# A GUIDE TO SURFACE DEPOSIT AND BORROW PIT IDENTIFICATION USING LIDAR

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# Introduction

The Ministère des Forêts, de la Faune et des Parcs du Québec has collected LiDAR data for the entire territory of Québec since 2015.

LiDAR, the acronym for *Light Detection and Ranging*, is a remote sensing technology used mainly to capture highly precise altitude information. This information serves to determine land topography, vegetation height and structure, and so on.

Because of the density and high level of xyz precision of LiDAR points, the technology is extremely useful for mapping surface geology and glacial elements (Demchuck *et al*., 2005; Smith *et al*., 2006). The digital terrain model is especially useful for mapping details that cannot be observed from any other data source (e.g. aerial photographs), since the bare ground removes the camouflage effect of vegetation (Webster *et al.,* 2009).

At the same time, it has been shown that aerial LiDAR can generate significant economic spinoffs in some fields (Demchuck *et al*., 2005; Chiverrell *et al*., 2008; Lacroix and Charrette, 2013; Lacroix et Charrette, 2013; Leboeuf *et al.* 2015; Scheiber *et al*. 2015), in particular for forest road construction, where identification of granular or sandy material is a vital step.

The granular material inventory method generally comprises two phases: preliminary analysis work and fieldwork. The first phase consists in analyzing the available documentation (maps, aerial photographs, written documents, etc.) in order to identify the main geological units that may be able to supply aggregate (Brazeau, 1993). The second phase involves field work confirmation of the characteristics of sites identified in the first phase.

The use of LiDAR during this initial planning stage can certainly facilitate the task, among other things by identifying surface deposits more easily and more precisely. However, there has been very little research, so far, on the use of LiDAR for this purpose. It should also be noted that the use of remote sensing tools does not eliminate the need for field work (Smith *et al*., 2006; Chiverrell *et al*., 2008).

The Ministère des Forêts, de la Faune et des Parcs du Québec (MFFP) has produced this document with the goal of facilitating identification of surface deposits and hence the search for materials suited to civil engineering work. The document uses the following data:

- Hillshaded digital terrain model (hillshaded DTM) produced using LiDAR.
- Digital terrain model (DTM) produced using LiDAR.
- Aerial photographs with a spatial resolution of 30 cm in true colours composite.

**Hillshaded digital terrain model (hillshaded DTM)**

The hillshaded digital terrain model is a raster file that simulates the three-dimensional appearance of a relief map. It therefore does not contain altitude values. Shadow and light are shades of grey associated with integers from 0 to 255 (from black to white). The spatial resolution of this raster is 2 metres.

**Digital terrain model (DTM)**

The digital terrain model is a raster file that provides real numerical values representing altitudes in metres relative to the mean sea level. The raster file's pixel elevation values correspond to the linear interpolation of the network of irregular triangles created from the ground points. The raster's spatial resolution is 1 metre.

The LiDAR images contained in this document are the result of superimposing the DTM and hillshaded DTM to accentuate relief. Colour shading and transparency were applied to the DTM.

The data (DTM and hillshaded DTM) are available free of charge via Québec's interactive ecoforest data map at:

(https://www.donneesquebec.ca/igo/mffpecofor).

**True colour 30 cm aerial photographs**

This raster file is an assembly of numerous natural colour aerial photographs. The photographs are generally taken at a ground resolution of 30 cm.

For surface deposit interpretation, the aerial photographs should ideally be used stereoscopically to highlight relief.

These data can be ordered and purchased from the Québec Government's Géoboutique at:

(http://geomatheque.com/contact.aspx).

**Borrow pit potential of deposits**

All deposits have been ranked in five potential classes: zero, low, moderate, high or very high (Table 1). Classification was determined on the basis of particle size, deposit structure (graded, layered) and extraction constraints (presence of watercourses, height of water table, etc.).

Deposits with "zero" potential are of no interest in locating aggregate borrow pits.

In deposits with "low" potential, the particles are not suitable for road construction and the materials are not conducive to extraction (ungraded material).

In deposits with "moderate" potential, the particle sizes may be suitable on a highly localized basis, or there may be some extraction constraints.

In deposits with "high" potential, particle sizes are adequate but the structure requires a certain amount of manipulation (sorting).

In deposits with "very high" potential, particle sizes are suitable and the structure requires little to no manipulation (sorting).

Table 1. Potential of surface deposits for borrow pit location

| Potential | | | | |
|---|---|---|---|---|
| **Zero** | **Low** | **Moderate** | **High** | **Very high** |
| 1aa – Cochrane till | 1a – Undifferentiated till | 1bc – Ribbed moraine | 2a – Ice-contact deposit | 2ae – Esker |
| 1ab – Glacial block fields | 1bd – Drumlins and drumlinoids | 1bf – End moraine | | 2ak – Kame |
| 1ad – Washed till | 1bg –De Geer moraine | 2be – Outwash plain | | 2bd – Glaciofluvial delta |
| 1ba – Ablation till | 1bp – Dead-ice moraine | 4p – Lacustrine beach | | 2at – Kame terracce |
| 1bi – Interlobate moraine | 1bt – Till mounds | 6s – Raised beach | | |
| 1bn – Corrugated moraine | 2bp – Esker delta | | | |
| 3ac – Current alluvial deposit | | | | |
| 3dd – Delta | 3ae – Recent alluvial deposit | | | |
| 3de – Cone of dejection | 3an – Ancient alluvial deposit | | | |
| 4gd – Glaciolacustrine delta | 3da – Alluvial cone | | | |
| 4a – Lacustrine plain | 4gs – Glaciolacustrine deposit with shallow water facies | | | |
| 4ga – Glaciolacustrine deposit with shallow water facies | 5g – Glaciomarine deposit | | | |
| 5a – Marine deposit with deep water facies | 5s – Marine deposit with shallow water facies | | | |
| 5l – Marine deposit with deep water facies | | | | |
| 6a – Existing beach | | | | |
| 6g – Raised glacial boulder field | | | | |
| 7e – Thick organic deposit | | | | |
| 7t – Thin organic deposit | | | | |
| 8a – Altered materials | | | | |
| 8c – Colluviums | | | | |
| 8e – Scree | | | | |
| 8f – Block fields | | | | |
| 8g – Landslides | | | | |
| 8p – Translational slides | | | | |
| 9a – Active dune<br>9s – Stabilized dune<br>R – Bedrock | | | | |

# Glacial Deposits

Glacial deposits were formed directly by glaciers, with no major impact from meltwater. They are composed of non-sorted particles of different sizes, which may be loose or consolidated. They are not usually sought-after as an aggregate source, and their potential ranges from zero to moderate

## 1. Formation

The term "glacial deposit" refers to sediment left behind by a glacier with no major impact from meltwater. These deposits are composed of debris from the glacier bed or sides, as well as deformations of the source rock or even sediment from the valley walls, carried by the ice (Benn and Evans, 2010; Tranhaile, 2013; MFFP, 2014).

## 2. Location

Glacial deposits can be found throughout Québec. They are the largest type of deposit in terms of size, accounting for more than 62 % of the total area in sectors of southern Québec where deposits are interpreted (MFFP, 2017). The till is usually located in large plains or systems composed of slopes and convex or concave forms. Deposit thickness depends largely on its position on the slope (e.g. top, mid-slope, bottom) and the form of the terrain (e.g. convex, concave).

## 3. Deposit Description

Glacial deposits are composed of till. Till is a loose or consolidated, non-sorted deposit composed of rock flour and angular to subangular particles. Particle size can range from clay to boulder, depending on the region (Gutiérrez, 2013; Tranhaile 2013; MFFP, 2014).

The Ministère des Forêts, de la Faune et des Parcs du Québec (MFFP) has identified two categories of glacial deposits: those with no particular morphology and those with a particular morphology by which they can be identified (Table 2).

Table 2. Glacial deposits with and without particular morphology and their area as a percentage of Southern Québec

| Glacial deposits with no particular morphology | % | Glacial deposits with a particular morphology | % |
|---|---|---|---|
| 1a – Undifferentiated till | 62 | 1ba – Ablation till[1] | - |
| 1aa – Cochrane till | 0.5 | 1bd – Drumlins and drumlinoids | 0.2 |
| 1ac – Crystalline rock till[1] | - | 1bt – Till mounds | <0.1 |
| 1as – Sedimentary rock till[1] | - | 1bp – Dead-ice moraine | 0.9 |
| 1ad – Washed till[1] | <0.1 | 1bc – Ribbed (Rogen) moraine | <0.1 |
| 1ab – Glacial block fields | <0.1 | 1bn – Corrugated moraine[2] | <0.1 |
| | | 1bg – De Geer moraine | 0.1 |
| | | 1bf – End moraine | 0.1 |
| | | 1bi – Interlobate moraine[2] | <0.1 |

Glacial deposits with no particular morphology:

- Till is deposited partly by the glacier base (lodgment till), as the glacier advances, or by stagnant ice when the glacier retreats (ablation till). The two kinds are difficult to distinguish in photointerpretation, and it is mainly for this reason that they are grouped together and classified as "undifferentiated till" (Robitaille and Allard, 2007; MFFP, 2014).
- In Québec, deposits, especially undifferentiated tills, are also classified by thickness. When a deposit is less than one metre thick, the deposit code is preceded or followed by one of the codes shown in the following tables:

[1] Not mapped on aerial photographs.

[2] Mapped very little on aerial photographs.

Table 3. Till category and thickness

| Deposit category | Code | Modal thickness |
|---|---|---|
| Thick deposit | 1a | More than 1 m |
| Moderately thick deposit | 1ay | 50 cm to 1 m |
| Thin deposit | 1am[1] | 25 to 50 cm |

Where till alternates with rock outcrops, the classifications shown in Table 4 must be used.

Table 4. Category and thickness of tills with rock outcrops

| Deposit category | Code | Modal thickness |
|---|---|---|
| Thin to very thin deposit | R1a | Less than 50 cm and rock outcrops covering an area of 25 % to 50 % of the area under study. |
| No deposit[2] | R | Rock outcrops are numerous and account for more than 50% of the area under study. |

- Cochrane till is located specifically in northwestern Abitibi. It was deposited during the second glacial surge and tends to be composed of clay.
- Crystalline rock till exhibits the same characteristics as undifferentiated till on aerial photographs. The two types can only be distinguished by an onsite textural evaluation. Crystalline rock till is therefore not mapped on aerial photographs.
- Sedimentary rock till exhibits the same characteristics as undifferentiated till on aerial photographs. The two types can only be distinguished by an onsite textural evaluation. Sedimentary rock till is therefore not mapped on aerial photographs.
- Washed till is found in depressions where fine particles have been deposited by outwash water, and on the sloped flanks and peaks of hills. It is often found in gullies and alongside watercourses. Its makeup includes a small percentage of fine particles and a large percentage of bigger elements (pebbles, stones, boulders).
- Glacial block fields occur in low relief areas, especially on large, undulating till plains where dead-ice moraines and ribbed moraines are often found. They usually cover an area ranging from a few hundred square metres to a few hectares, and are often irregular in shape. They are composed of subrounded stones and blocks with no fine particles.

Glacial deposits with a particular morphology:

- Ablation till was deposited by the melting of stagnant ice. Its topography is generally composed of ridges and troughs with no specific orientation. The ridges and troughs tend to be flared and broad, contrary to the narrower profiles of dead-ice moraines which also have more ridges and troughs than ablation till. Ablation till is composed of a small percentage of fine particles (mostly sand) and a large percentage of gravel, pebbles, stones and blocks.
- Typically, a drumlin is an egg-shaped or whale-back shaped hill running parallel to the glacier flow. Drumlins may occur singly, but are often found in groups (drumlin field). Drumlinoids are narrower and more slender in shape than drumlins.
- Like drumlins and drumlinoids, till mounds are streamlined and longer in shape, and lie parallel to the flow of ice. They are composed of till and are located downstream of a rock core.
- Interlobate moraines form at the boundary between two glacial lobes. They look like long, flat, sinuous ridges or embankments that may sometimes be several dozen metres high and hundreds of kilometres long. Interlobate moraines are dominated mainly by glaciofluvial deposits and glacial sediments: sand, gravel and boulders. The deposits are layered in some places and unstructured elsewhere.
- Dead-ice moraine is deposited when the glacier melts. The debris usually accumulates on lodgment till, which is much denser and more compact.

[1] Code M1A exists (very thin deposit) but is not used in photointerpretation.

[2] Absent deposit is described in the Rock Substrate sheet.

Typically, its topography is composed of ridges and troughs with no specific orientation. The ridges and troughs are narrow and more numerous than in ablation till or ice-contact deposits. Dead-ice moraine is usually composed of loose, washed till and is often thinner than the underlying till. It contains a high percentage of large particles and may also include pockets of layered sediments.

- Ribbed moraine, also known as Rogen moraine, forms subglacially. It comprises a series of ridges running parallel to the glacial front. The ridges are broad, with flat tops, and can be several kilometres long. The concave space between the ridges is usually narrower than the width of the ridge tops. The ridges that make up ribbed moraine are composed of till rich in blocks that may contain layers of sediment screened by water.

- Corrugated moraine forms along an active glacial margin. The low ridges (between 3 and 10 metres high) run parallel to the glacial front. They are separated by small, sometimes wet depressions.

- De Geer moraine forms in shallow bodies of water at the glacial front. Its topography comprises small ridges (3 to 10 metres high) parallel to the glacial front. The ridges are narrow and thin, and are usually interspersed with smooth, regular and often flat areas of land. The small ridges that make up De Geer moraine are composed of till, sometimes with a bare surface, and are generally stony and may be covered with boulders or gravel.

- Frontal moraine forms at the snout of a glacier and accurately marks its former position. A frontal moraine may be several dozen metres high and hundreds of kilometres long. It is composed of large quantities of glacial sediment: sand, gravel and boulders. The deposits are layered in some places and have no apparent sedimentary structure in others.

## 4. Identification Criteria

<u>Thick till (1a)</u>

The geographic location, existing maps and topographical position must be known and analyzed when interpreting deposit thickness, since the interpretation process requires the use of context-related and comparative criteria.

Hillshaded models do not provide an accurate appreciation of slope incline. A smooth rendering may indicate a flat area or a regular slope. In addition, hillshaded models do not show changes in slope angles due to increases in the thickness of unconsolidated hillside deposits. The main strength of a hillshaded model is that it shows the texture of the ground under the canopy.

- LiDAR indicators

In areas with flat relief, thick till is present on undulating plains, and is accompanied by drumlins or ribbed moraine in coastal sectors.

In sectors dominated by hills and mountains, the following criteria can be used to identify thick till:

a) Thick till is found on flanks at the bottom of slopes, on concave slopes or on flat, flared peaks (Figure 1).
b) It may be found mid-slope on flanks if the slope incline is significantly reduced.
c) Gullies are indicative of thick till (Figures 1, 2 and 3).
d) There are few or no fractures or faults on the ground surface.
e) Soil texture is relatively smooth.
f) Depth of drainage ditches alongside road infrastructures (where present) can be indicative of thick till.
g) Till is thick on sites where the topography includes broad, flared landforms with gently undulating relief.

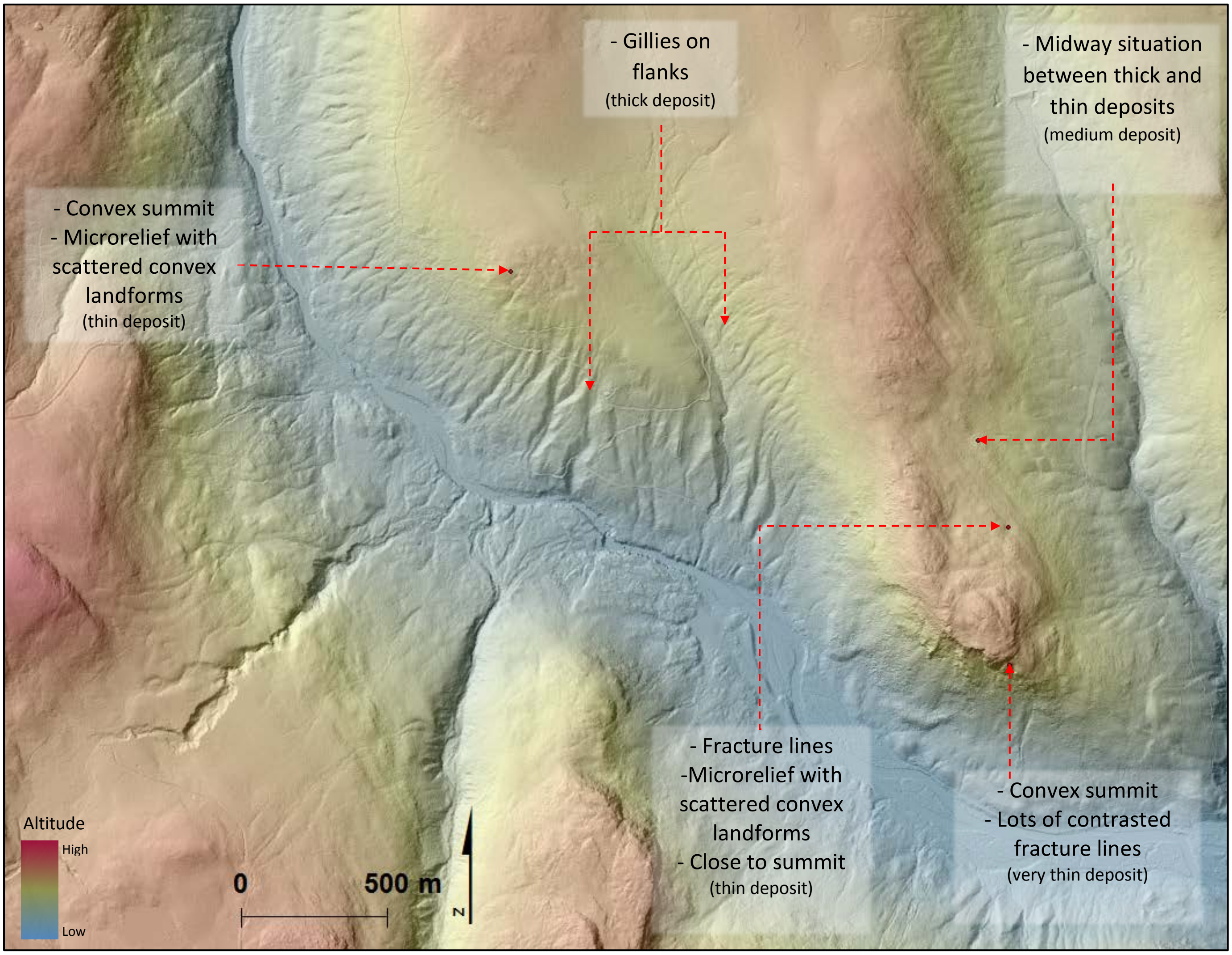


Figure 1. Example showing tills, on LiDAR, in the Eastern Balsam Fir- White Birch ecozone

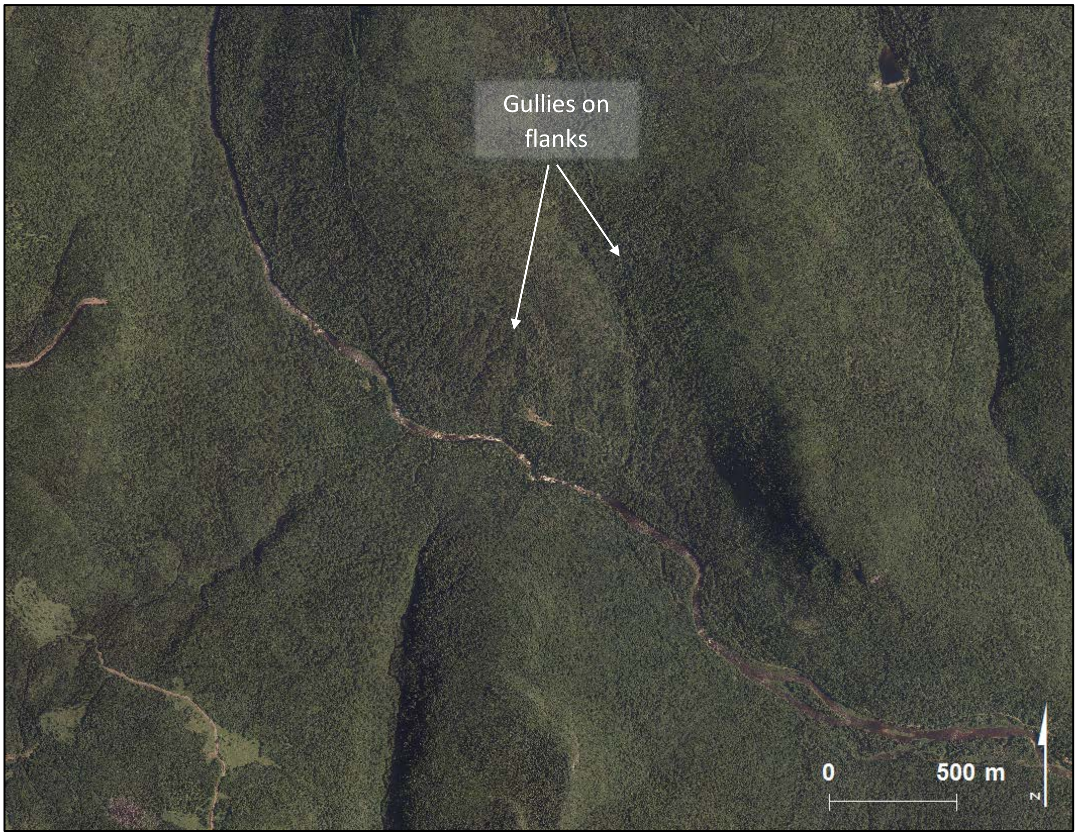


Figure 2. Example showing tills, on an aerial photograph, in the Eastern Balsam Fir- White Birch ecozone

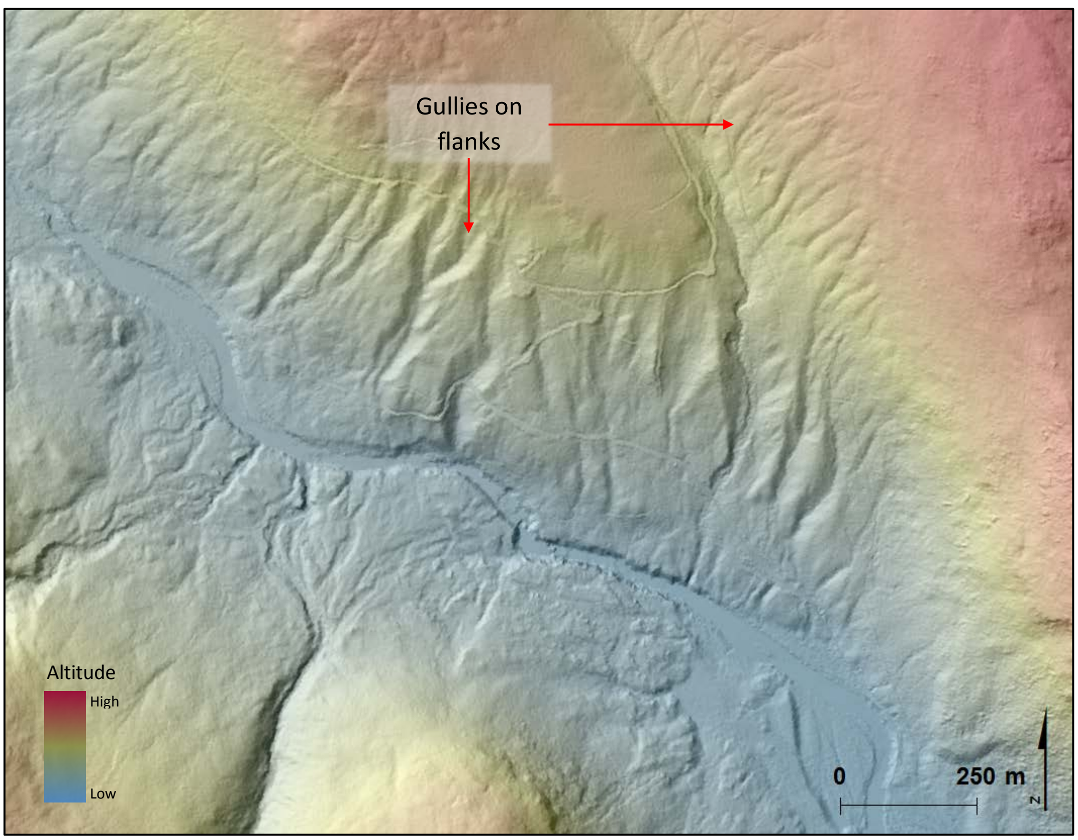


Figure 3. Example showing ravines in thick till, on LiDAR, in the Eastern Balsam Fir- White Birch ecozone

- Aerial photograph indicators

a) Indicators shown on LiDAR can also be visible on aerial photographs if not hidden by vegetation.

