3. White circle indicates location of forms. See text for discussion.
The purpose of this study was to examine large meltwater erosion marks present in garnet-mica-schist (Scotland Fm.) along a ≈350m reach of Bailey’s Brook, North Franklin, CT. The most important findings from this study, to date, include:

- The asymmetric hillslope at Bailey’s Ravine is similar to regional topographic trends that reflect a bedrock-controlled pattern trending SSW-NNE.
- Small escarpments crossed by Bailey Brook also display this orientation, creating a stair-step long-profile for the stream.
- The largest erosion forms occur where Bailey Brook cuts through these escarpments.
- The erosional forms at Bailey’s Ravine are grossly oversized in comparison to modern discharge. This together with the small size of Bailey Brook’s drainage basin, and location of forms high on the valley side suggests that meltwater from retreating ice was responsible for the features.
- Terrestrial laser scanning provides a method for quantifying shape that may help with future comparison to fluvial forms.
- Three classes of forms are recognized based on the construction of hypsographic curves for each form. Details are provided in this report on how the curves were built.
- The forms were likely sculpted at a time when the area was still ice-covered. Erosion of the forms ended some between ice positions “A” and “B” in Figure 21. This interpretation is based upon the fact that these large forms were sculpted on a hill. The only way to deliver meltwater would have been to drive flow uphill in response to hydrostatic pressure within subglacial channels. The position and orientations of eskers downstream supports this interpretation.
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