## Moderately thick till (1ay)

- LiDAR indicators

a) Moderately thick till occurs in a variety of topographies (e.g. mid-slope, flat summit, etc.).
b) Interpretation of till thickness uses context-related and comparative criteria. Intermediate till is a transitional deposit between thick till and thin till. It is interpreted using observable criteria whose values fall mid-way between those applicable to thick till and thin till (Figure 1).

- Aerial photograph indicators

a) Indicators shown on LiDAR can also be visible on aerial photographs if not hidden by vegetation.

## Thin till (1am)

- LiDAR indicators

a) Thin till occurs in a variety of topographies (e.g. convex slopes and summits, flat summits, etc.).
b) Microrelief forms (crevasses, striations, fracture lines) indicating the proximity of the base rock are visible (Figure 4).
c) Fracture lines or crevasses are less prevalent than in surrounding thinner sectors.
d) Thin till is also found on convex slopes or at the top of very steep slopes where rocks are present (R or R1a).

- Aerial photograph indicators

a) Indicators shown on LiDAR can also be visible on aerial photographs if not hidden by vegetation.

## Very thin till (R1a)

- LiDAR indicators

a) Very thin till is found in areas with numerous fracture lines, regardless of steepness.
b) Fracture lines or crevasses are more contrasted compared to those in surrounding sectors with thicker deposits (Figure 5).

- Aerial photograph indicators

a) Surface rock will be shown in the pale grey colour associated with bare rock and with the presence of lichen that colonises these sites (Figure 6).
b) These sectors are often drier and support the presence of lichen or xerophilic plants (oak, white pine, etc.). In the Spruce Moss and Balsam Fir-White Birch bioclimatic domains, vegetation will be less dense on these sites.

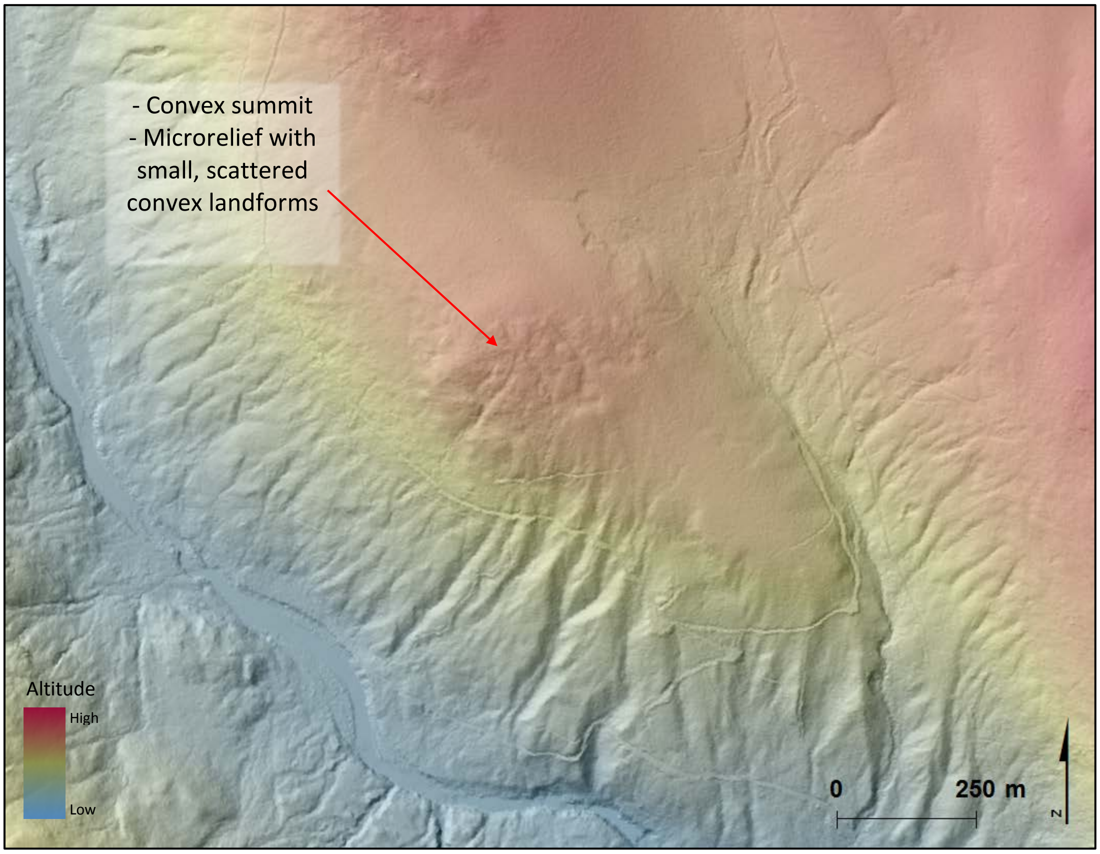


Figure 4. Example of thin till (1am), on LiDAR, in the Eastern Balsam Fir- White Birch ecozone

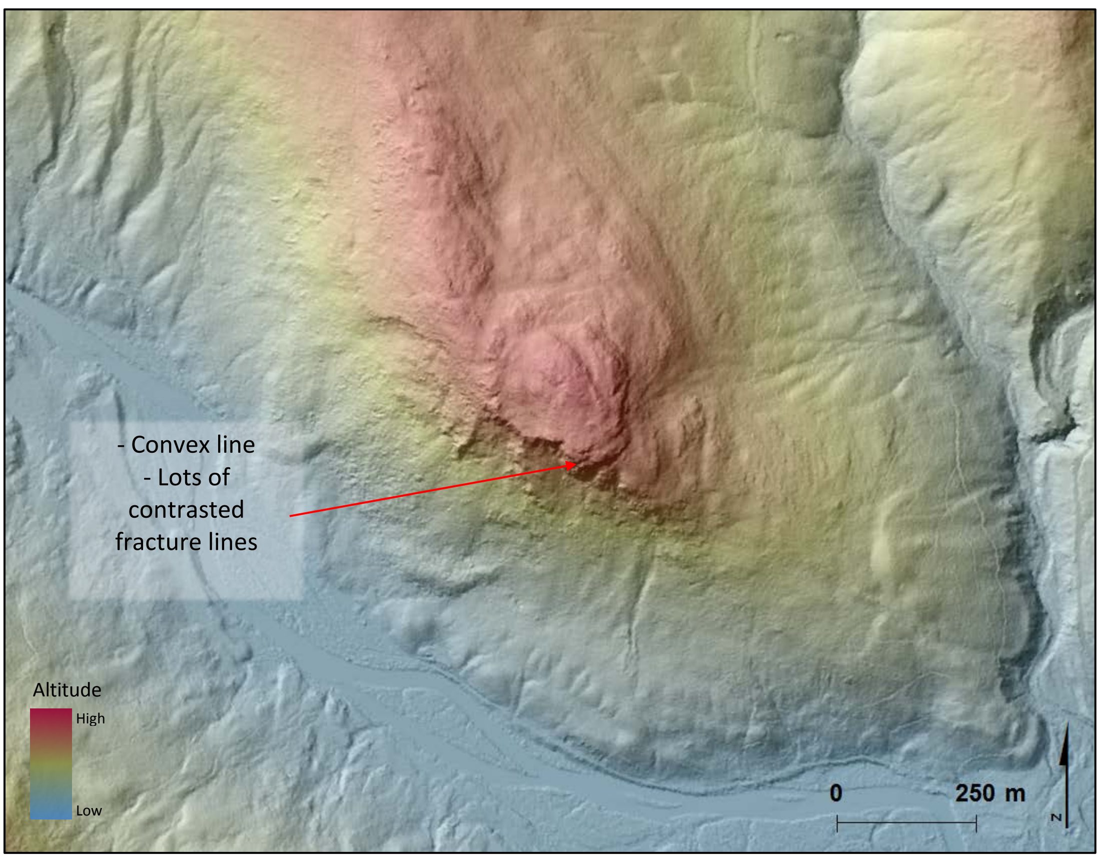


Figure 5. Example of very thin till (R1a), on LiDAR, in the Eastern Balsam Fir- White Birch ecozone


Figure 6. Example of very thin till (R1a), on an aerial photograph, in the Eastern Balsam Fir- White Birch ecozone

## Glacial block field (1ab)

- LiDAR indicators

a) It is very difficult to identify glacial block fields using LiDAR (Figure 7). Aerial photographs are the best tools for this.

- Aerial photograph indicators

a) The area's relief is fairly flat, similar to the large undulating till plains.
b) Deposits of this type usually cover areas ranging from several hundred square metres to a few hectares and are often irregular in shape.
c) The sector is covered by a high concentration of unstructured stones and boulders (Figures 8 and 9).

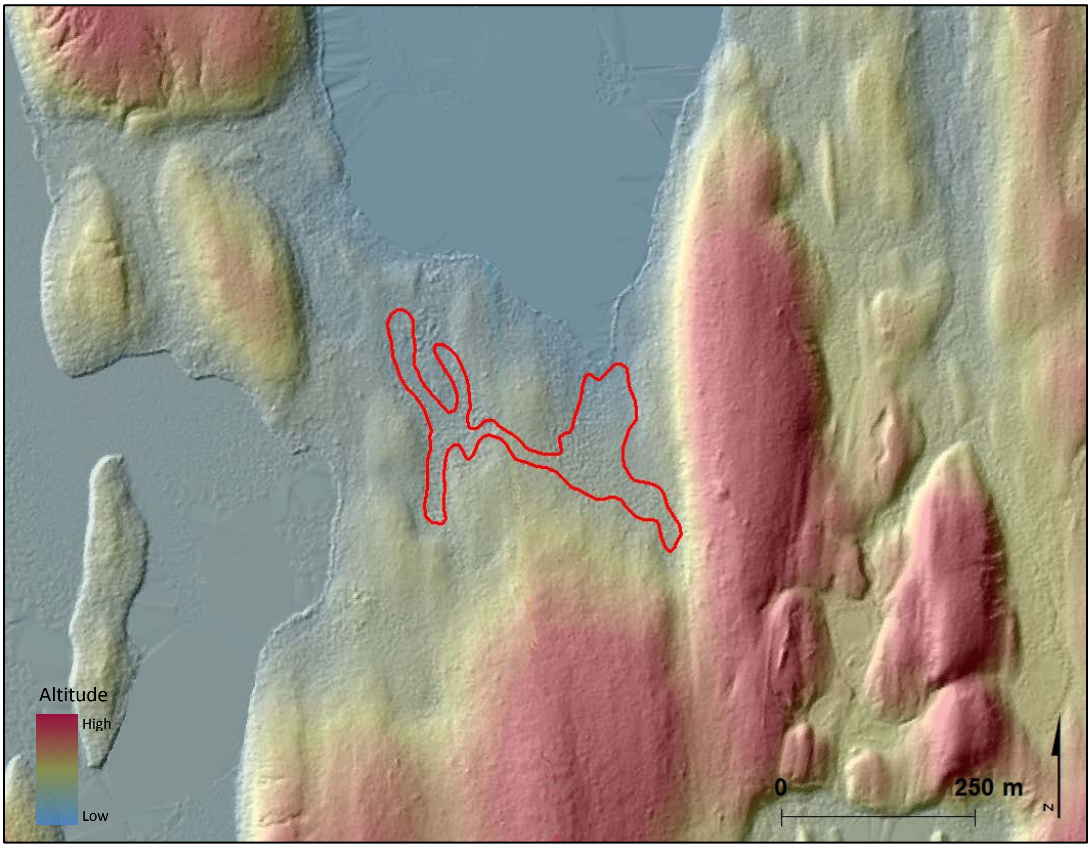


Figure 7. Example of a glacial block field (1ab), on LiDAR, in the Western Spruce-Moss ecozone

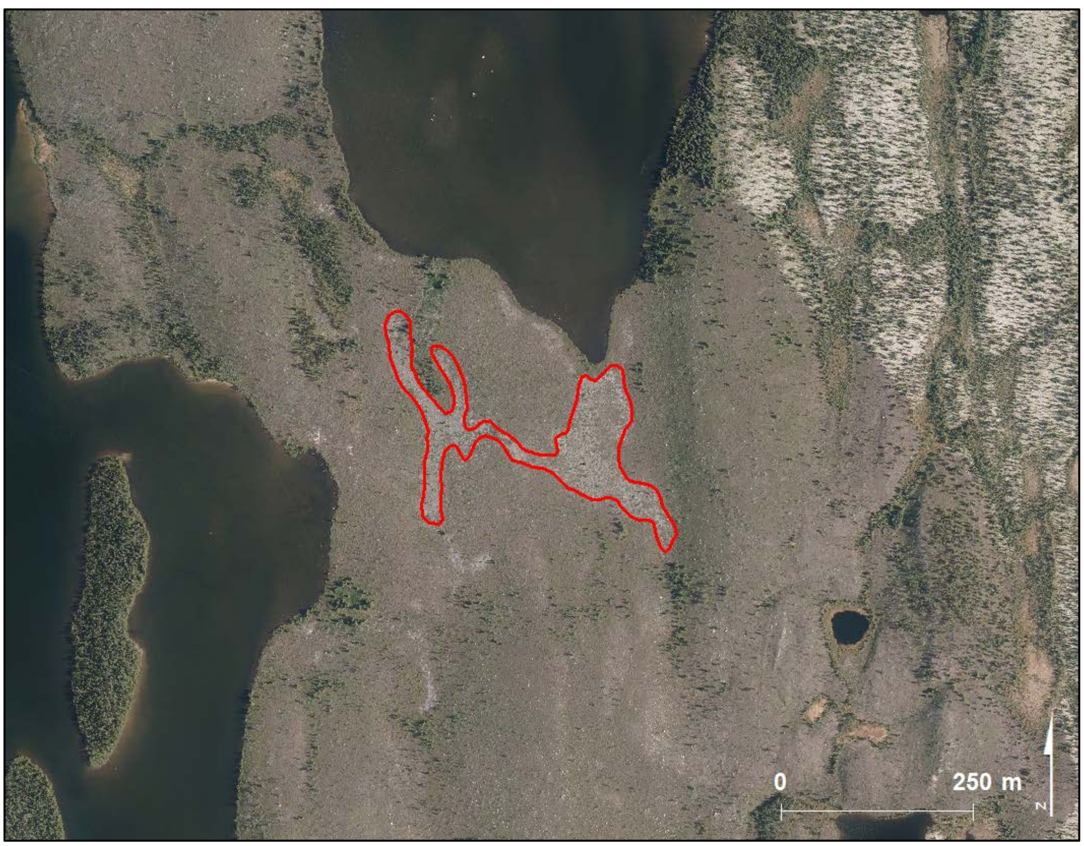


Figure 8. Example of a glacial block field (1ab), on an aerial photograph, in the Western Spruce-Moss ecozone

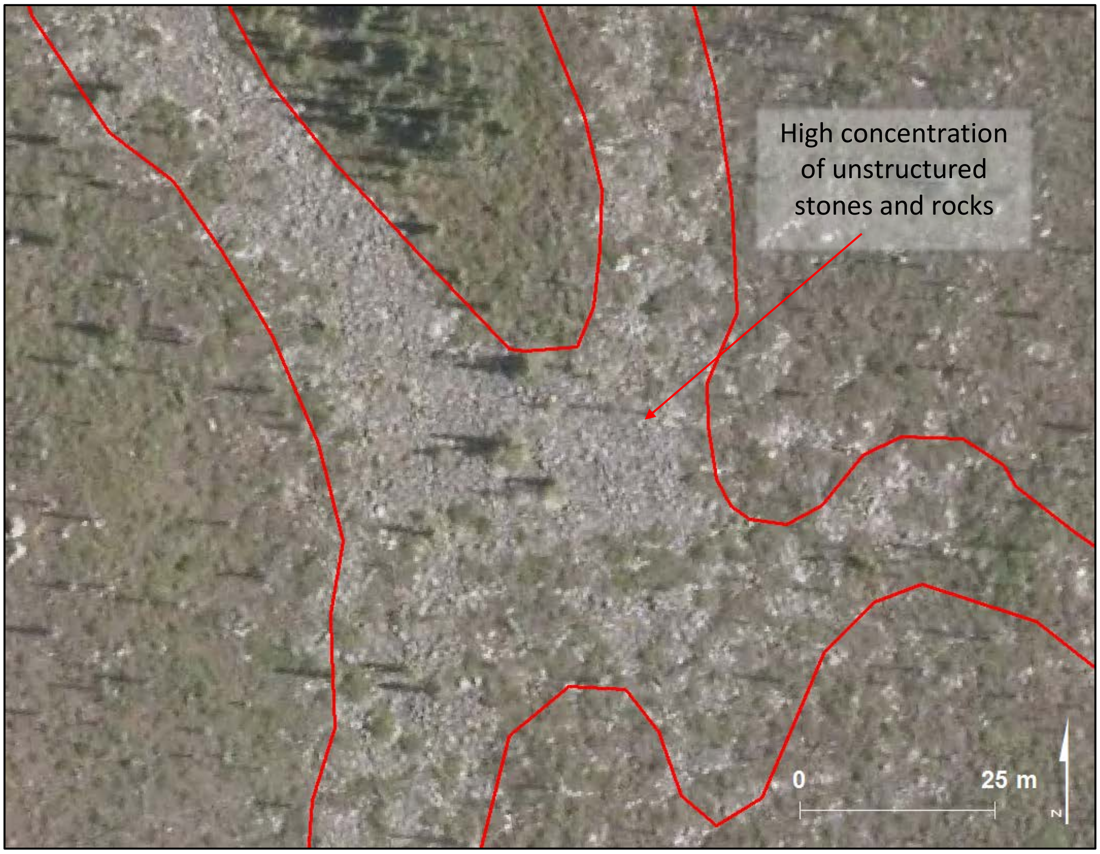


Figure 9. Example of a glacial block field (1ab), on an aerial photograph, in the Western Spruce-Moss ecozone

## Drumlins, drumlinoids (1bd) and till mounds (1bt)

- LiDAR indicators

a) Drumlins, drumlinoids and till mounds are usually located in areas where the topography is fairly flat (e.g. undulating till plains). These sectors are often very thick (Figures 10, 11 and 12).
b) They are typically half-oval or whale-backed in shape, with a main axis running parallel to the ice flow. They can range from a few metres to several dozen metres in height (Figures 10 and 12).
c) They may occur individually, but are usually found in groups (drumlin field).
d) Drumlins are often separated by small strips of organic deposits. This also applies to till mounds.
e) Their surface is not very stony.
f) In the case of till mounds, it is possible to see the rock core around which the drumlin-like mound formed (Figures 13 and 14).

- Aerial photograph indicators

Indicators shown on LiDAR can also be visible on aerial photographs if not hidden by vegetation.

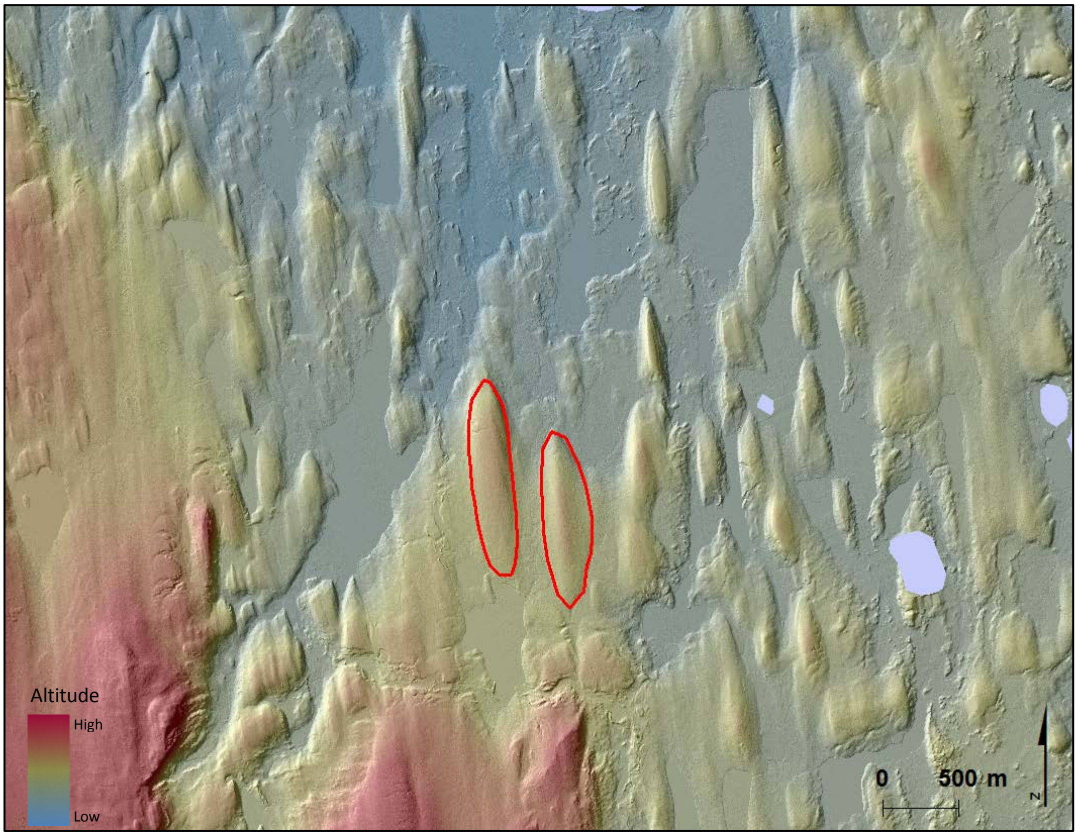


Figure 10. Example of drumlin fields (1bd), on LiDAR, in the Western Spruce-Moss ecozone


Figure 11. Example of drumlin fields (1bd), on an aerial photograph, in the Western Spruce-Moss ecozone

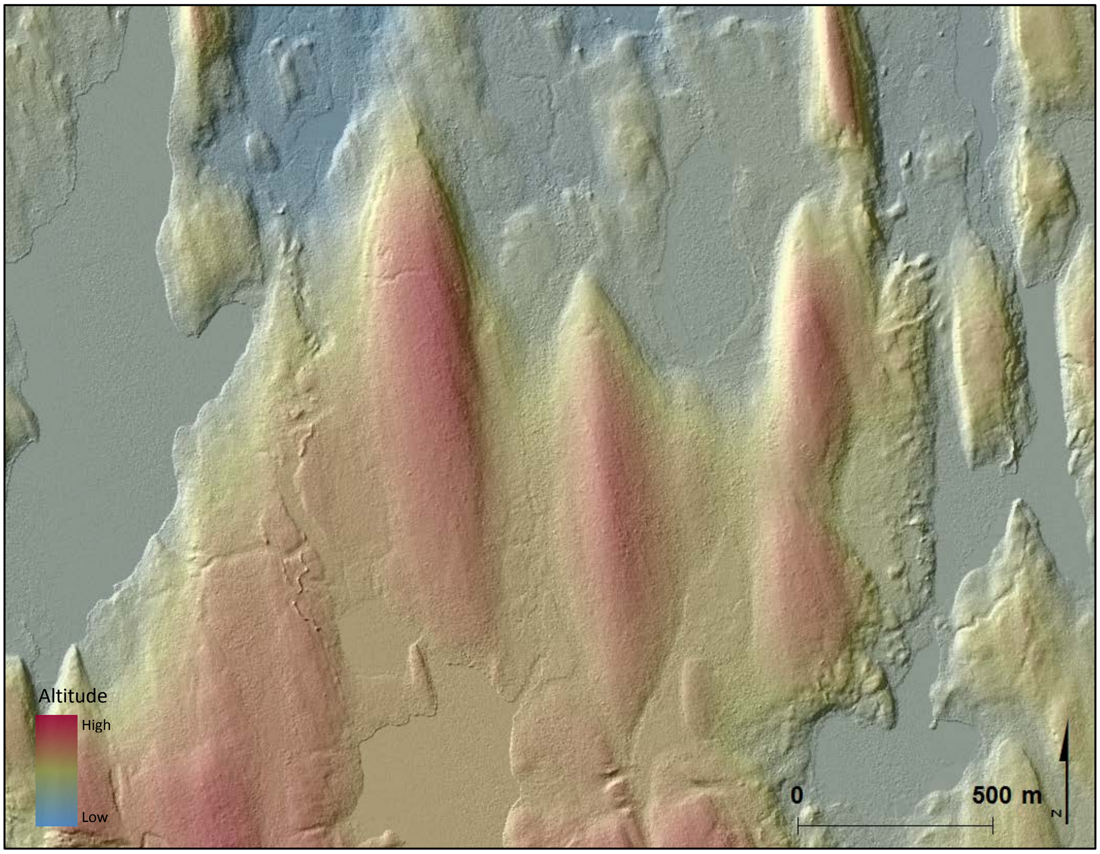


Figure 12. Example of drumlins (1bd), on LiDAR, in the Western Spruce-Moss ecozone

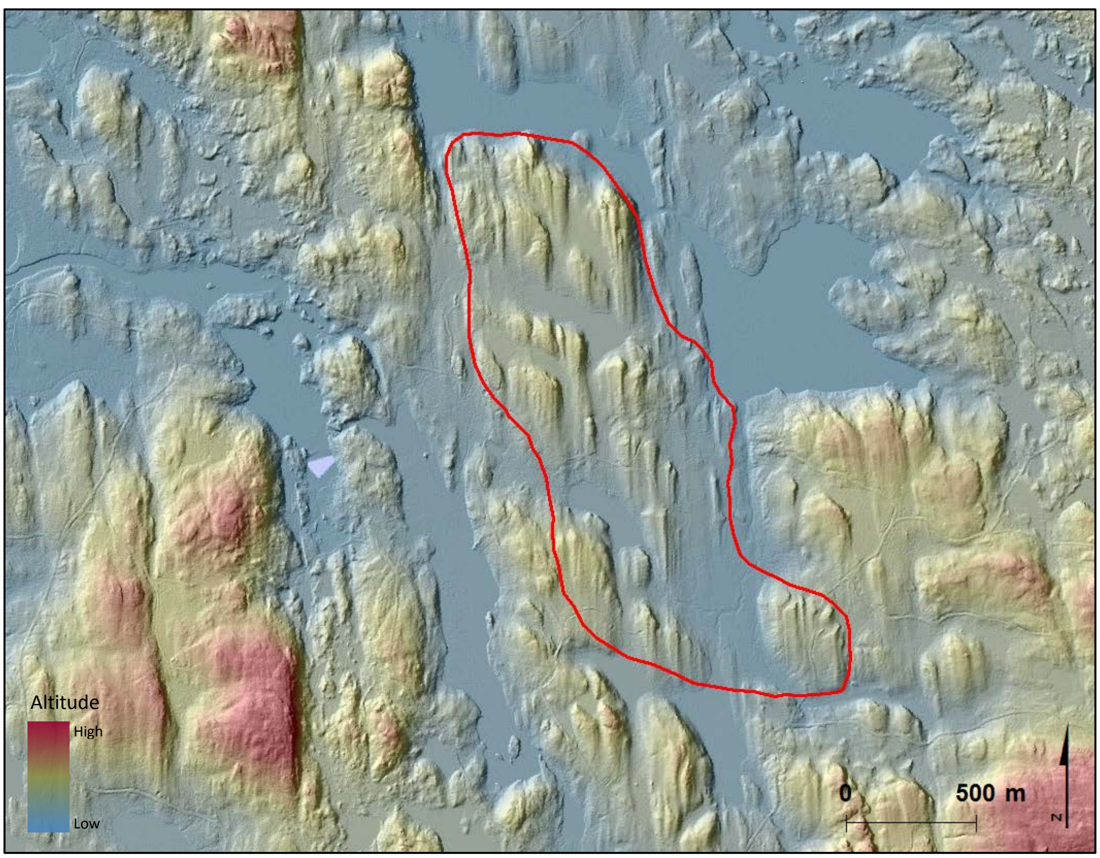


Figure 13. Example of till mounds (1bt), on LiDAR, in the Western Balsam Fir-White Birch ecozone

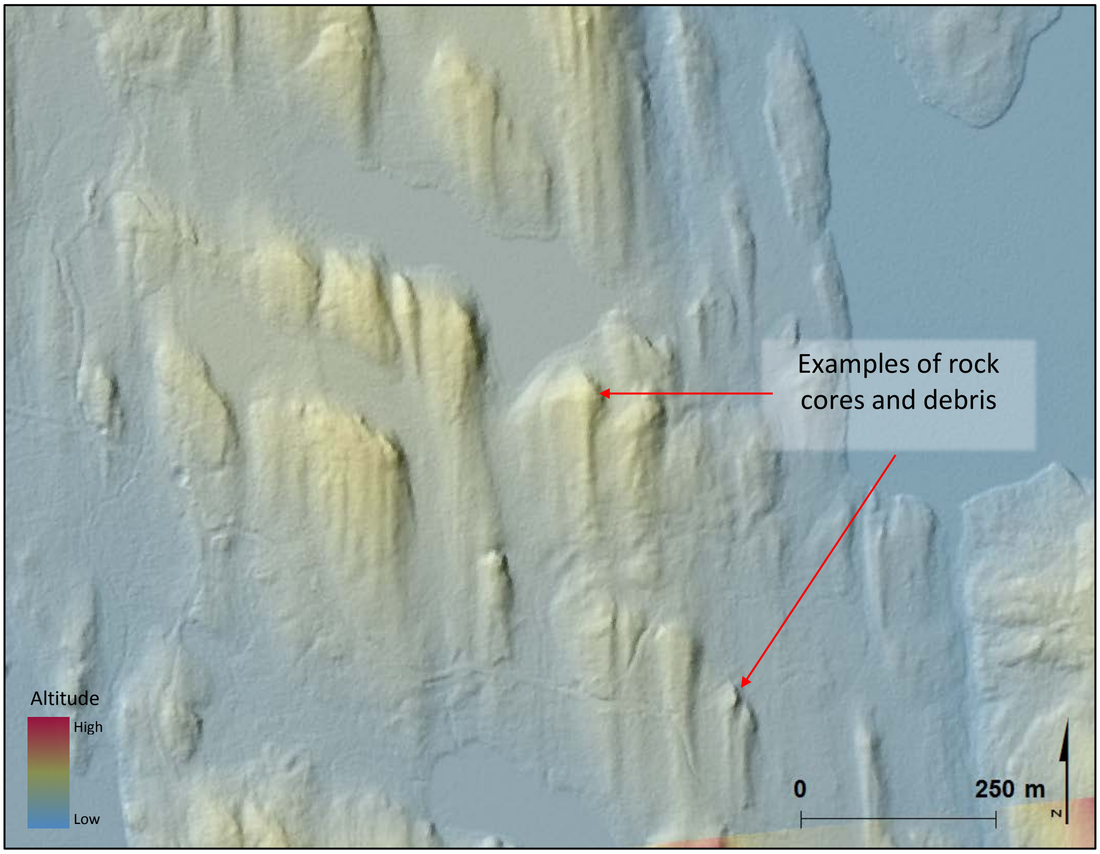


Figure 14. Example of till mounds (1bt), on LiDAR, in the Western Balsam Fir-White Birch ecozone

## Dead-ice moraine (1bp)

- LiDAR indicators

a) Dead-ice moraine forms in valleys and plains.
b) It is located at the bottom of till slopes, often on the margins of glaciofluvial systems (Figure 15).
c) It comprises a set of ridges and mounds with no specific orientation. The mounds are usually narrow and may be several metres high (Figures 15 and 16).
d) It is important not to confuse dead-ice moraine with ice-contact deposits (2a). Ice-contact deposits are longer or more flared than dead-ice moraine, which is sharper. Dead-ice moraine also occurs higher up a hillside than most ice-contact deposits.
e) The relief texture is very rough due to the large number of mounds and their narrow profiles (Figure 16).

- Aerial photograph indicators

a) Some LiDAR indicators may also be visible on aerial photographs.
b) Tree vegetation is less dense and the trees themselves are not as tall as on outwash plains or on the till surrounding the dead-ice moraine.
c) In boreal forest areas, there may be more lichens and/or heath, as well as more pine and/or spruce, than on outwash plains or surrounding till.

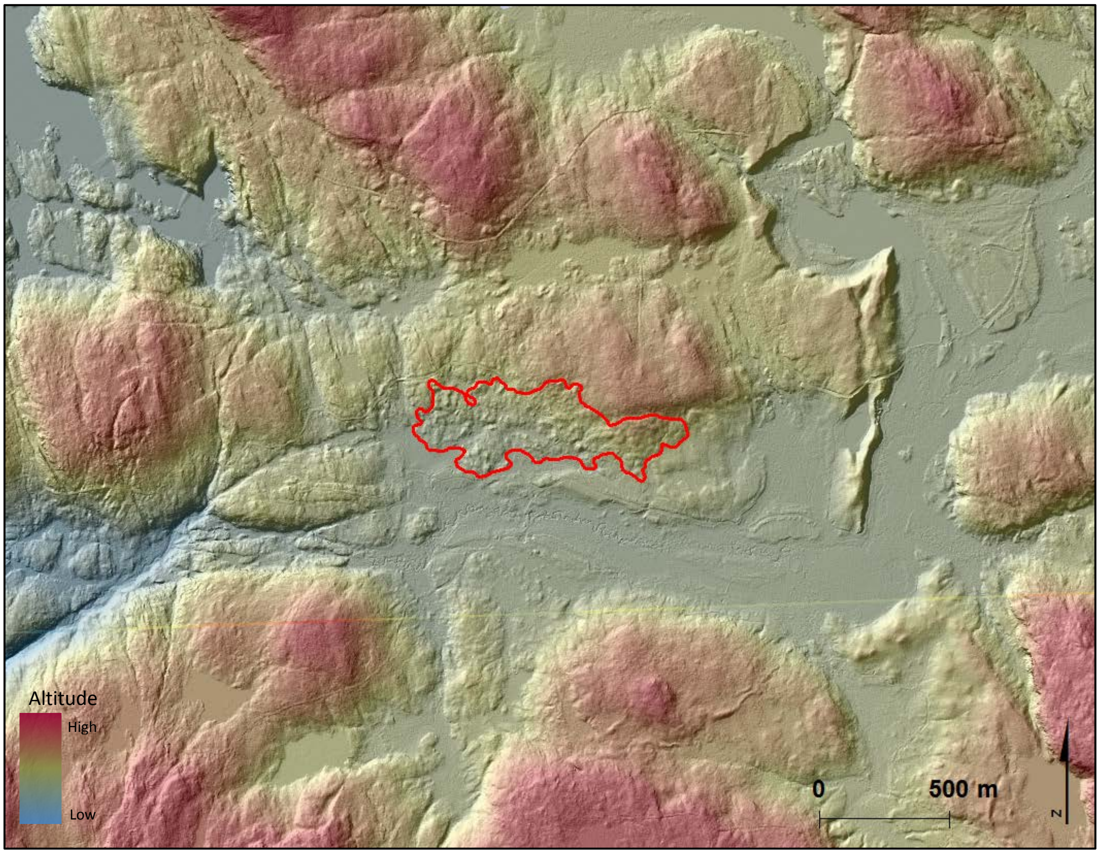


Figure 15. Example of dead-ice moraine (1bp), on LiDAR, in the Western Sugar Maple-Yellow Birch ecozone

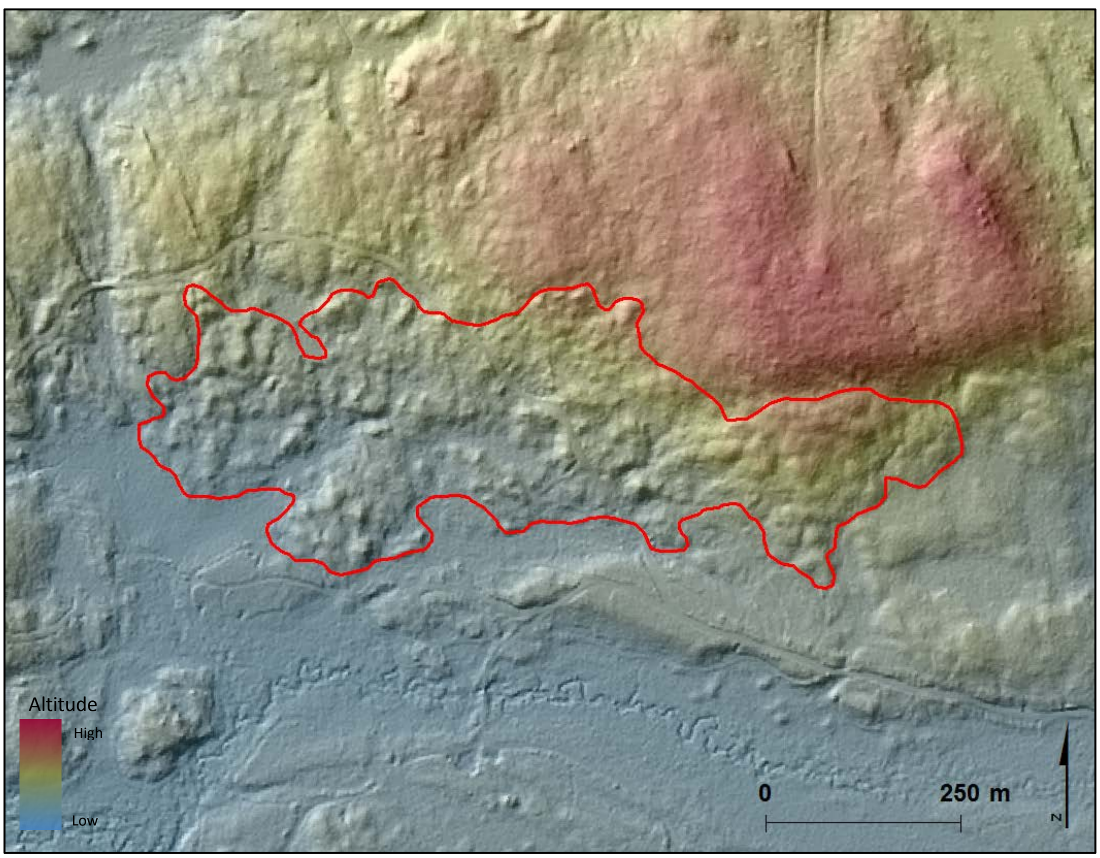


Figure 16. Example of dead-ice moraine (1bp), n LiDAR, in the Western Sugar Maple-Yellow Birch ecozone

## Ribbed moraine or Rogen moraine (1bc)

- LiDAR indicators

a) Ribbed moraine usually occurs in areas with fairly flat topography, such as undulating till plains, or in sectors with generally thick deposits (Figure 17).
b) It is composed of parallel ridges that formed at the glacier snout. The ridges may be up to a dozen metres in height.
c) It is always composed of groups of several moraine structures.
d) The ridges are often sectioned lengthwise, separated from one another by small strips of organic deposits or ponds.
e) Ribbed moraine is commonly found near drumlins. In these cases, the ribbed moraines usually occupy the lower portions of land, while the drumlins occupy the higher portions.
f) Their presence is often manifested in the form of sawtooth lakeshores.

- Aerial photograph indicators

a) Some LiDAR indicators may also be visible on aerial photographs (Figure 18).
b) Ridge surfaces are very stony.

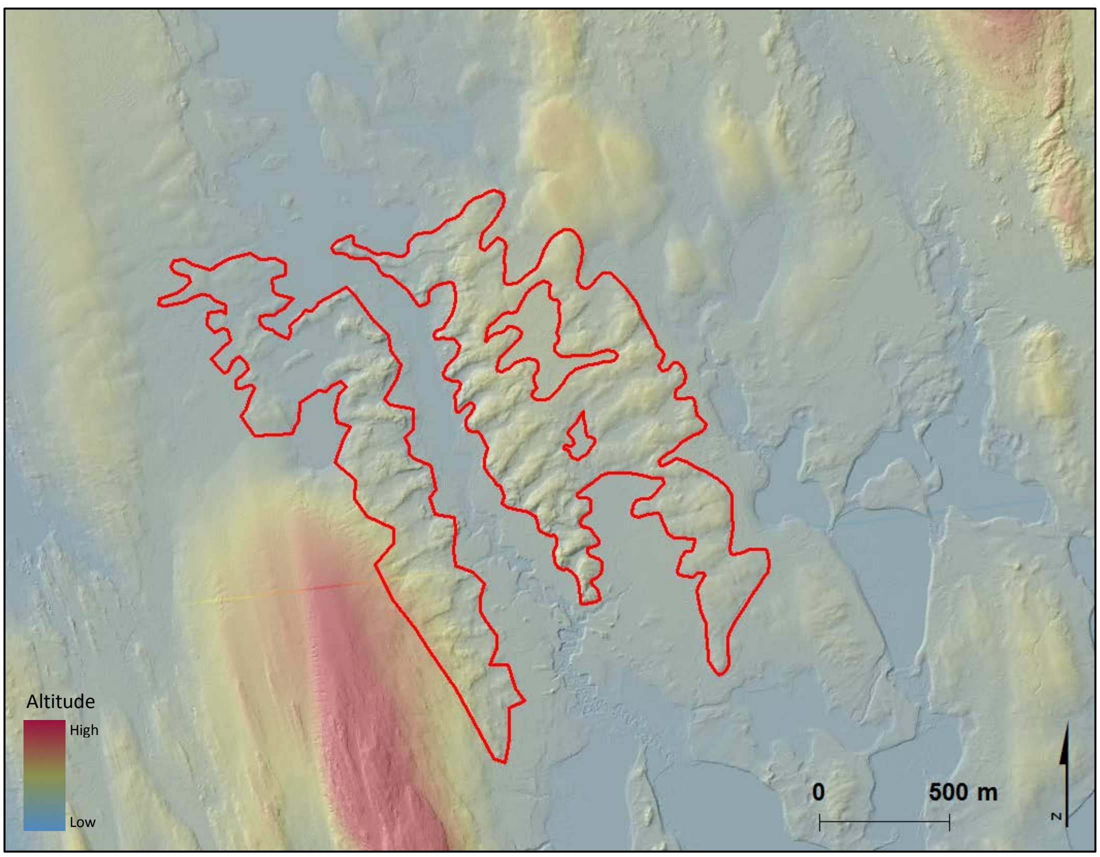


Figure 17. Example of ribbed moraine (1bc), on LiDAR, in the Western Spruce-Moss ecozone

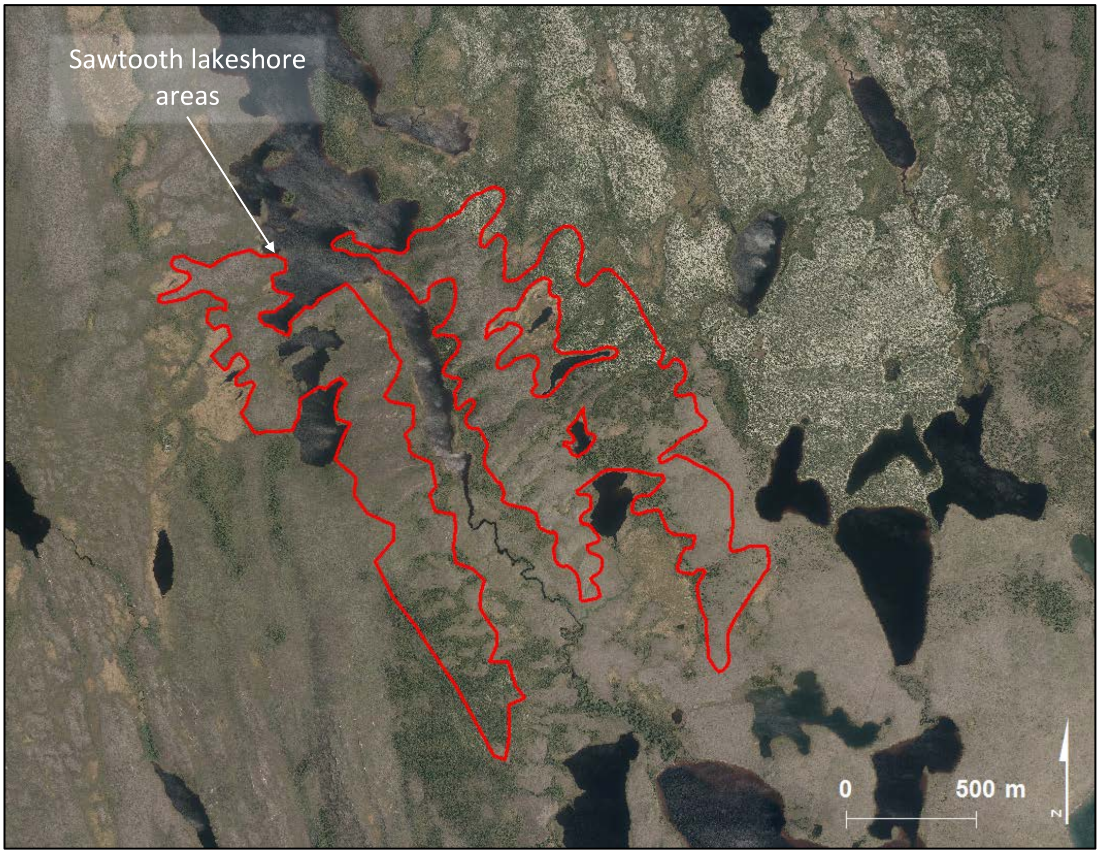


Figure 18. Example of ribbed moraine (1bc), on an aerial photograph, in the Western Spruce-Moss ecozone

## De Geer moraine (1bg)

- LiDAR indicators

a) De Geer forms in areas formerly covered by glacial seas and preglacial lakes.
b) It is composed of groups of narrow ridges measuring between anywhere from 1 to 5 metres wide and several dozen metres long. The ridges are rarely more than two metres high (Figure 19).
c) The ridges always occur in groups and lie parallel to the glacial front.

- Aerial photograph indicators

a) Some LiDAR indicators may also be visible on aerial photographs.
b) Tree vegetation is sparser and less dense, and the trees themselves are not as tall as other nearby vegetation in the outwash plain or on till.
c) In boreal forest areas, there may be a lot of lichen and/or heath plants on the ridges (Figure 20).
d) The ground is very stony.

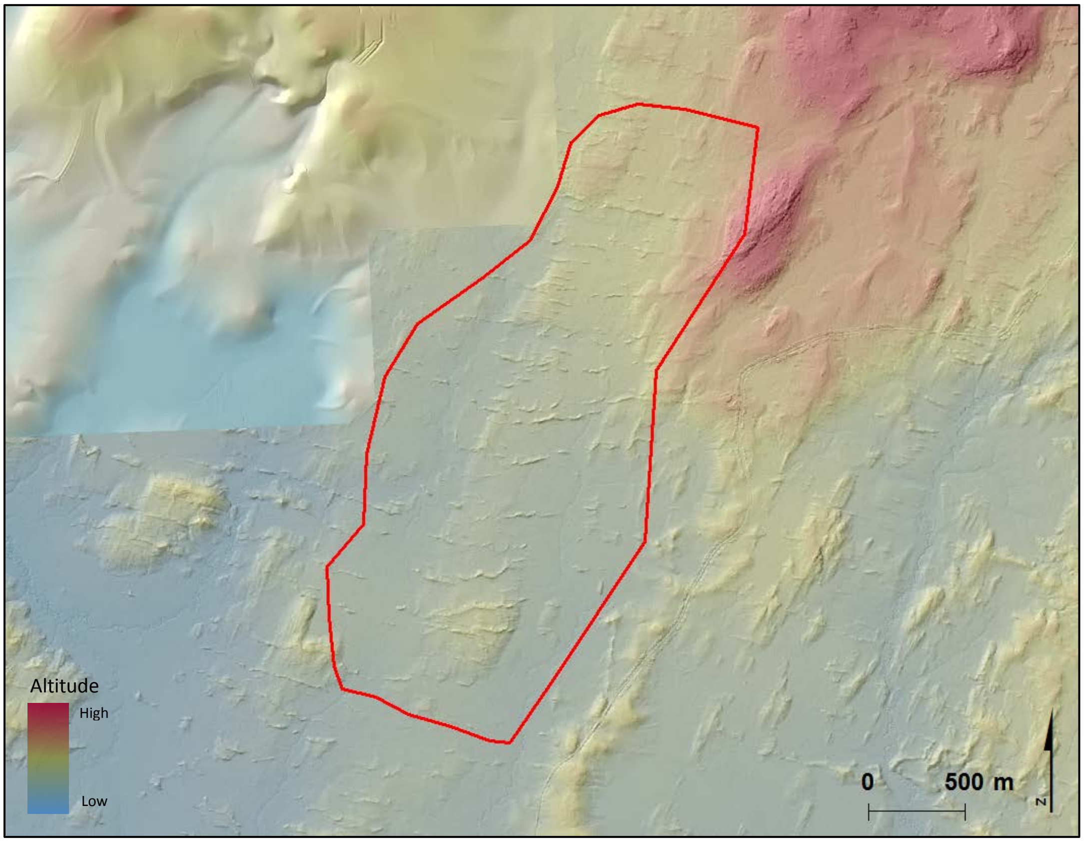

Figure 19. Example of De Geer moraine (1bg), on LiDAR, in the Western Spruce-Moss ecozone

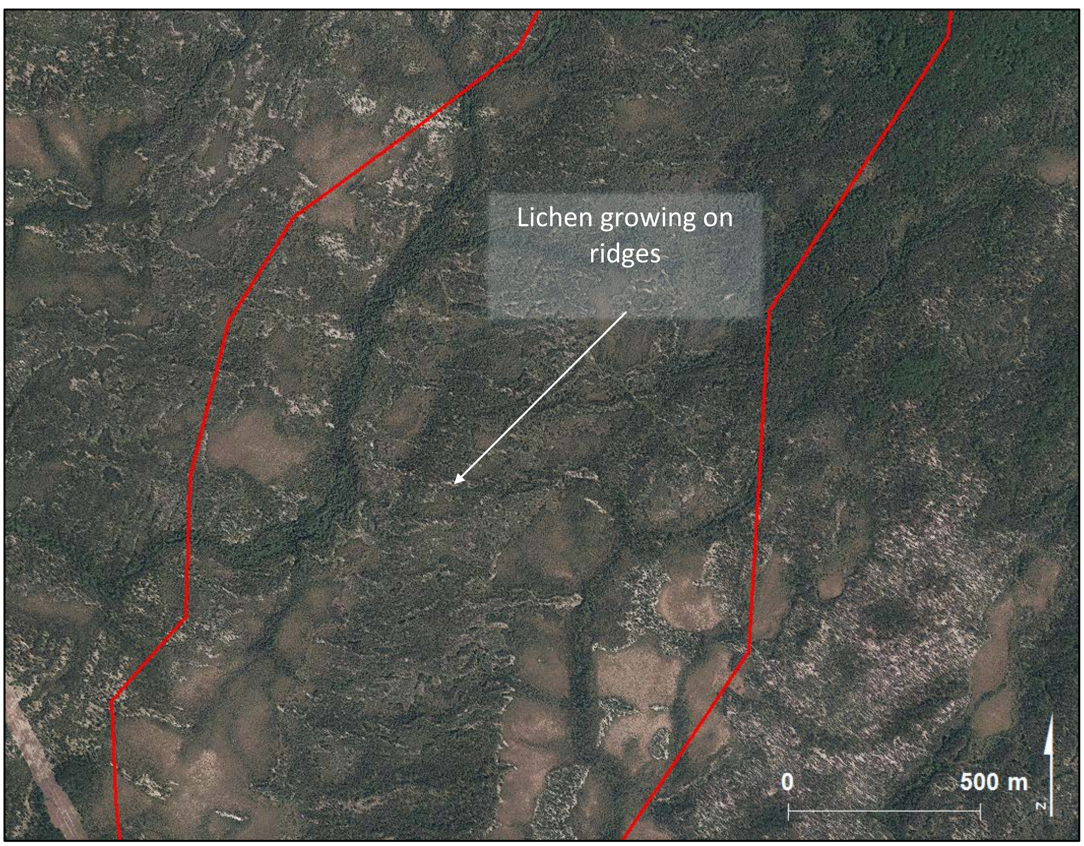

Figure 20. Example of De Geer moraine (1bg), on an aerial photograph, in the Western Spruce-Moss ecozone

## Frontal moraine (1bf)

First of all, it is important to review existing maps and studies, since most moraine fronts have been identified.

- LiDAR indicators

a) Frontal moraine is a ridge that looks like a sinuous piece of string of varying widths. It is often broken up, and usually follows an East-West orientation, although some sections may be oriented differently.
b) It can be found in all topographical positions and is not associated with specific topographical positions like eskers.
c) A series of low, parallel ridges often occurs behind major glacial fronts. Their undulating appearance gives the land a wrinkled aspect (Figure 22).
d) The texture will appear to be smoother ahead of the moraine front (Figure 21).
e) The segments can range in length from several dozen metres to several dozen kilometres.
f) The ridges vary considerably in width, from a few dozen metres to several hundred metres.
g) Height can vary from several metres to several dozen metres.

- Aerial photograph indicators

Usually, only the main ridges are high enough to be detectable because the vegetation that grows on them is raised, highlighting their shape and orientation in the surrounding landscape.

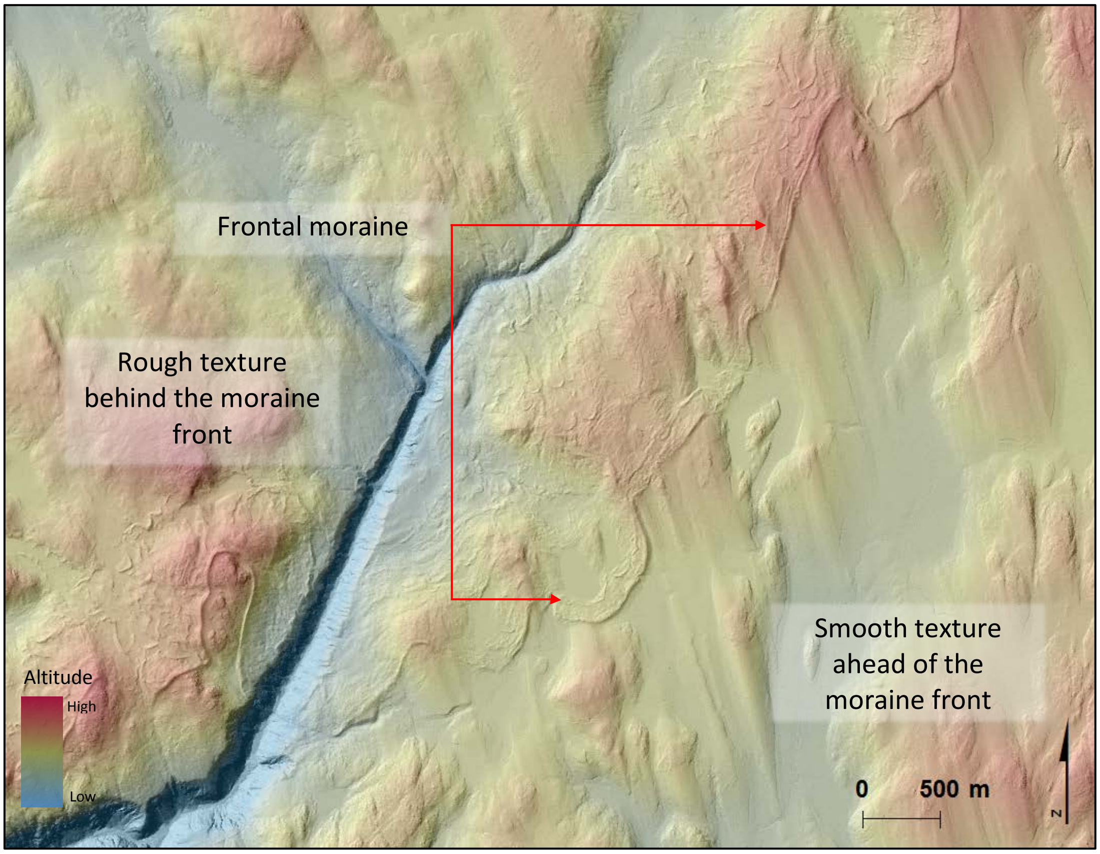


Figure 21. Example of frontal moraine (1bf), on LiDAR, in the Eastern Balsam Fir-White Birch ecozone

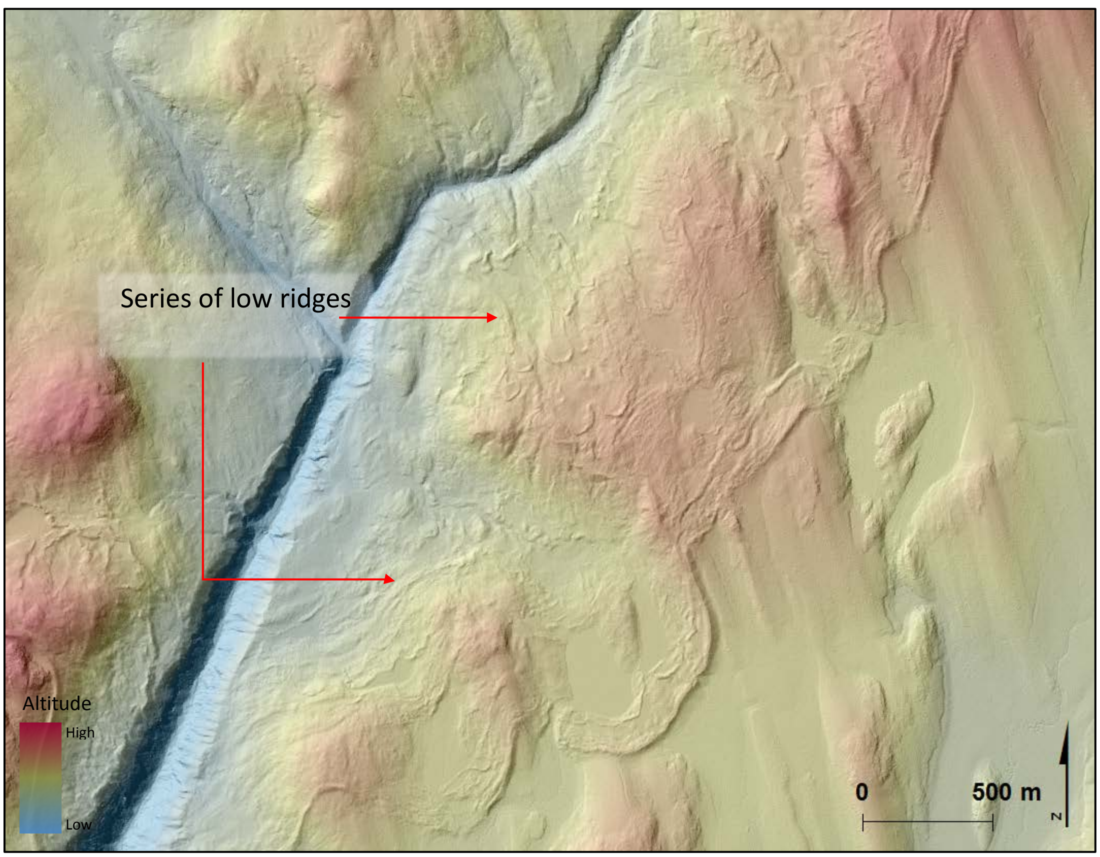


Figure 22. Example of frontal moraine (1bf), on LiDAR, in the Eastern Balsam Fir-White Birch ecozone

## 5. Borrow Pit Potential

Glacial deposits are not generally sought-after for borrow pits.

Some sections of frontal moraine (1bf) may offer moderate potential. In certain places, the moraine materials were reworked by ocean waves or transported by glacier meltwater. In these specific locations, the deposit is less heterogeneous, composed mainly of layered sand and gravel on a pebble bed (Brazeau, 1993). Frontal moraines that came into contact with invading seawater sometimes offer potential for gravel pits. However, the material tends to be located on the edges of the moraine, usually on the side opposite the glacial retreat or on the outwash plain in front of the moraine.

Ribbed moraine (1bc) also offers moderate potential. The ridges that make up ribbed moraine are composed of sandy till that may contain gravel and boulders, which in turn may enclose layers of sediments sorted by the action of water (MFFP, 2014). Screening may be needed and the presence of large boulders may be a limiting factor.

The sand and gravel extraction potential offered by the other glacial deposits ranges from zero to low. In some specific sectors, the undifferentiated till (1a – low potential) may be so sandy that it can be used for road construction purposes.

Dead-ice moraine (1bp – low potential) may have a suitable structure, but it usually contains a large number of large elements (stones, boulders) that make it difficult to extract commercially. However, the stony aspect of this moraine appears to diminish from north to south and it may, in certain cases, offer some potential.

# Glaciofluvial Deposits

Glaciofluvial deposits are composed of ice-contact deposits left behind by meltwater coming into contact with the glacier, and proglacial deposits transported and deposited at some distance from the ice margin. They comprise sand and gravel that may or may not be sorted. They offer good potential as an aggregate source.

## 1. Formation

Glaciofluvial deposits are left behind by glacial meltwater. Ice-contact deposits and proglacial deposits are distinguished by their proximity to the glacial front.

Ice-contact deposits are left behind by meltwater that comes into contact with retreating glaciers in a variety of natural, unstable environments (Robitaille and Allard, 2007). These deposits may have accumulated on, in, under or alongside the ice: for example, in glacier cavities or intra-glacial rivers. When the glacier melted, the sediment was deposited on the ground and formed certain characteristic morphologies.

Proglacial deposits were left behind by glacial meltwater and were deposited by watercourses at distances ranging from a few to many kilometres ahead of the glacier snout (MFFP, 2014).

## 2. Location

Ice-contact deposits and proglacial deposits are found in most regions of Québec, except for the St. Lawrence Lowlands, where they are rare (Brazeau, 1993). They are usually located at the bottoms of glacier valleys of varying widths with flanks.

## 3. Deposit Description

Ice-contact sediments are composed of sand, gravel, pebbles, stones and sometimes boulders that are rounded or subrounded in shape. The rocks that make up this type of sediment are not as rounded as those found in proglacial deposits, since they have usually not been transported by water (Benn and Evans, 2010). Their layers are often distorted and cracked. Particle size varies significantly between layers. They may be sorted (often less so than those found on outwash plains) and contain pockets of till (MFFP 2014, Tranhaile 2013, Brazeau, 1993).

Proglacial deposits are composed mainly of sand, gravel and rounded pebbles. This type of sediment is sorted and deposited in clear layers. In a glaciofluvial complex, particle size diminishes upstream to downstream (MFFP, 2014).

The Ministère des Forêts, de la Faune et des Parcs du Québec (MFFP) has identified four ice-contact deposits and three proglacial deposits (Table 5) (MFFP, 2014, Robitaille and Dionne, 2007).

Table 5. Ice-contact deposits and proglacial deposits and their mapped percentages in Southern Québec

| Ice-contact deposits | % | Proglacial deposits | % |
|---|---|---|---|
| 2a – Ice-contact deposit | 2,5 | 2bd – Glaciofluvial delta | 0,3 |
| 2ae – Esker | 0,2 | 2bp – Esker delta | <0,1 |
| 2ak – Kame | <0,1 | 2be – Outwash plain | 3,4 |
| 2at – Kame terrace | <0,1 | | |

Ice-contact deposits:

- Ice-contact deposits are left by meltwater that comes into contact with a withdrawing glacier. Their topography is often lumpy with scattered kettles.
- Eskers are formed in supra-, intra- or sub-glacial water, during glacial melt. They are shaped like long,

rectilinear or sinuous ridges, and may be continuous or broken. The esker core is often composed of coarse materials (gravel and pebbles), while the top and sides are composed mainly of sand layers (Brazeau, 1993).

- Kames are composed of sediments that accumulate in stagnant glacier depressions. Once the ice has melted, the kame looks like a steep-sided hill or mound. Kames vary in height.
- A kame terrace is composed of piles of sediments left behind by meltwater between the glacier and a valley flank. The residual topography has the appearance of a lumpy terrace attached to the flank, sometimes with scattered kettles and kames.

Proglacial deposits:

- A glaciofluvial delta is a deposit that forms at the downstream end of a glaciofluvial watercourse, at the junction with a lake or former sea. Its surface is often flat and it may sometimes be conical in shape when viewed from the air.
- An esker delta forms in a proglacial lake or sea, at the downstream end of an esker. Its surface is often flat, full of kettles and bordered by steep slopes (prodelta slope). Esker deltas are usually not shown on maps.
- An outwash plain is formed by meltwater from the glacier front and is deposited by glaciofluvial watercourses at distances varying from a few hundred metres to several dozen kilometres (MFFP, 2014). The particles that make up an outwash plain are sorted to a greater extent than the deposits left behind by the glacier itself (till) and its component rocks are more rounded in shape. These layered deposits are generally composed of sand and gravel beds, since the water flowed fast enough to transport finer particles (clay and loam) and deposit them in calmer water. Water speed, and hence sediment size, tended to diminish further away from the outwash plain head (Benn and Evans, 2010). The lithologic facies of glaciofluvial deposit composition may change abruptly as a result of seasonal or episodic changes in watercourse currents (MFFP, 2014; Tranhaile, 2013).

## 4. Identification Criteria

### Ice-contact deposits (2a)

- LiDAR indicators

a) Ice-contact deposits (2a) are often located in ice-walled glacier valleys of various widths (Figure 1).
b) They are generally found in the same environment as the outwash plain (2be).
c) They have a fairly flat surface with mounds that may be up to several metres high (Figure 23).
d) There will be one or more eskers or esker fragments near the deposits (Figure 23).
e) The site may be full of or dominated by kettles (Figure 23).

- Aerial photograph indicators

a) Some LiDAR indicators may also be visible on aerial photographs.
b) Tree vegetation is sparser, less dense and not as tall as other nearby vegetation on the outwash plain or till.
c) In boreal forest areas, there may be an abundance of lichens or heath plants and pine or black spruce trees.

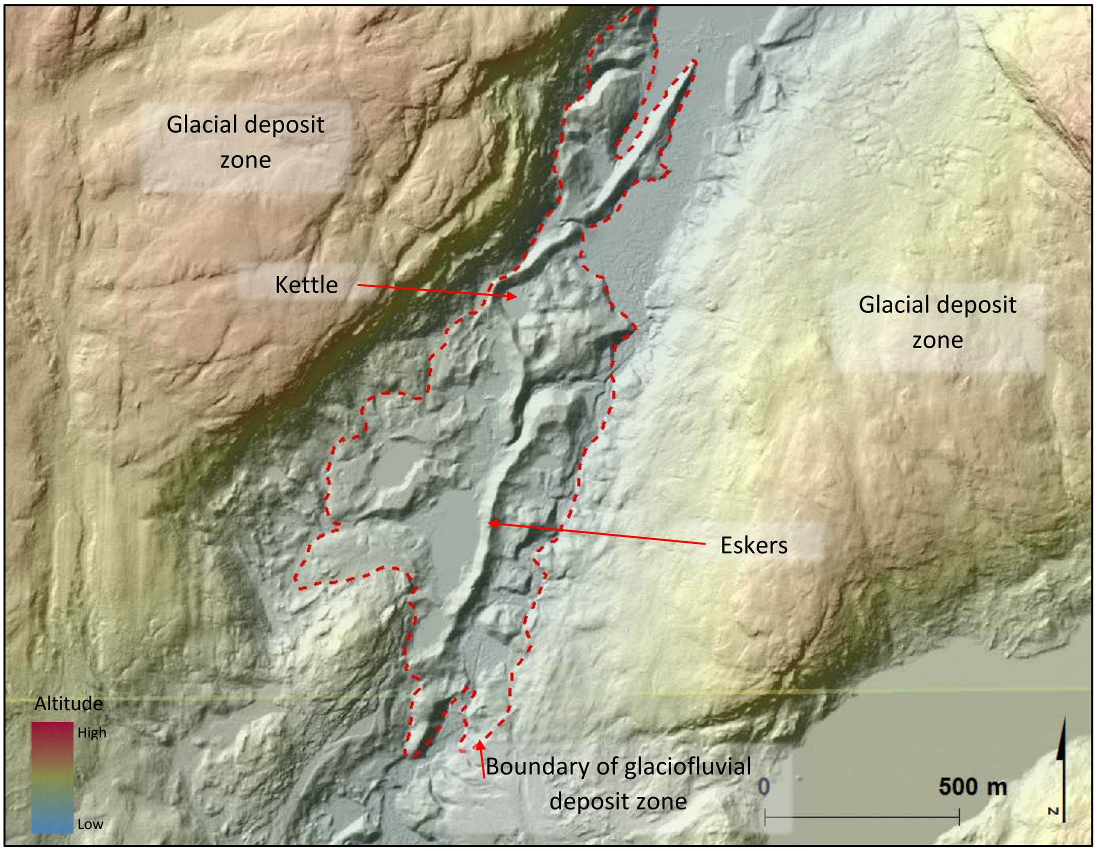


Figure 23. Example of ice-contact deposit (2a), on LiDAR, in the Eastern Spruce-Moss ecozone

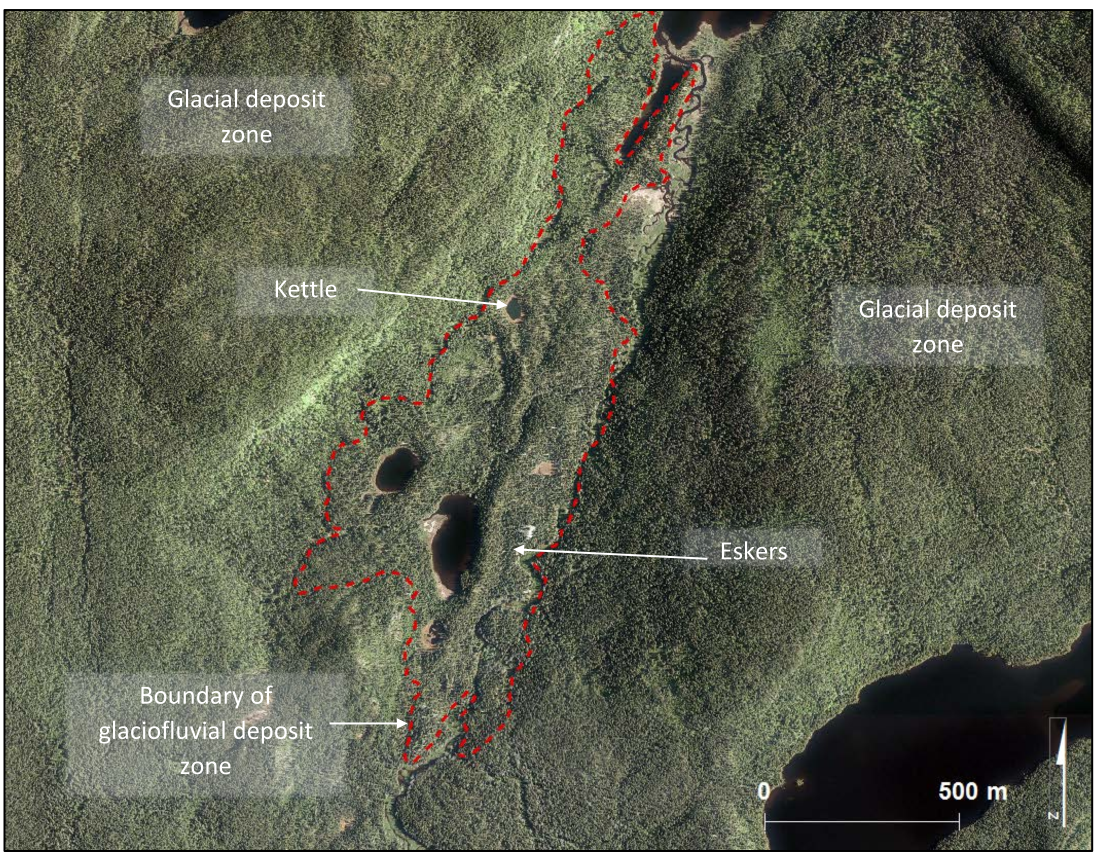


Figure 24. Example of ice-contact deposit (2a), on an aerial photograph, in the Eastern Spruce-Moss ecozone

## Eskers (2ae)

- LiDAR indicators

a) Most eskers formed in ice-walled glacial valleys of varying widths (Figure 25).
b) They are usually found in the same environment as outwash plains (2be).
c) They usually look like long rectilinear or sinuous ridges oriented in the same direction as the ice flow and somewhat perpendicularly to the glacier front (Figure 25) (Levasseur, 1995).
d) The size of an esker can vary from a few metres (2 to 3 metres) up to 30 metres. They rarely exceed 30 metres.
e) Their texture is smooth or slightly bumpy.
f) Eskers are often observed along with other ice-contact elements such as kettles (Millette, 2013).

- Aerial photograph indicators

a) Some LiDAR indicators may also be visible on aerial photographs.
b) Tree vegetation is sparser, less dense and not as tall as other nearby vegetation in the outwash plain or on till.
c) In boreal forest areas, there may be an abundance of lichens or heath plants and pine or black spruce trees.

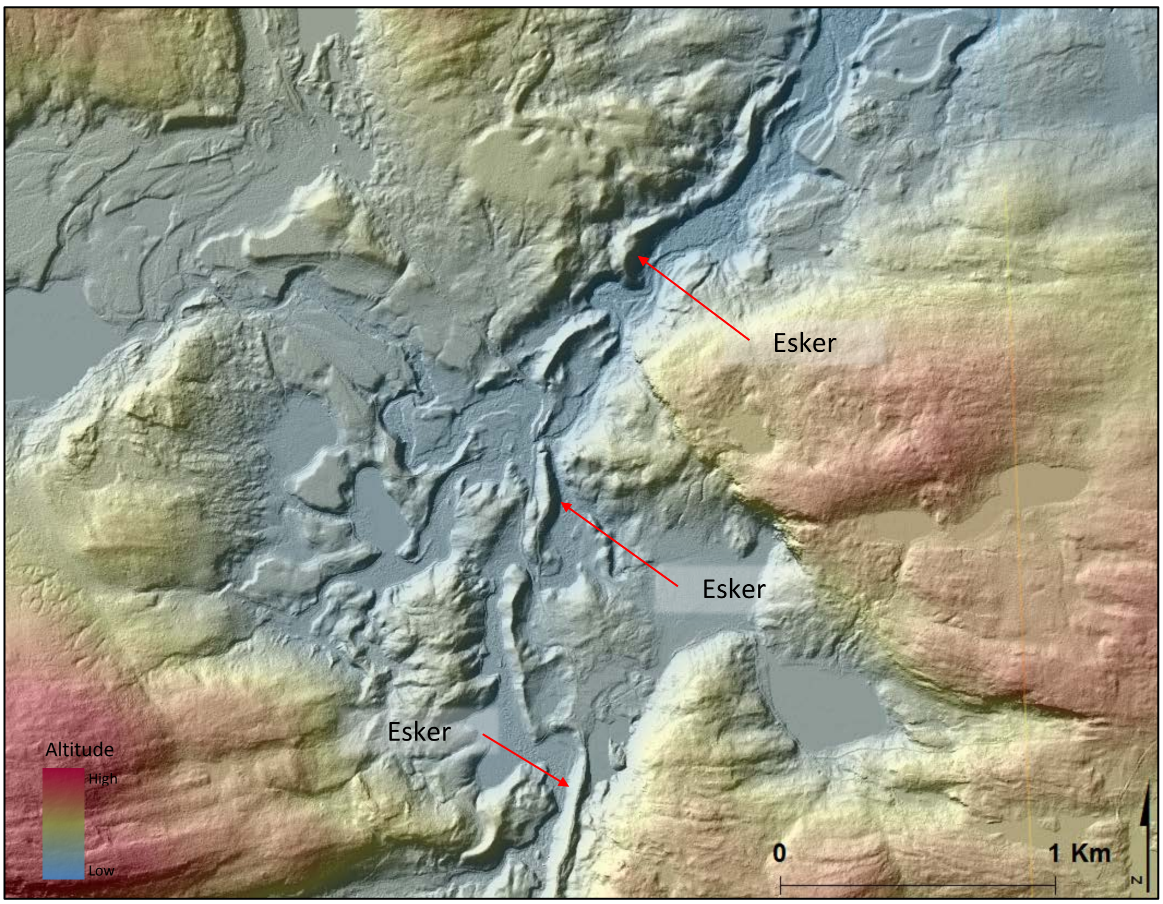

Figure 25. Example of eskers (2ae), on LiDAR, in the Western Sugar Maple-Yellow Birch ecozone

## Kames (2ak)

- LiDAR indicators

a) Kames are located in glacier valleys of varying widths, with flanks.
b) They are usually located in the same environment as the outwash plain (2be).
c) They look like steep-sided humps or mounds, and vary in height. They can be several dozen metres in diameter and height.
d) They are usually observed as isolated mounds or in small groups.
e) They are fairly rare and are difficult to identify on aerial photographs and LiDAR because they can be confused with shapes that originate in the rock bed.

## Kame terraces (2at)

- LiDAR indicators

a) Kame terraces formed in ice-walled glacier valleys of varying widths.
b) They are usually located in the same environment as the outwash plain (2be).
c) Their shape is plateau-like and fairly horizontal, and they are attached to the flanks of the slopes bordering the outwash plains (Figure 26).
d) Their surface is always significantly higher than that of the outwash plain; they can be up to 50 metres higher.

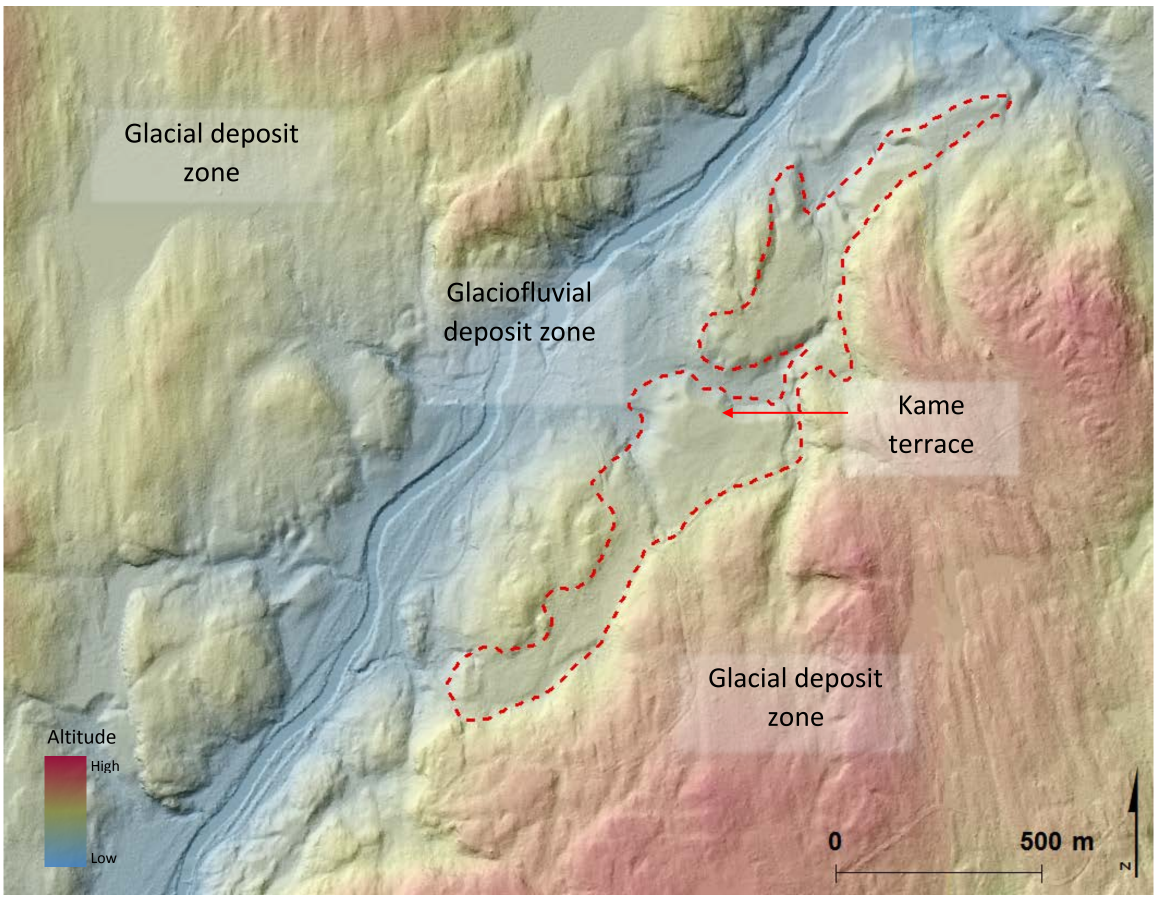

Figure 26. Example of kame terrace (2at), on LiDAR, in the Western Sugar Maple-White Birch forest

- Aerial photograph indicators

a) Some LiDAR indicators may also be visible on aerial photographs.
b) Tree vegetation is sparser, less dense and not as tall as other nearby vegetation in the outwash plain or on till.
c) In boreal forest areas, there may be a lot of lichens or heath plants, and pine or black spruce trees.

## Glaciofluvial delta (2bd)

- LiDAR indicators

a) Glaciofluvial deltas are often located at the intersection of an existing or former watercourse and a valley, lake or ancient sea (Figure 27).
b) Glaciofluvial deltas have table-like surfaces and can be up to 50 metres high.
c) The surface is often broken up by channels formed by glaciofluvial meltwater or existing watercourses (Figure 28) (Millette, 2013).

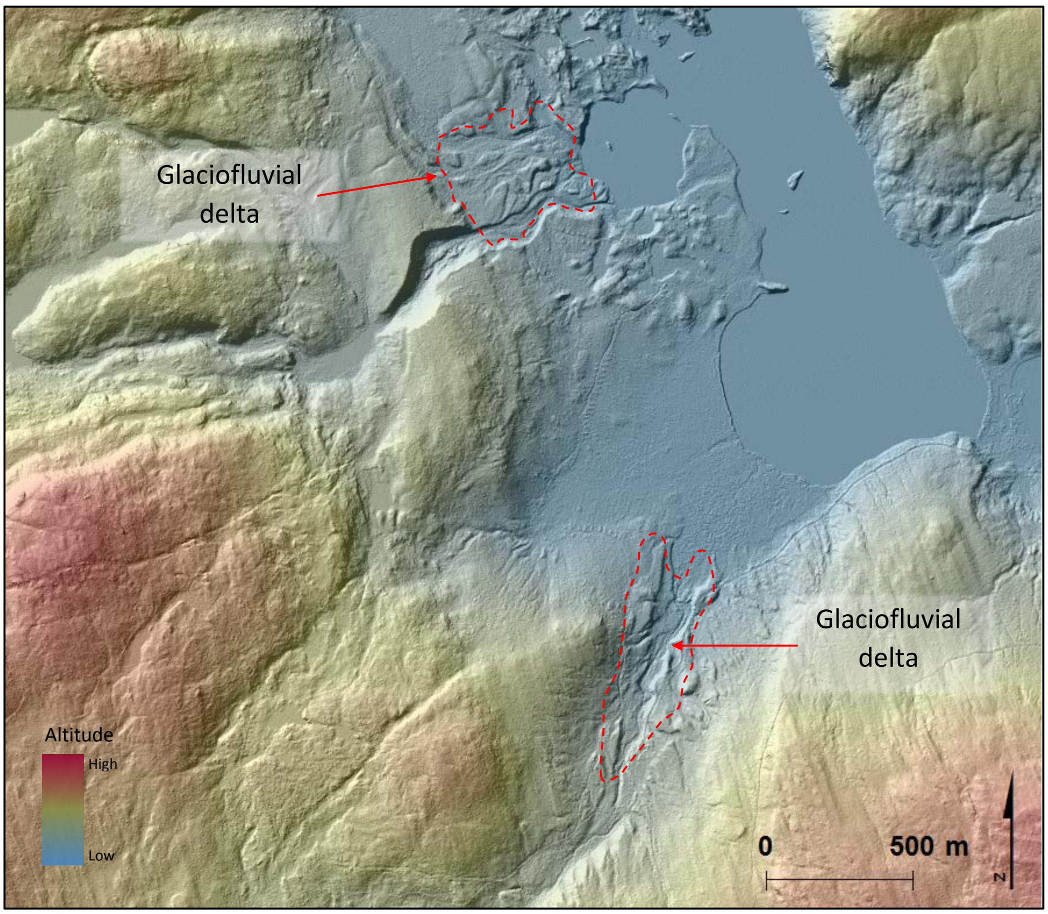

Figure 27. Example of glaciofluvial deltas (2db), on LiDAR, in the Western Sugar Maple-Yellow Birch ecozone

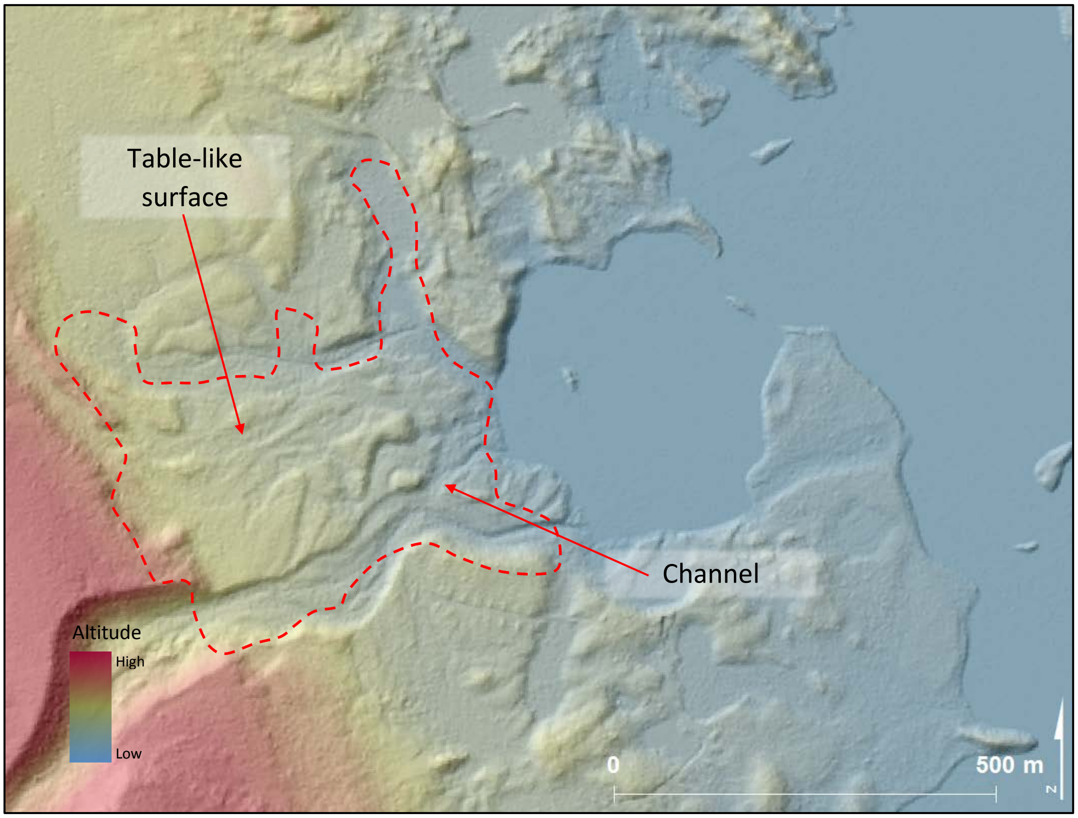


Figure 28. Example of the table-like surface and channels on a glaciofluvial delta (2db), on LiDAR, in the Western Sugar Maple-Yellow Birch ecozone


Figure 29. Example of the table-like surface and channels on a glaciofluvial delta (2db), on an aerial photograph, in the Western Sugar Maple-Yellow Birch ecozone

## Outwash plain

- LiDAR indicators

a) Outwash plains usually formed in ice-walled glacier valleys of varying widths.
b) The surface of an outwash plain is flat, uniform and smooth in texture (Figure 30).
c) It may be dissected by a meandering watercourse or former spillway (Figure 31).
d) Glaciofluvial terraces may also be located along the banks of existing rivers. They are composed of residual outwash, broken up by erosion (MFFP, 2014).

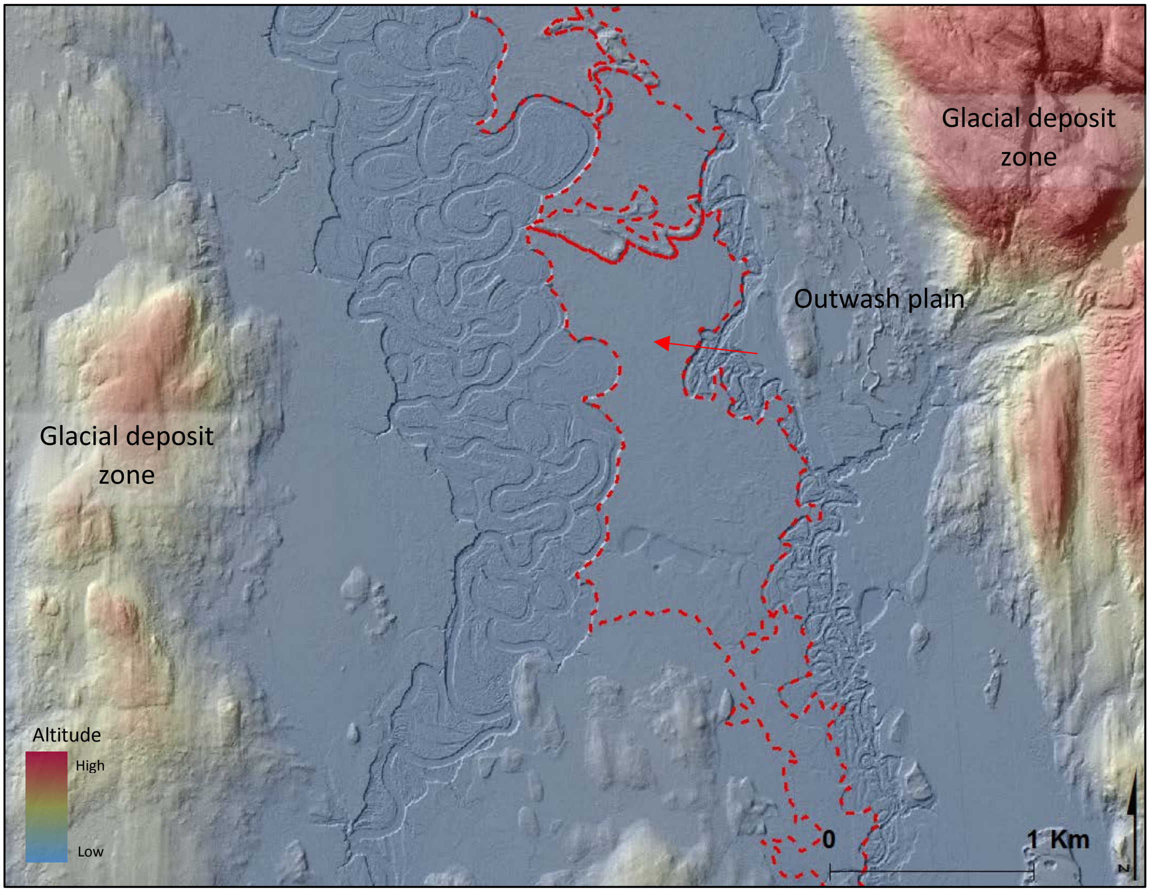

Figure 30. Example of outwash plain (2be), on LiDAR, in the Eastern Spruce-Moss ecozone

- Aerial photograph indicators

a) Some LiDAR indicators may also be visible on aerial photographs.
b) Tree vegetation is sparser, less dense and not as tall as other nearby vegetation on the till (Figure 31).
c) In boreal forest areas, there may be an abundance of lichens or heath plants, and pine or black spruce trees.

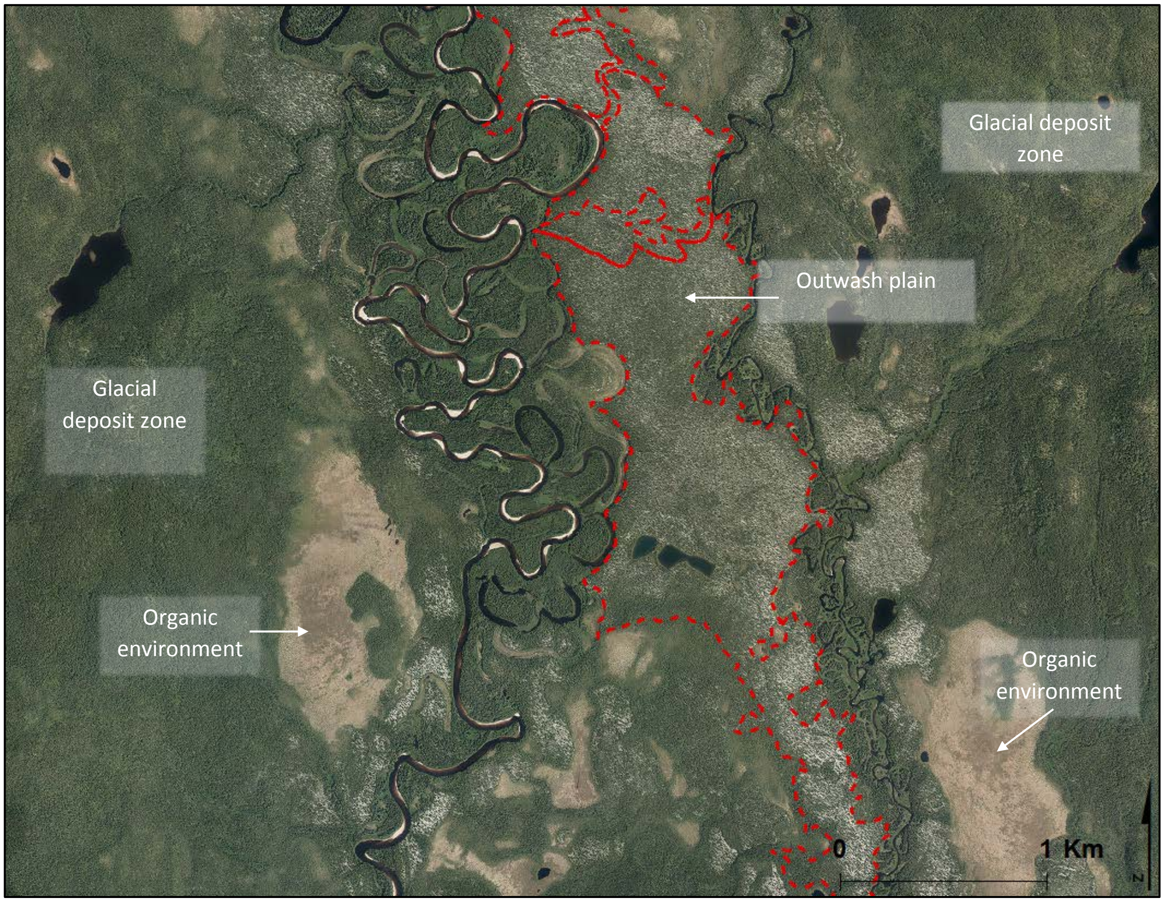


Figure 31. Example of outwash plain (2be), on an aerial photograph, in the Eastern Spruce-Moss ecozone.

## 5. Borrow Pit Potential

It is generally agreed that glaciofluvial deposits are very good sources of gravel and sand with different particle sizes (Brazeau, 1993, 2011; Chiverrell et *al.*, 2008; Cooper, 1984; Rioux, 1993; Smith *et al*., 2005). Particle size varies greatly, generally resulting in fairly high bearing capacity values and easy workability on site. Their permeability allows for easy and effective drainage.

Some deposits in this category, including eskers, kames and kame terraces, offer good potential for sand and gravel mining.

Ice-contact deposits (2a) also offer good potential, although excavation can be difficult due to the presence of large boulders. The fact of identifying this type of deposit does not necessarily mean that the materials will have the desired characteristics, since extensive variations are possible.

Other authors have suggested that indicators relating to existing vegetation and location may also help to identify borrow pits. Some (Chouinard, 1984; Johnsen *et al*., 2004; Kerr *et al*. 2005; Knepper *et al*. 1995; Smith *et al*., 2005) have found that the presence of xerophilic species or abrupt changes in vegetation (e.g. white birch or poplar in a softwood stand) may be indicators of the desired soil type. Chouinard (1984) lists other physical criteria for specific deposits:

Ice-contact deposits (2a)

- On the tops of mounds;
- Near kettles;
- Where vegetation density diminishes for no apparent reason;
- Near a lake inlet or at the intersection of a secondary watercourse and a lake.

Esker (2ae)

- Near parallel erosion indicators along the esker;
- At the dividing point of an esker;
- At the place at which an esker is split by perpendicular erosion (Demchuck, 2005);
- Where the top of the esker has been eroded, resulting in a flat summit;
- In the esker, near kettles;
- In the esker, between kettles or lakes;
- Where vegetation density diminishes for no apparent reason.

Kame terrace (2at)

- In a kame terrace, where fluvial erosion cuts through the terrace deposits.

Proglacial deposits offer moderate to very high potential. Glaciofluvial deltas (2bd) have the best (very high) potential for aggregates. They are composed mainly of sand and gravel, sorted and deposited in separate layers (MFFP, 2014). Outwash plains (2be) generally offer moderate potential and are usually less sought-after than ice-contact deposits. Proglacial deposits are composed mainly of moderate to coarse particle, well-layered sand with a portion of gravel. Particle size can vary laterally and vertically within a given deposit, but less so than in ice-contact materials (Brazeau, 1993; Rioux, 1984).

Other authors have suggested that indicators relating to existing vegetation and location may also help to identify borrow pits. Some (Chouinard, 1984; Johnsen *et al*., 2004; Kerr *et al*. 2005; Knepper *et al*. 1995; Smith *et al.*, 2005) have found that the presence of xerophilic species or abrupt changes in vegetation (e.g. white birch or poplar in a softwood stand) may be indicators of desired soil type. Chouinard (1984) lists other physical criteria for specific deposits:

Outwash plain (2be)

- At the junction of streams or braided channels (75 to 300 m);
- Near a kettle;
- At the start of the outwash;
- Where vegetation density diminishes for no apparent reason;
- At the intersection of a stream and kettle;
- At the point where the plain narrows due to the proximity of adjacent rock formations.

Glaciofluvial delta (2bd)

- In a glaciofluvial delta, at the point where a secondary watercourse flows into a lake;
- In forming deltas (sand build-up on lakeshores).

# Fluviatile Deposits

Fluviatile deposits were formed mainly along watercourses during flooding. They offer very little potential as a source of aggregates due to the environment in which they are located (close to watercourses and the water table).

## 1. Formation

Fluviatile deposits are divided into two groups: alluvial deposits and deltaic deposits.

Alluvial deposits form on land near watercourses (rivers, streams), and meanders are often still visible. The main cause is watercourse flooding as a result of heavy rain, meltwater or both (Gutiérrez, 2013). During these events, sediment is transported and deposited in flooded areas on either side of the watercourse, as the flow recedes.

The magnitude, frequency and duration of the overflow creates flood-risk areas at varying elevations and distances from the watercourse. These areas sometimes but not always align to form a series of flat terraces separated by talus slopes (Robitaille and Allard, 2007). The type of vegetation depends on the growth conditions and characteristics of each terrace (Hupp and Osterkamp, 1996).

Deltaic deposits are located at the mouth of a watercourse or at the nickpoint of a torrent. They come in a variety of shapes, but are often conical. They are almost never mapped.

## 2. Location

Fluviatile deposits are visible throughout Québec. They are commonly found in the valleys and plains associated with glaciofluvial, lacustrine and marine deposits. They are always adjacent to a watercourse.

## 3. Deposit Description

The particles that make up these deposits are clearly layered. They are composed of gravel and sand, along with a small percentage of silt, clay or organic matter (MFFP, 2014). Some authors (Gutiérrez, 2013; Trenhaile, 2013; Zwolinski, 1992) note that the material located close to the watercourse is more abundant and coarser, and that the finer sediment is transported further away.

The Ministère des Forêts, de la Faune et des Parcs du Québec has identified three types of alluvial fluviatile deposits (Table 6) (MFFP, 2014).

Table 6. Fluviatile deposits and their area as a percentage of Southern Québec

| Alluvial deposits | % | Deltaic deposits | % |
|---|---|---|---|
| 3ac – Present | <0.1 | 3dd – Delta | <0.1 |
| 3ae – Recent | 0.1 | 3da – Alluvial cone | <0.1 |
| 3an – Ancient | 0.7 | 3de – Cone of dejection | <0.1 |

Alluvial fluviatile deposits:

- Present fluviatile deposits form in the minor bed or lowflow channel of a watercourse (islets, banks). They are often smaller in size than recent and old fluviatile deposits.
- Recent fluviatile deposits form in the flood plains (high flow channel) of a watercourse during flooding.
- Ancient fluviatile deposits are old deposits left behind during entrenchment or displacement of the bed of the watercourse of which they were a part (non-floodable high-level terraces).

Deltaic fluviatile deposits:

- Deltas form at the mouths of existing watercourses.
- Alluvial cones are created by an existing watercourse, at the bottom of a steep slope.
- A cone of dejection is created by a torrent, at the nickpoint of a slope.

## 4. Identification Criteria

### Present fluviatile deposits (3ac)

- LiDAR indicators

a) The surface is flat, with curved marks showing the position of former meanders (Figure 32).
b) LiDAR cannot distinguish between the three types of fluviatile deposits; aerial photographs are essential for this.

- Aerial photograph indicators

a) Some LiDAR indicators may also be visible on aerial photographs.
b) An active watercourse is always present.
c) The area covered by a deposit is usually no more than a few square metres.
a) The deposit is located in the minor bed of the watercourse, often as a beach alongside the watercourse (pale colour) (Figure 35).
b) The deposit is an unconsolidated mineral deposit with little to no vegetation cover (Figure 35).

### Recent fluviatile deposits (3ae)

- LiDAR indicators

a) The surface is flat, with curved marks showing the position of former meanders.
b) LiDAR cannot distinguish between the three types of fluviatile deposits; aerial photographs are essential for this.

- Aerial photograph indicators

a) Some LiDAR indicators may also be visible on aerial photographs.
b) An active watercourse is always present.
c) The deposit is located in the high flow channel of the watercourse, often on a plateau protruding slightly (by a few metres) from the watercourse. It may be flooded seasonally or occasionally during the year.
d) Vegetation is composed of herbaceous plants, grass, bushes or trees and is usually not very dense.

### Ancient fluviatile deposits (3an)

- LiDAR indicators

a) The surface is flat, with curved marks showing the position of former meanders.
b) LiDAR cannot distinguish between the three types of fluviatile deposits; aerial photographs are essential for this.

- Aerial photograph indicators

a) Some LiDAR indicators may also be visible on aerial photographs.
b) An active watercourse is always present.
c) The deposit formed in an old flood-risk area before the existing watercourse was entrenched, often on a plateau above the watercourse. It may be flooded during extreme high water conditions. The terrace is higher than recent fluviatile deposits but lower than the outwash plain (2be) (Figures 34 and 35).
d) Vegetation is composed of bushes or trees.
e) The vegetation pattern may consist in curved clumps (Figure 35).

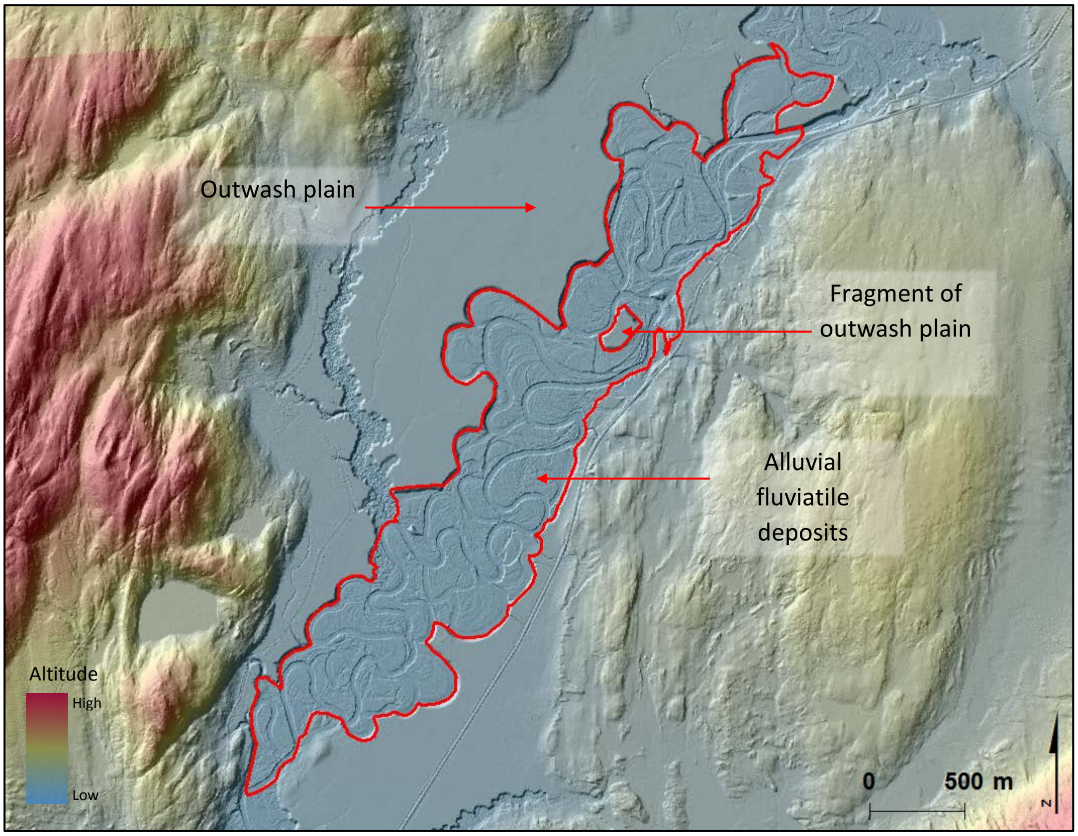


Figure 32. Example of alluvial fluviatile deposits, on LiDAR, in the Eastern Spruce-Moss ecozone

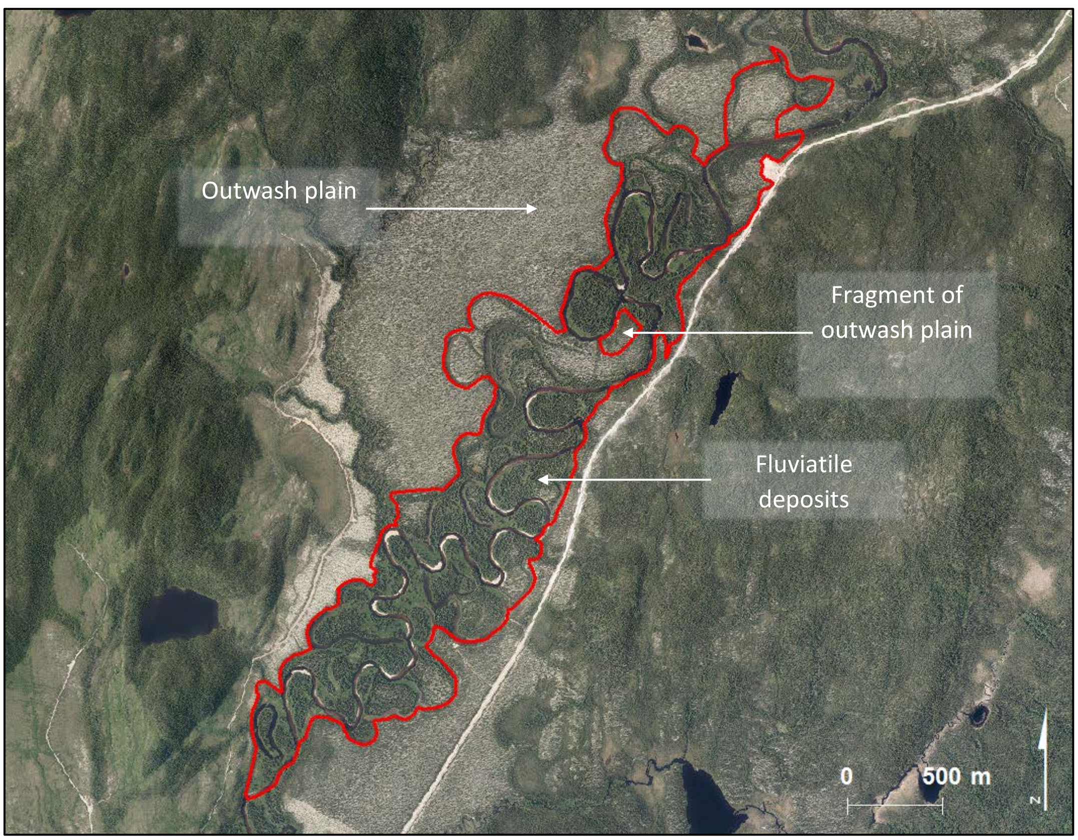


Figure 33. Example of alluvial fluviatile deposits, on an aerial photograph, in the Eastern Spruce-Moss ecozone

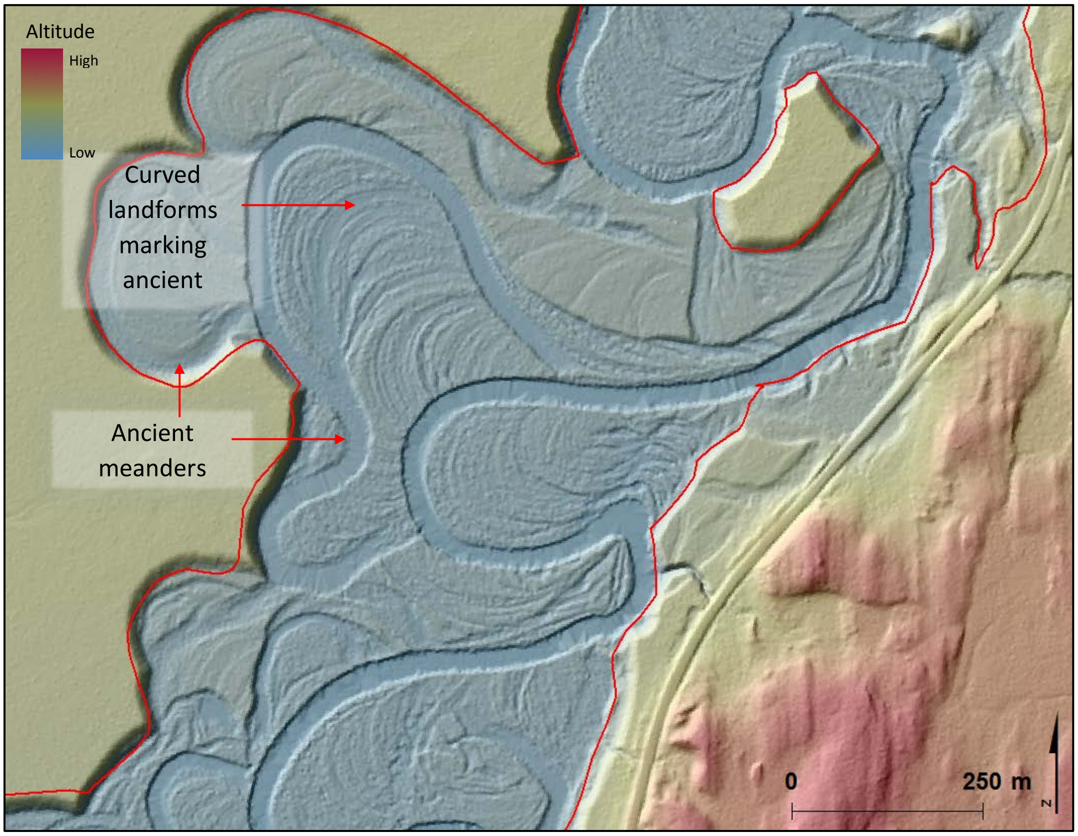

Figure 34. Example of alluvial fluviatile deposits, on LiDAR, in the Eastern Spruce-Moss ecozone

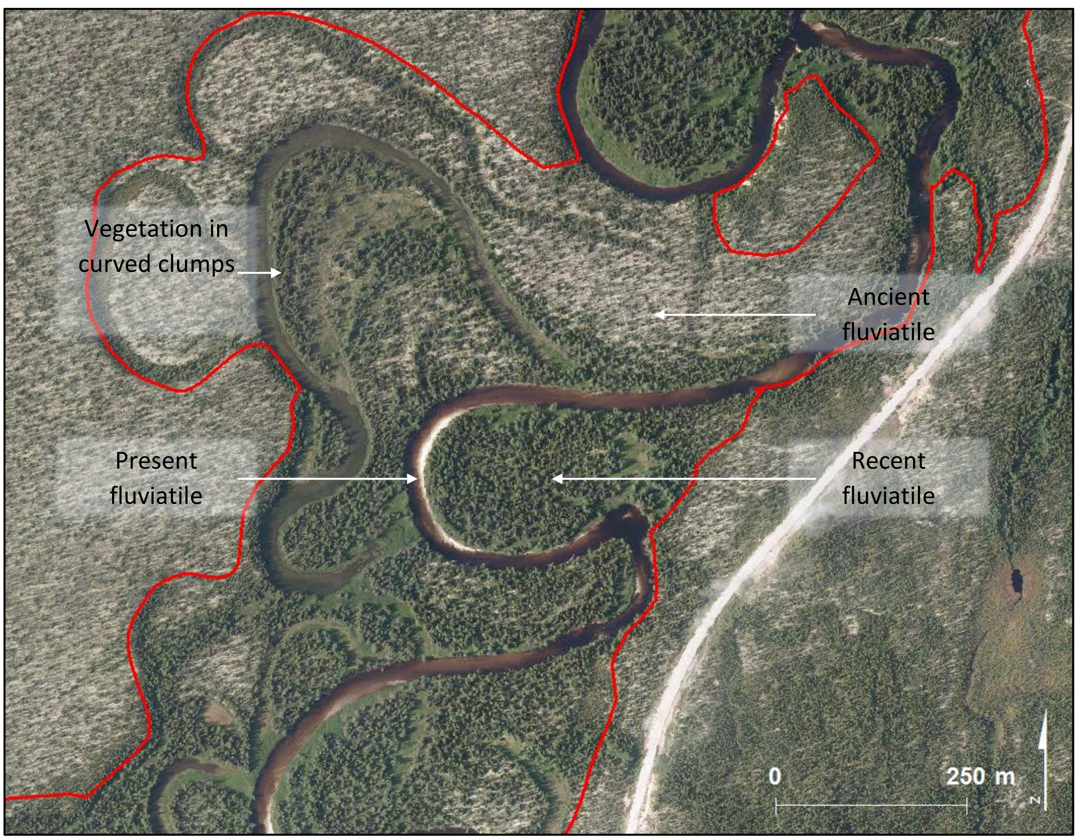

Figure 35. Example of alluvial fluviatile deposits, on an aerial photograph, in the Eastern Spruce-Moss ecozone

## 5. Borrow Pit Potential

Fluviatile deposits offer very little potential as aggregate sources. Although the materials of which they are composed may be suitable, the fact that they are located close to a watercourse and to the water table means that they are difficult to extract.

# Lacustrine Deposits

Lacustrine deposits are formed by decantation, currents or waves at the bottom of proglacial lakes. Their characteristics differ according to their proximity to the sediment source and the depth of the water in which they were deposited. Their potential as a source of aggregate ranges from zero to moderate.

## 1. Formation

Lacustrine deposits were formed by decantation, currents or waves at the bottom of proglacial lakes (MFFP, 2014). These lakes were bodies of water that formed on the margins of glaciers, after withdrawal of the ice. The lake water was sometimes confined by the ice, and sometimes by topographical elements, moraine, etc.

## 2. Location

Numerous proglacial lakes were formed during the last deglaciation. Many have been identified, including Lac Barlow and Lac Ojibway (Vincent & Hardy, 1977; Veillette, 1994), Lac Candona (Parent & Occhietti, 1988), Lac Vermont (Ridge *et al.*, 1999) and Lac Memphrémagog (Parent & Occhietti, 1999).

The main lacustrine deposit zones mapped by the Ministère des Forêts, de la Faune et des Parcs are shown in Figure 36.

Generally speaking, lacustrine deposits are found in large plains covering areas of several square kilometres.

## 3. Deposit Description

The characteristics of lacustrine deposits differ according to their proximity to the sediment source and the depth of the water under which they were deposited. Generally speaking, the particles are finer further away from the glacier front and in deeper water (Tranhaile 2013; Benn and Evans, 2010).

The Ministère des Forêts, de la Faune et des Parcs du Québec has identified five types of lacustrine deposits (Table 7) (MFFP, 2014; Robitaille and Dionne, 2007):

Table 7. Lacustrine deposits and their area as a percentage in Southern Québec

| Lacustrine deposits | % |
| --- | --- |
| 4ga – Glaciolacustrine, deep water facies | 5.2 |
| 4gs –Glaciolacustrine, shallow water facies | 1.1 |
| 4gd – Glaciolacustrine delta | <0.1 |
| 4p – Beach | <0.1 |
| 4a – Lacustrine plain | <0.1 |

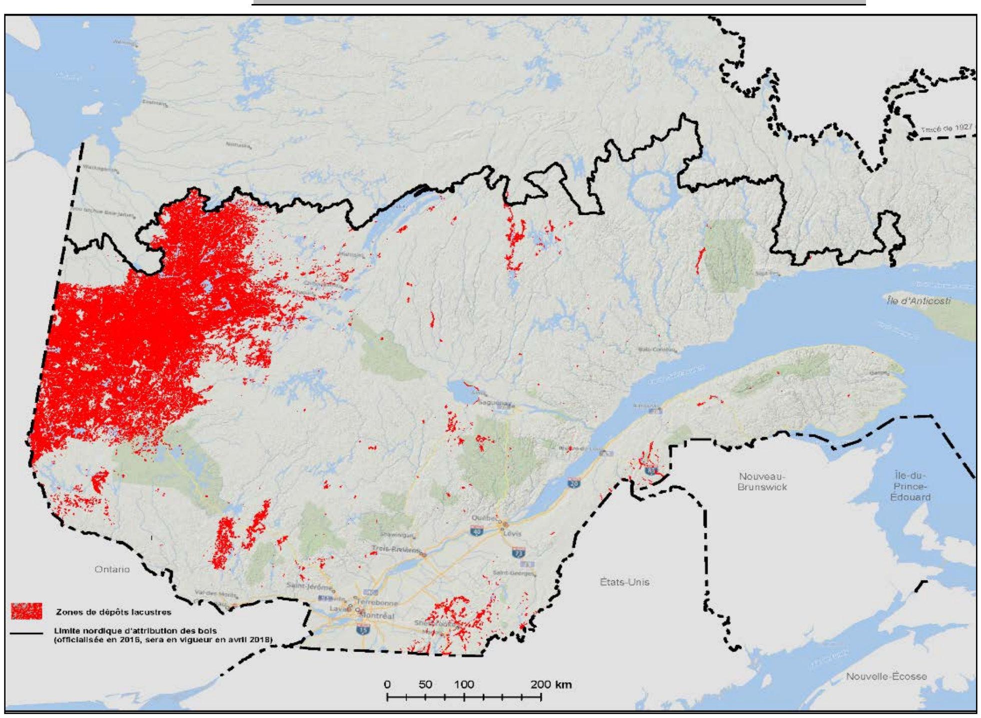


Figure 36. Lacustrine deposits in Québec, mapped by the MFFP (4th inventory)

1. Deep water facies lacustrine deposits are formed by decantation in deep-water areas of the lake, and are composed of very fine, varved silt, clay and sand particles. Density is moderate and there is very little stone cover.

2. Shallow water facies lacustrine deposits are formed by decantation in shallow-water areas of a proglacial lake or in areas of the lake with current, i.e. near glaciofluvial eskers or deltas. Density is low and stone cover is low to zero.

3. Glaciolacustrine deltas are formed at the mouth of a glaciofluvial watercourse in a proglacial lake. They are composed of sand, silt and sometimes gravel. This type of deposit is almost never mapped in Québec.

4. Beaches are formed in shallow-water areas of a proglacial lake where waves were present. They are composed of sand, gravel or both – silt may sometimes be present. The particles are sorted and density is low. Beaches may sometimes be composed of glacial pavement blocks carried by floating ice and washed smooth by waves.

5. A lacustrine plain is a deposit that forms on the edge or at the end of a lake, forming a flat area after the water has withdrawn. It is composed of organic materials, fine sand, silt and clay. Very few such plains have been mapped in Québec.

## 4. Identification Criteria

It is important to consult existing maps to make sure the area under study is in a region where proglacial lakes were present. Knowledge of the height of the marine or lacustrine limit is also required (Table 8).

All lacustrine deposits are generally found on large plains covering areas of several square kilometres.

### Deep water facies lacustrine deposits (4ga)

- LiDAR indicators

a) The surface is flat, uniform and usually with surface washout caused by erosion due to runoff water (Figure 37).
b) Deposit composition can sometimes be determined from the shape of the gulley bed. Gullies where the branch ends, where washout begins, exhibit U-shaped flared entrenchment, suggesting that the deposit is composed of clay (Figures 37 and 38) (Paine and Kiser, 2012). The gulley sides are also steeper and sawtoothed when composed of clay. They may have a feather-like appearance on LiDAR.
c) Evidence of landslides can also be used to determine the presence of clay in a sector. This increases the probability of glaciolacustrine deposits even if clay is not present on the deposit surface. Often, the bottom of a landslide is composed of clay, whereas the surface of the plateau on which the landslide originated may be sandy.
d) A tree-shaped or feather-shaped drainage network with numerous branches on flat land is often indicative of a clay deposit.

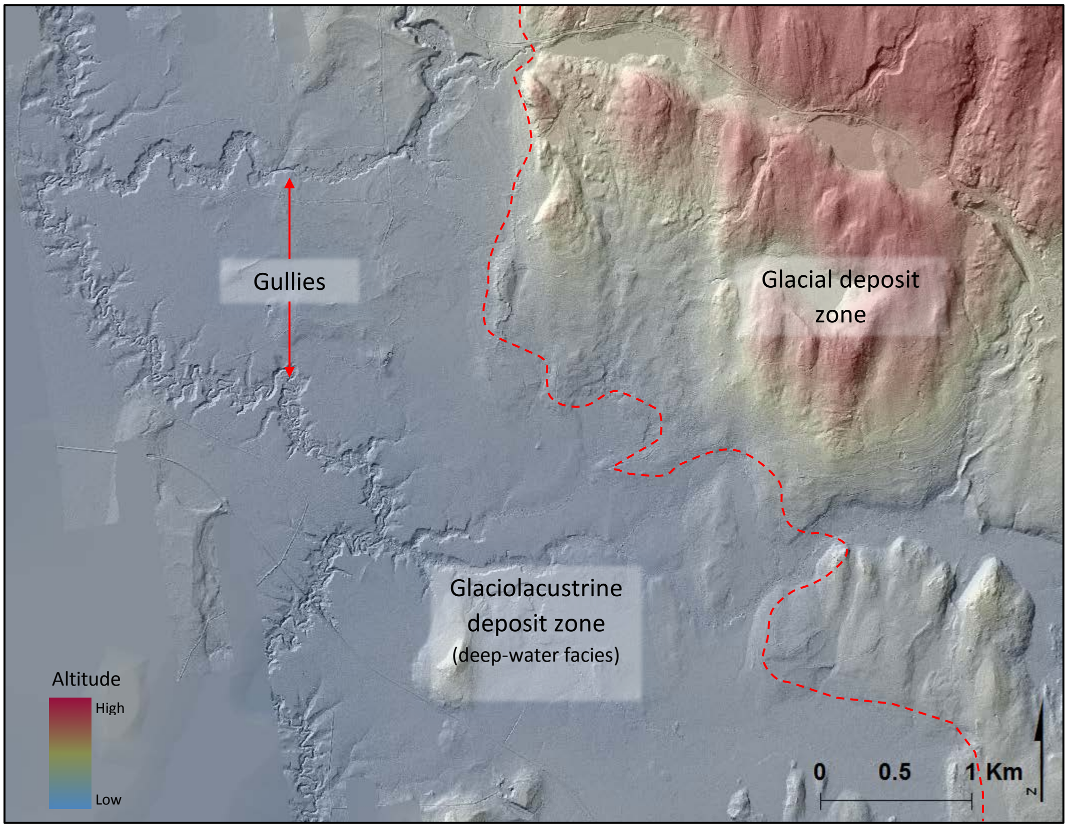


Figure 37. Example of a deep-water facies glaciolacustrine deposit (4ga), on LiDAR, in the Western Balsam Fir-White Birch ecozone

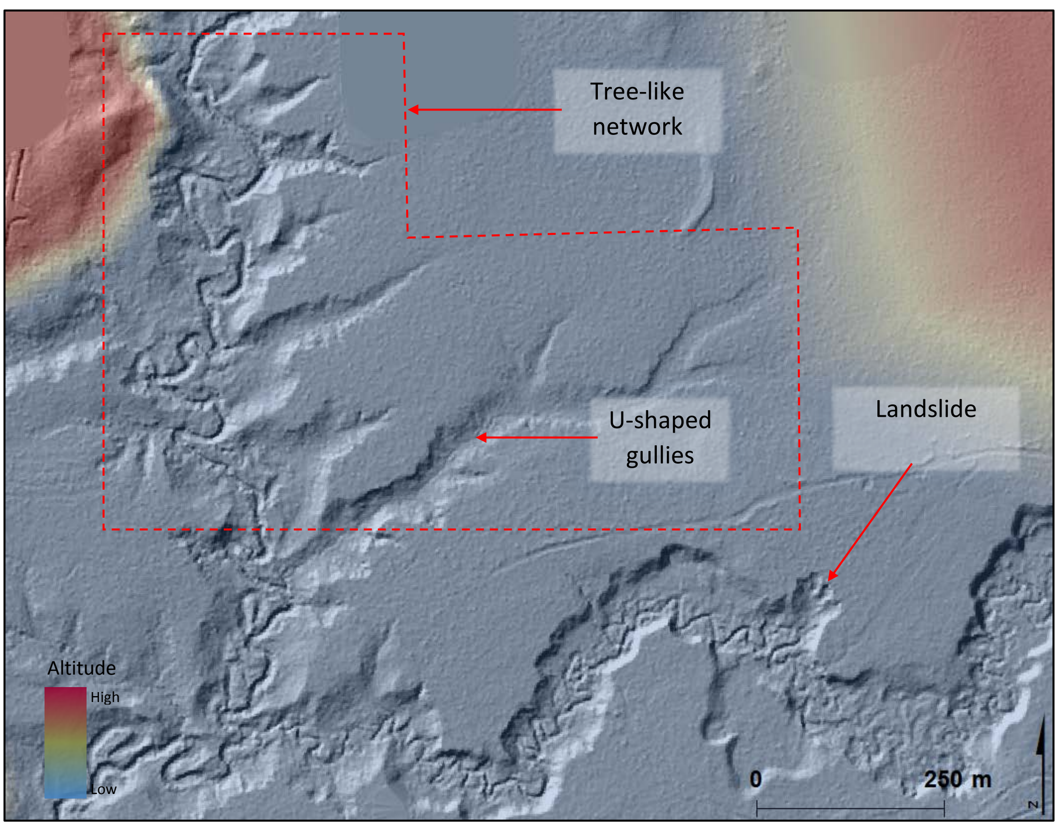


Figure 38. Example of gullies in a deep-water facies glaciolacustrine deposit (4ga), on LiDAR, in the Western Balsam Fir-White Birch ecozone

- Aerial photograph indicators

a) Some LiDAR indicators may also be visible on aerial photographs.
b) The pale coffee brown colour of the watercourses and lakes may indicate the presence of lacustrine clay (Figure 39).
c) Where the ground is exposed (e.g. landslide talus slope or major watercourse erosion), the soil colour is an indicator. Clay (4ga) will be grey to blue-grey on the photograph. Once the maximum level of the clay has been identified, the altitude can be used as a reference for the entire sector. 4gs will always be located at a higher level than 4ga.


Figure 39. Example showing the brown colour of the water in a dendritic drainage system in a deep water facies glaciolacustrine deposit (4ga), on LiDAR, in the Western Balsam Fir-White Birch ecozone

## Shallow water facies lacustrine deposits (4gs)

- LiDAR indicators

a) The landscape is generally dissected by fewer gullies, since drainage mostly takes place by gravity because the coarser materials allow the water to drain vertically.
b) The surface is flat, uniform and may be dissected by gullies created by erosion from runoff water.
c) The shape of the gullies may also be an indicator of deposit composition. Entrenchment at the ends of the gullies, where washout begins, is quicker and narrower than for gullies cut in clay (Figures 40 and 41).
d) The gullies are narrower than in clay.

- Aerial photograph indicators

a) Some LiDAR indicators may also be visible on aerial photographs.
b) Where the ground is exposed (e.g. landslide talus slope or major watercourse erosion), the soil colour is an indicator. Sand (4gs) will be pale grey to yellowish-grey on the photograph.

Generally speaking, shallow water facies lacustrine deposits lie above deep water facies lacustrine deposits. Superimposition of identification criteria is therefore possible, as shown in Figure 41.

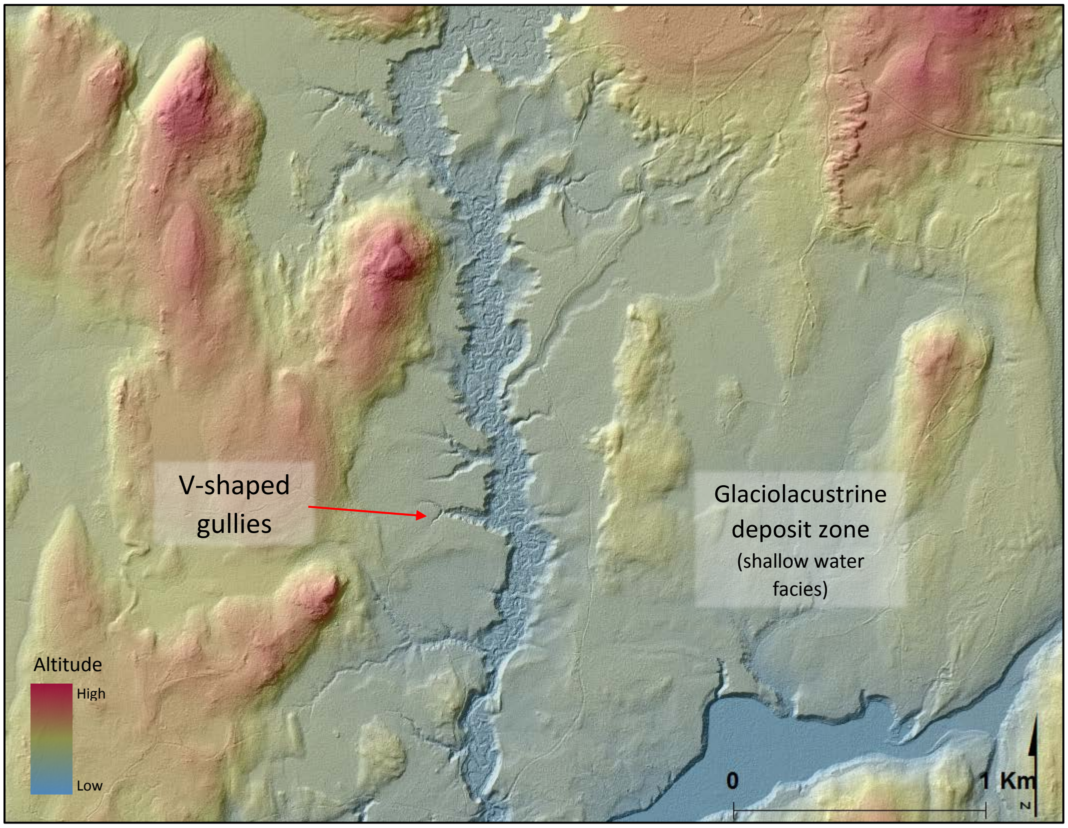


Figure 40. Example of a shallow water facies glaciolacustrine deposit (4gs), on LiDAR, in the Western Balsam Fir- White Birch forest

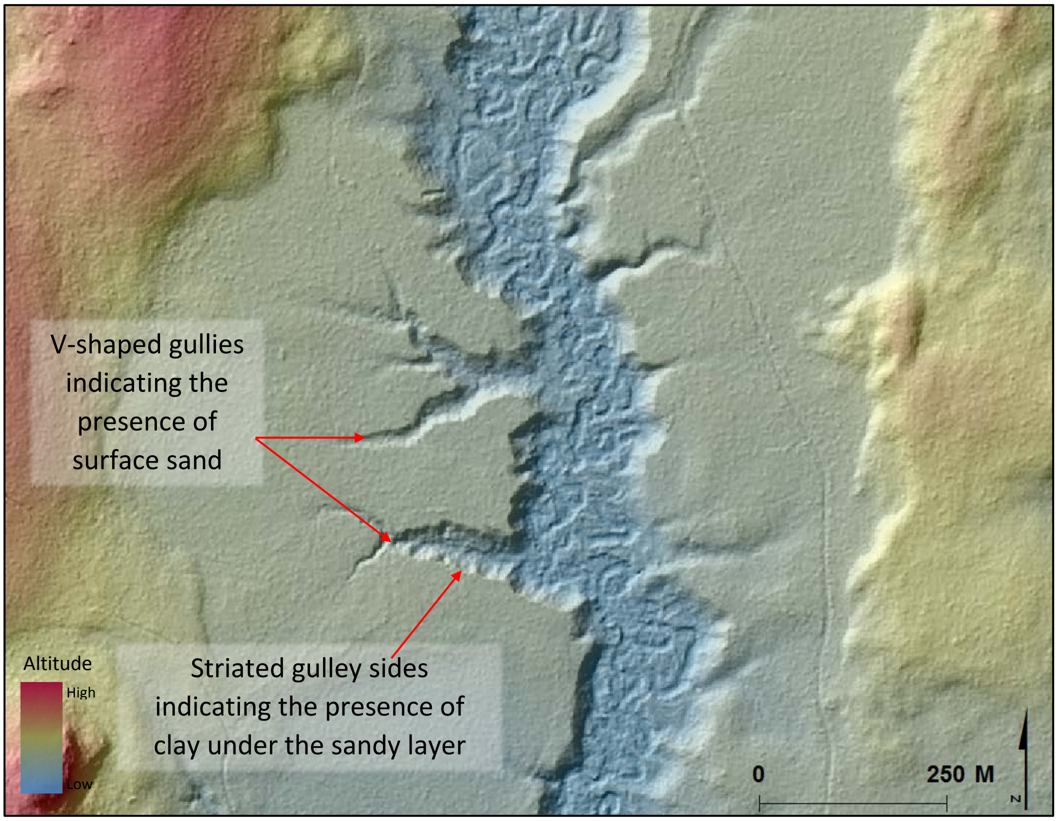


Figure 41. Example of gullies in a shallow water facies glaciolacustrine deposit (4gs), on LiDAR, in the Western Balsam Fir-White Birch ecozone

## Beaches (4p)

- LiDAR indicators

a) It is sometimes possible to see ancient emergent beaches, which can be identified by a series of parallel ridges on gentle or steep slopes. The ridges indicate the presence of an ancient proglacial lake (Figures 42 and 44).

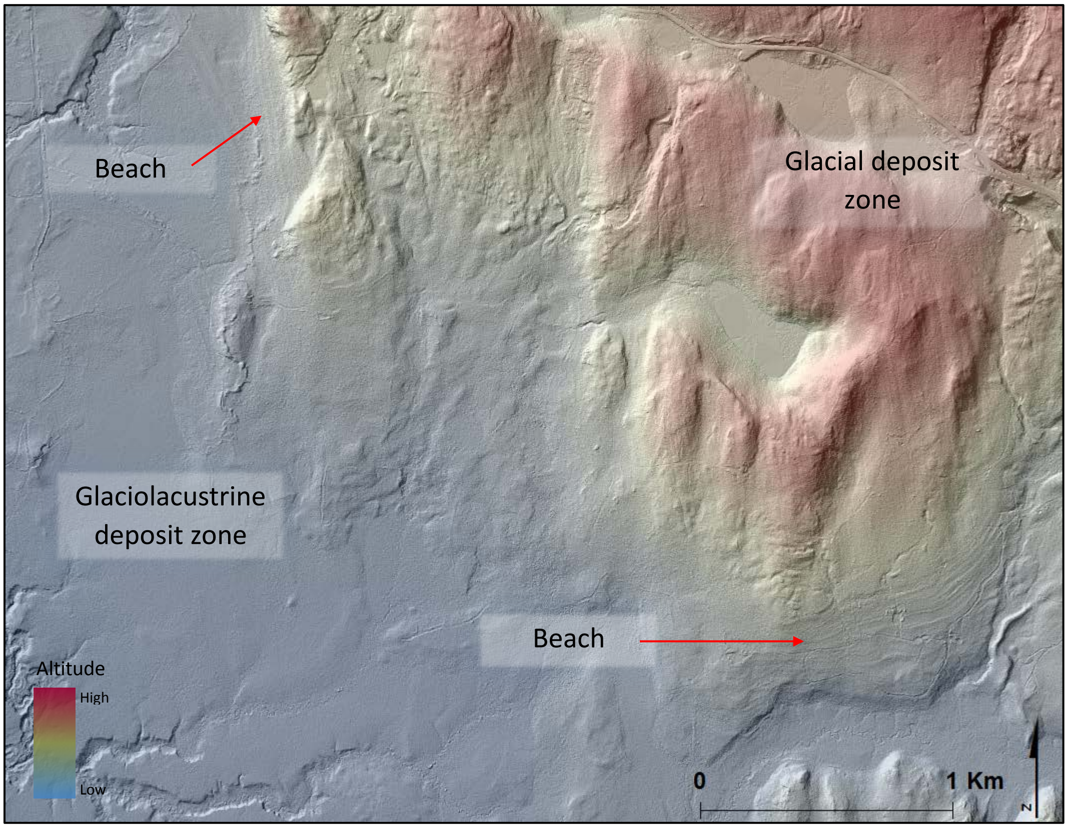


Figure 42. Example of a lacustrine beach (4p), on LiDAR, in the Western Balsam Fir-White Birch ecozone


Figure 43. Example of a lacustrine beach (4p), on an aerial photograph, in the Balsam Fir-White Birch ecozone

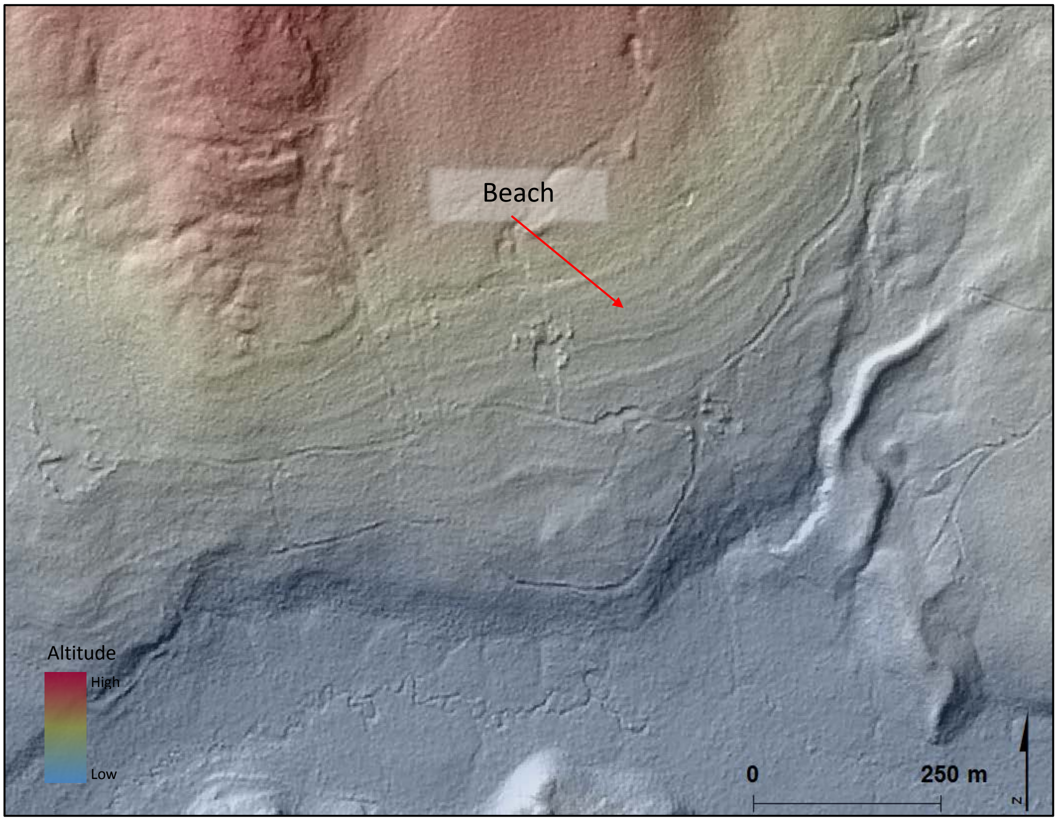


Figure 44. Example of parallel ridges indicating a lacustrine beach (4p), on LiDAR, in the Balsam Fir-White Birch ecozone

## 5. Borrow Pit Potential

The potential offered by lacustrine deposits as a source of aggregate ranges from zero to moderate.

Shallow water facies glaciolacustrine deposits (4gs – poor potential) and beaches (4p – moderate potential) offer the best potential because of their sand/gravel composition and their sorted or layered structure. Cooper and Gartner (1984) also note that deltas and lacustrine beaches are actively sought when locating borrow pits in Ontario. However, they note that these structures offer a high percentage of fine material and a lower percentage of gravel.

The other lacustrine deposits offer zero potential because they contain mostly fine materials (clay, loam).

It may be interesting to note that eskers may be visible under lacustrine deposits in certain places. These eskers may be a very good source of aggregate (Figures 45 to 53).

Eskers such as these are found in environments exhibiting signs of lacustrine deposits (flat land, beaches, etc.). They often have flat as opposed to convex summits. In the field they will be buried under several metres of lacustrine sand.

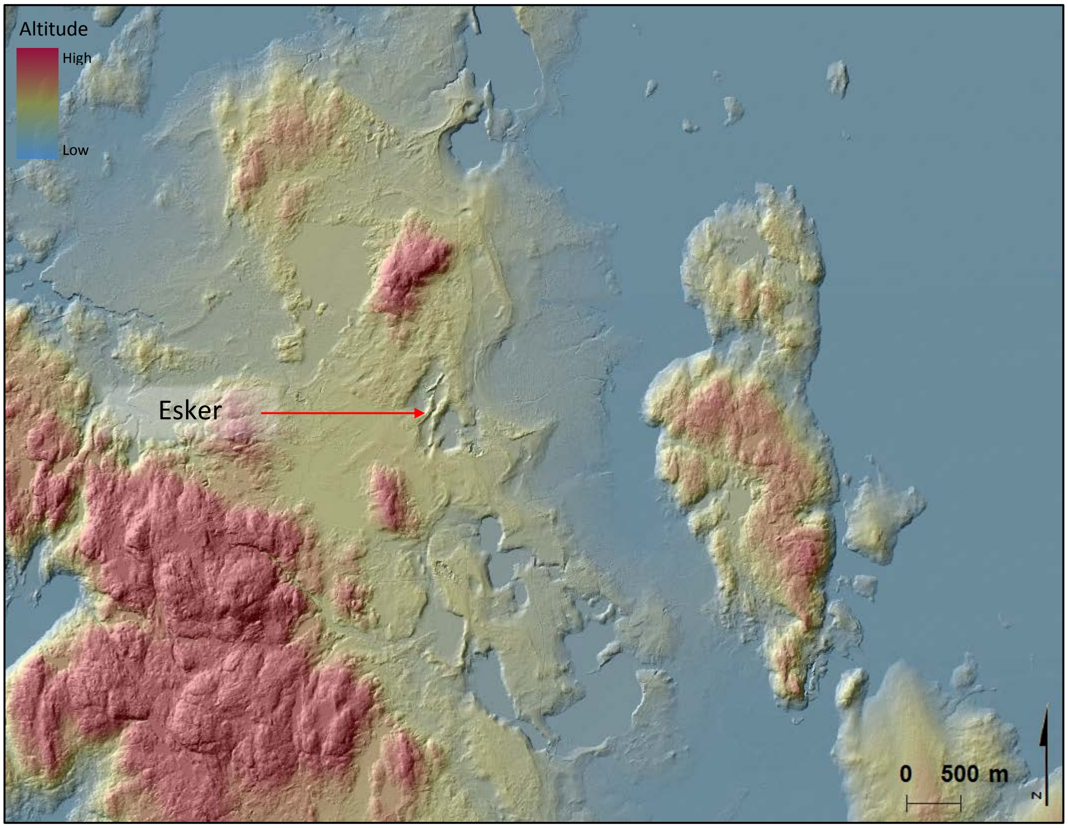


Figure 45. Example of an esker under a lacustrine deposit, on LiDAR, in the Western Sugar Maple-Yellow Birch ecozone


Figure 46. Example of an esker under a lacustrine deposit, on an aerial photograph, in the Western Sugar Maple-Yellow Birch ecozone

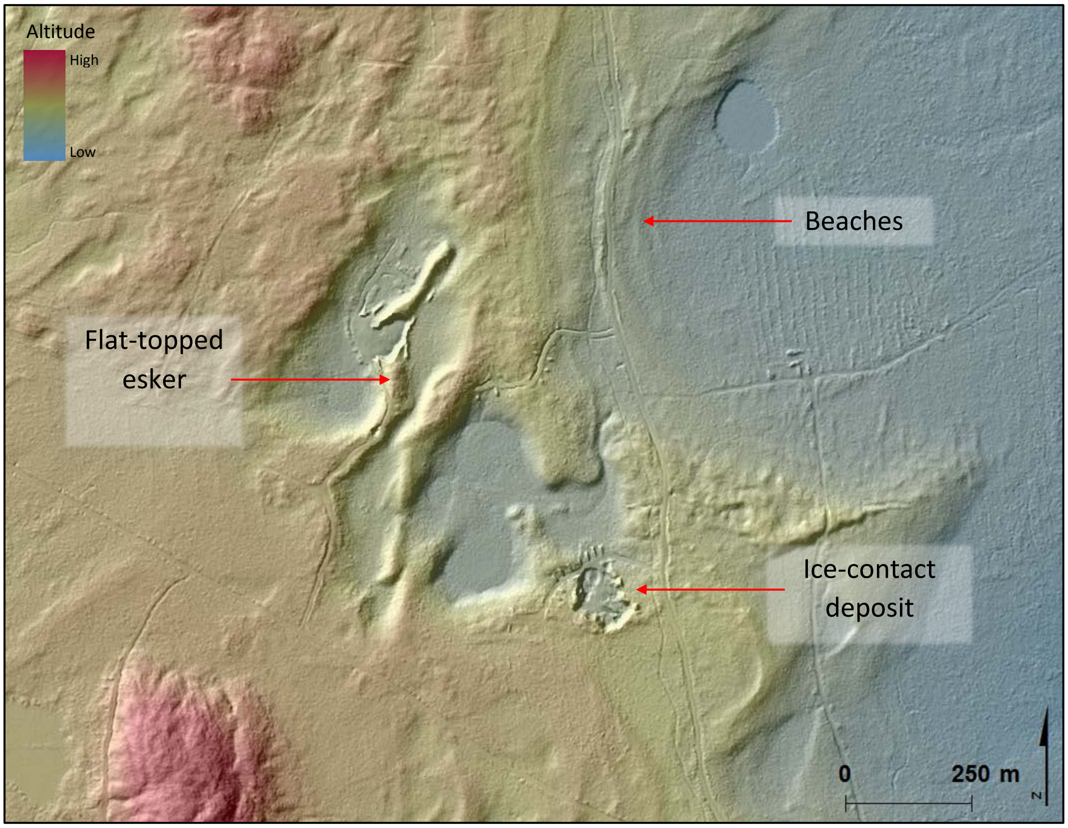


Figure 47. Example of an esker under a lacustrine deposit, on LiDAR, in the Western Sugar Maple-Yellow Birch ecozone

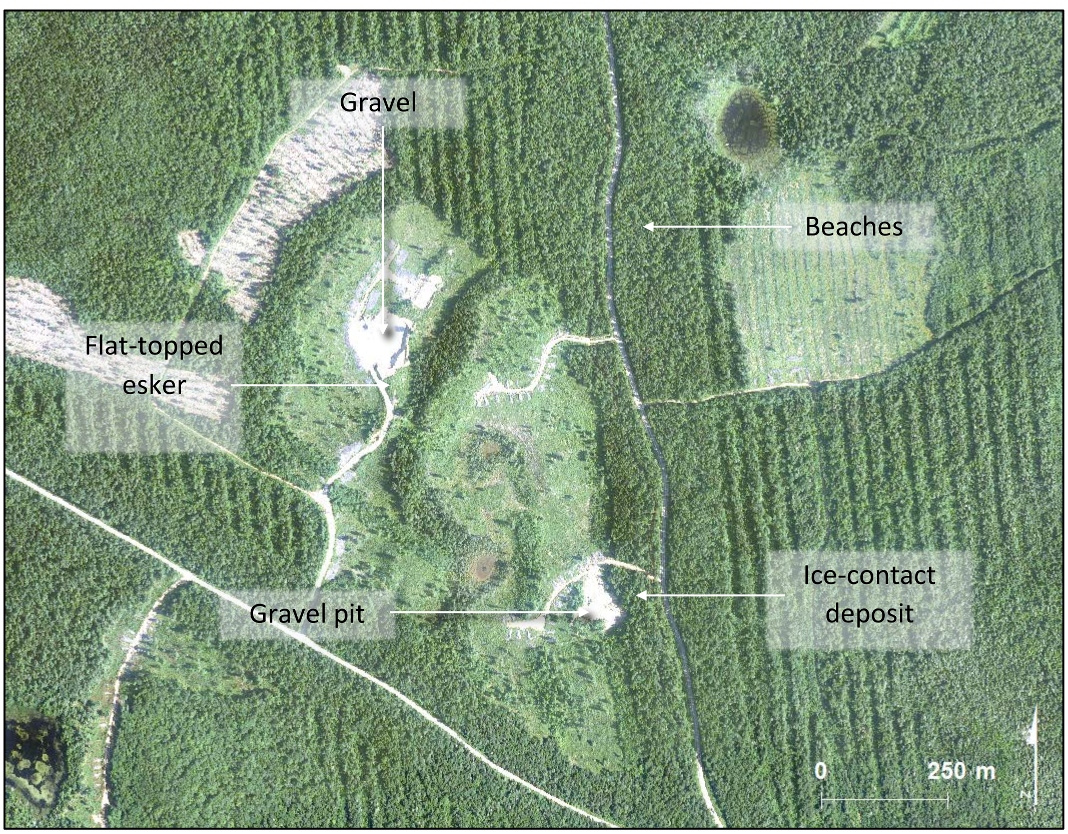


Figure 48. Example of an esker under a lacustrine deposit, on an aerial photograph, in the Western Sugar Maple-Yellow Birch ecozone

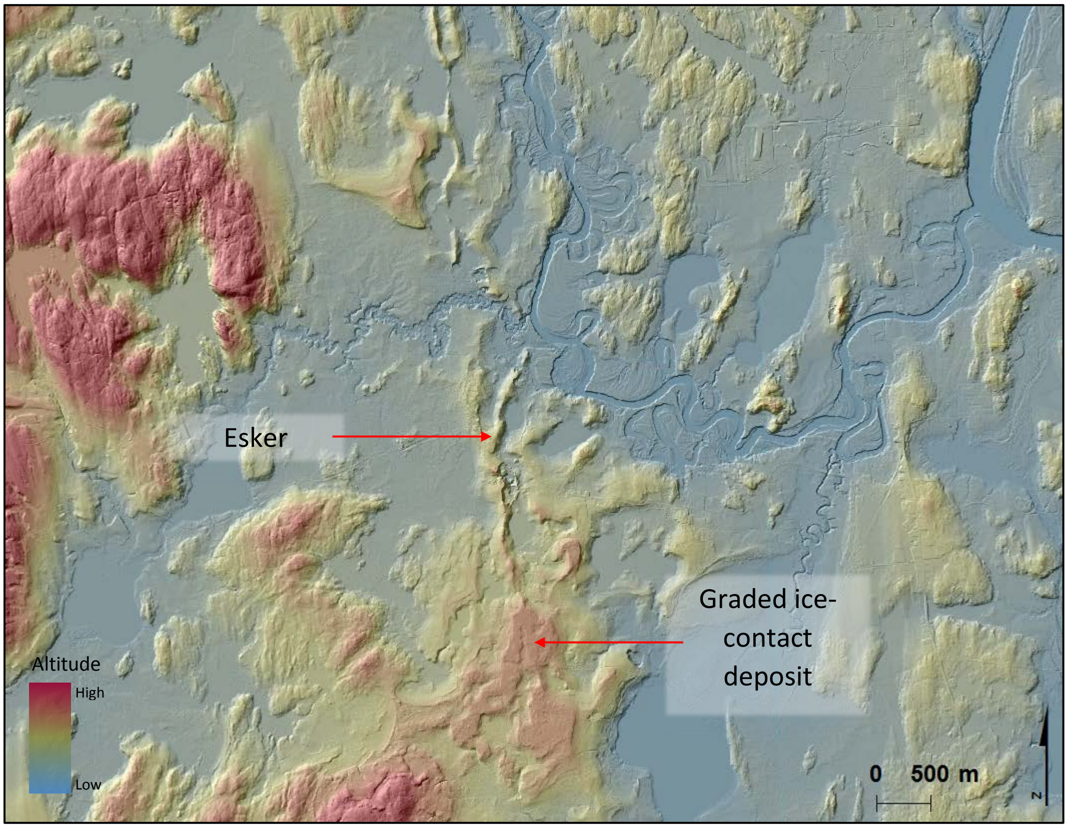


Figure 49. Example of an esker under a lacustrine deposit, on LiDAR, in the Western Sugar Maple-Linden ecozone

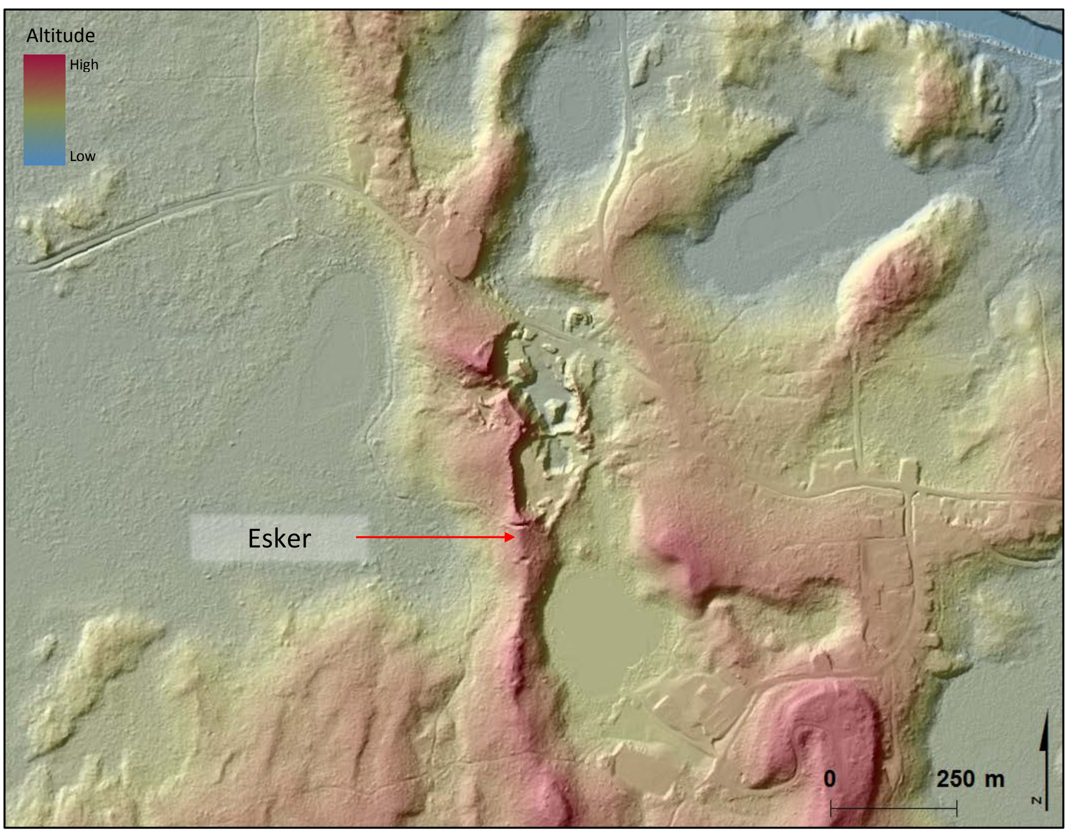


Figure 50. Example of an esker under a lacustrine deposit, on LiDAR, in the Western Sugar Maple-Linden ecozone


Figure 51. Example of an esker under a lacustrine deposit, on an aerial photograph, in the Western Sugar Maple-Linden ecozone

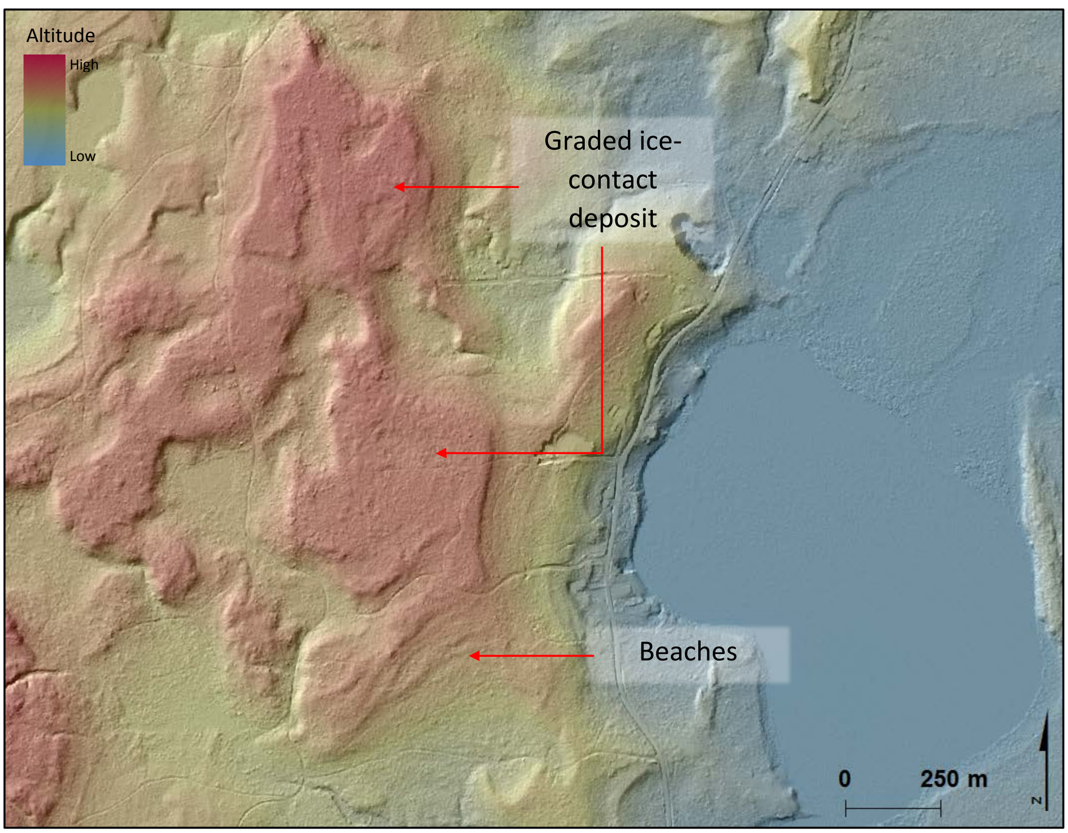


Figure 52. Example of a graded ice-contact deposit under a lacustrine deposit, on LiDAR, in the Western Sugar Maple-Linden ecozone

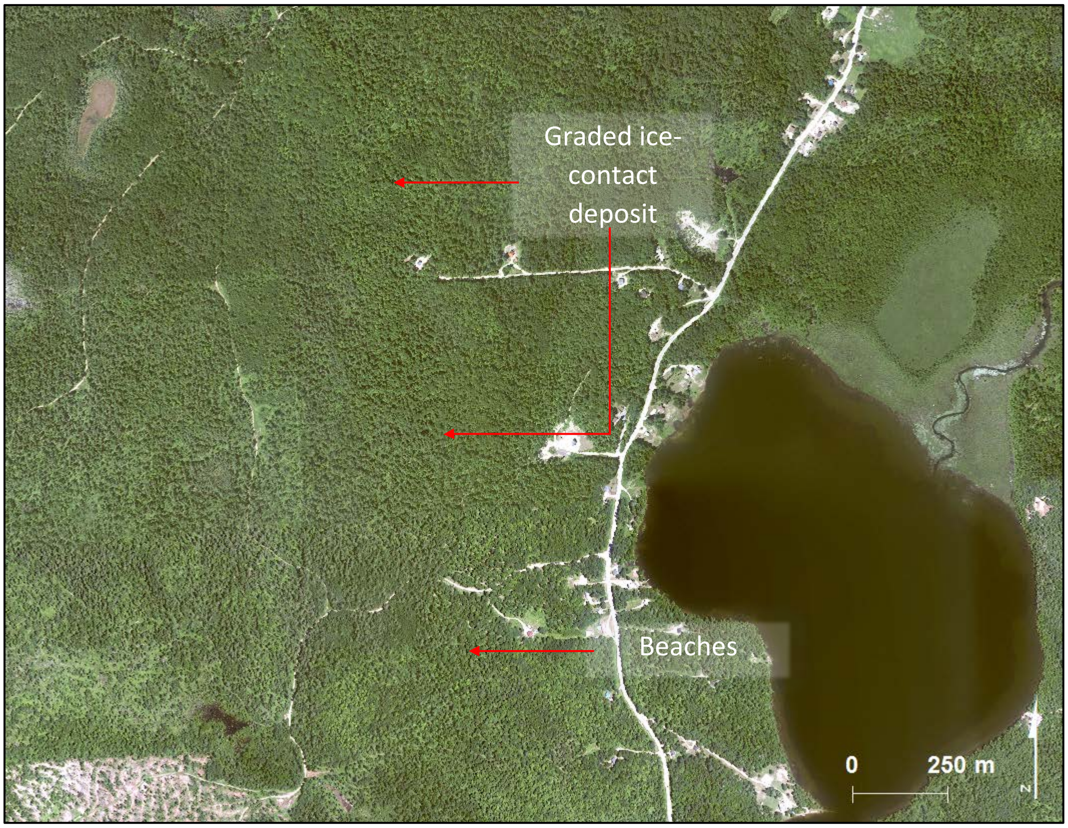


Figure 53. Example of an esker under a lacustrine deposit, on an aerial photograph, in the Western Sugar Maple-Linden ecozone

Table 8. Maximum altitudes of glaciolacustrine boundaries of Québec's main proglacial lakes (Taken from Ministère des Forêts, 1991 - 1998. Surface deposit maps. Working document. 1:50 000. Service des inventaires forestiers)

| Map Sheets | Altitude (m) | Sources |
|---|---|---|
| 22G03 | 470 | |
| 22G06 | 480 (N)<br>460 (S) | |
| 22G10 | 510 | |
| 22G11 | 480 | |
| 22G14 | 480 | |
| 22J05 | 320 | Dredge (1976) |
| 22J12 | 320 | |
| 22J13 | 320 | |
| 22K11 | 380 | |
| 31G14 | 275 (N)<br>245 (S) | |
| 31G15 | 280 | Lajoie (1962, 1967); Richard (1984) |
| 31G16 | 280 | Prichonnet (1977); Elson (1969); Tremblay (1977) |
| 31H01 | 300 | Boissonnault (1983); Dubé (1983); Parent and Occhieti (1988) |
| 31H02 | 274 | Cloutier, 1982); Parent et Occhieti (1988) |
| 31H08 | 274 | Cloutier, 1982); Parent and Occhieti (1988) |
| 31J01 | 381 | Tremblay (1977); Lamothe (1977); Parry and Macpherson (1964) |
| 31J04 | 229 | Lajoie (1962, 1967) |
| 31J05 | 229 | Lajoie (1962, 1967) |
| 31J11 | 260 | Lajoie (1962, 1967) |
| 31J12 | 244 | Lajoie (1962, 1967) |
| 31K01 | 229 | Lajoie (1962) |
| 31K08 | 229 | Lajoie (1962) |
| 31K09 | 244 | Lajoie (1962) |
| 31M01 | 280 | Veillette (1988) |
| 31M03 | 300 (N)<br>290 (S) | Veillette (1988) |
| 31M05 | 320 | Veillette (1988) |
| 31M06 | 300 (SW)<br>310 (SE)<br>320 (NW)<br>330 (NE) | Veillette (1988) |
| 31M07 | 320 | Veillette (1988) |
| 31M09 | 361 | Veillette (1988) |
| 31M10 | 370 | Veillette (1988) |
| 31M11 | 340 | Veillette (1988) |
| 31M12 | 340 (NE)<br>320 (SE) | Veillette (1988) |
| 31M13 | 342.9 (NE)<br>327.7 (SE) | Veillette (1987, 1988); Vincent and Hardy (1979) |
| 31M14 | 335.3 (SW)<br>342.9 (SE)<br>350.5 (NW)<br>358.0 (NE) | Veillette (1987, 1988); Vincent and Hardy (1979) |
| 31M15 | 350.5 (SW)<br>342.0 (SE)<br>338.0 (NW)<br>365.7 (NE) | Veillette (1987, 1988); Vincent and Hardy (1979) |
| 31M16 | 342.9 (SW)<br>350.5 (SE)<br>365.7 (NE)<br>358.1 (NW) | Vincent and Hardy (1979) |
| 31N11 | 365 | Veillette (1987) |
| 31N12 | 350 | Veillette (1987) |
| 31N13 | 350.5 (SW)<br>358.1 (SE)<br>365.7 (NW)<br>371.5 (NE) | Veillette (1988); Vincent and Hardy (1979) |
| 31N14 | 358.1 (SW)<br>371.5 (NW)<br>377.3 (NE) | Veillette (1988); Vincent and Hardy (1979) |
| 31N15 | 380 | |
| 31O01 | 450 | |
| 31O08 | 450 | |
| 32B13 | 425 | |
| 32C02 | 377 | Veillette (1983) |
| 32C03 | 371.5 (SW)<br>377.3 (SE)<br>383.1 (NW)<br>388.9 (NE) | Vincent and Hardy (1979) |
| 32C04 | 365.7 (SW)<br>371.5 (SE)<br>377.3 (NW)<br>383.1 (NE) | Vincent and Hardy (1979) |
| 32C05 | 377.3 (SW)<br>383.1 (SE)<br>388.9 (NW)<br>394.7 (NE) | Vincent and Hardy (1979) |
| 32C06 | 383.1 (SW)<br>388.9 (SE)<br>394.7 (NW)<br>400.5 (NE) | Vincent and Hardy (1979) |
| 32C07 | 377 | Veillette (1983) |
| 32C08 | 385 | |
| 32C10 | 396 | |
| 32C12 | 394 | Vincent and Hardy (1979) |
| 32C13 | 418 | Vincent and Hardy (1979) |
| 32C16 | 425 | |
| 32D01 | 358.1 (SW)<br>377.3(NE)<br>365.7(SE)<br>371 (NW) | Vincent and Hardy (1979) |
| 32D02 | 350.5 (SW)<br>358.1 (SE)<br>365.7 (NW)<br>371.5 (NE) | Tremblay (1977); Vincent and Hardy (1979) |
| 32D03 | 342.9 (SW)<br>350.5 (SE)<br>350.0 (NW) | Tremblay (1977); Veillette (1983); |

| Map Sheets | Altitude (m) | Sources |
|---|---|---|
| | 365.7 (NE) | Vincent and Hardy (1979) |
| 32D04 | 342.9 (SE) 358.1(NE) | Boissonneau (1966); Veillette (1988); Vincent and Hardy (1979) |
| 32D05 | 358.1 (SW) 367.5 (SE) 371.5 (NW) 377.3 (NE) | Boissonneau (1966); Vincent and Hardy (1979) |
| 32D06 | 358.1 (SW) 367.5 (SE) 371.5 (NW) 377.3 (NE) | Vincent and Hardy (1979) |
| 32D07 | 365.7 (SW) 371.5 (SE) 377.3 (NW) 383.1 (SE) | Vincent and Hardy (1979) |
| 32D08 | 371.5 (SW) 377.3 (SE) 383.1 (NW) 388.9 (NE) | Vincent and Hardy (1979) |
| 32D09 | 391 | Vincent and Hardy (1979) |
| 32D10 | 378 | Vincent and Hardy (1979) |
| 32D11 | 380 | Tremblay (1973) |
| 32D14 | 391 | Vincent and Hardy (1979) |
| 32D15 | 406 | Vincent and Hardy (1979) |
| 32D16 | 418 | Vincent and Hardy (1979) |
| 32F01 | 425 | Vincent (1989) |
| 32F04 | 440 | Vincent (1989) |
| 32F05 | 380 | Veillette *et al.* (1991) |
| 32F12 | 380 | Veillette *et al.* (1991) |
| 32F13 | 380 | Veillette *et al.* (1991) |
| 32F16 | 425 | Vincent (1989) |
| 32G04 | 425 | Vincent (1989) |
| 32G05 | 425 | Vincent (1989) |
| 32G06 | 380 | Veillette *et al.* (1991) |
| 32G07 | 380 | Veillette *et al.* (1991) |
| 32G12 | 425 | Vincent (1989) |
| 32G13 | 425 | Vincent (1989) |
| 32G14 | 400 | Prichonnet et al (1984); Poly-Géo inc. (1991) |
| 32G15 | 411 | Prichonnet et al (1984); Poly-Géo inc. (1991) |
| 32G16 | 445 | Prichonnet et al (1984); Poly-Géo inc. (1991) |
| 32I12 | 457 | Vincent (1989) |
| 32I13 | 457 | Vincent (1989) |
| 32I14 | 457 | Vincent (1989) |
| 32J01 | 457 | Poly-Géo inc. (1991), Prichonnet |

| Map Sheets | Altitude (m) | Sources |
|---|---|---|
| | | et al (1984); Vincent (1989) |
| 32J02 | 450 | Poly-Géo inc. (1991), Prichonnet et al (1984); Vincent (1989) |
| 32J03 | 425 | Poly-Géo inc. (1991), Prichonnet et al (1984); Vincent (1989) |
| 32J04 | 425 | Poly-Géo inc. (1991), Prichonnet et al (1984); Vincent (1989) |
| 32J05 | 457 | Poly-Géo inc. (1991), Prichonnet et al (1984); Vincent (1989) |
| 32J06 | 450 à 460 | Poly-Géo inc. (1991) |
| 32J07 | 440 | Poly-Géo inc. (1991) |
| 32J08 | 427 | Poly-Géo inc. (1991), Vincent (1989) |
| 32J09 | 457 | Poly-Géo inc. (1991), Vincent (1989) |
| 32J10 | 457 | Poly-Géo inc. (1991), Vincent (1989) |
| 32J11 | 457 | Poly-Géo inc. (1991), Vincent (1989) |
| 32J12 | 457 | Vincent (1989) |
| 32J13 | 457 | Vincent (1989) |
| 32J14 | 435 | Poly-Géo inc. (1991) |
| 32K01 | 420 | |
| 32K02 | 425 | Vincent (1989) |
| 32K03 | 420 | |
| 32K04 | 380 | Veillette *et al.* (1991) |
| 32K05 | 457 | Vincent (1989) |
| 32K06 | 425 | Vincent (1989) |
| 32K07 | 425 | Vincent (1989) |
| 32K08 | 425 | Vincent (1989) |
| 32K09 | 425 | Vincent (1989) |
| 32K10 | 425 | Vincent (1989) |
| 32K11 | 425 | Vincent (1989) |
| 32K12 | 425 | Vincent (1989) |
| 32K13 | 457 | Vincent (1989) |
| 32K14 | 457 | Vincent (1989) |
| 32K15 | 425 | Vincent (1989) |
| 32K16 | 457 | Vincent (1989) |
| 32N01 | 457 | Vincent (1989) |
| 32N02 | 457 | Vincent (1989) |
| 32N03 | 457 | Vincent (1989) |
| 32O03 | 457 | Vincent (1989) |
| 32P02 | 457 | Vincent (1989) |

| Map Sheets | Altitude (m) | Sources |
|---|---|---|
| 32P03 | 457 | Vincent (1989) |
| 32P04 | 457 | Vincent (1989) |

# Marine Deposits and Coastal Marine Deposits

Marine deposits were created by sedimentation, whereas coastal marine deposits were subject to the action of tides and waves. The characteristics of marine deposits differ according to their proximity to the sediment source and the depth of the water in which they formed. As for coastal marine deposits, they are composed of graded, layered sand, gravel and pebbles. Their potential as sources of aggregate varies from zero to moderate.

## 1. Formation

When Québec was covered in glaciers, the land surface was pushed downwards by a strong compressive force. When the glaciers withdrew, some areas that were below sea level at the time were flooded by seawater (Desaulniers, 2015). These relatively calm bodies of water deposited sediment from different affluents over a period of several thousand years, forming marine deposits. The waters gradually withdrew as the Earth's crust rose, allowing the deposits to emerge.

Coastal deposits were reworked or left behind by water and drift ice, between the high-water and low-water marks (MFFP, 2015). They were shaped by the action of waves, marine currents and, to a lesser extent, drift ice (Robitaille and Allard, 2007).

## 2. Location

Five major regions of Québec were under water for periods ranging from 2,000 to 4,000 years. It is in these regions that there is the highest probability of finding a marine deposit (Figure 54). They are the Champlain Sea, formed in the Lower St. Lawrence region, the Laflamme Sea in the Saguenay-Lac-Saint-Jean region, the Goldthwait Sea at the mouth of the St. Lawrence River, the Tyrrell Sea, which borders Hudson Bay and James Bay, and the Iberville Sea, located in Ungava Bay (Dionne, 1972; Desaulniers, 2015). Each of these seas attained the maximum limit of submergence beyond which marine deposits are absent (Table 10).

Generally speaking, marine deposits occur in large plains covering areas of several square kilometres.

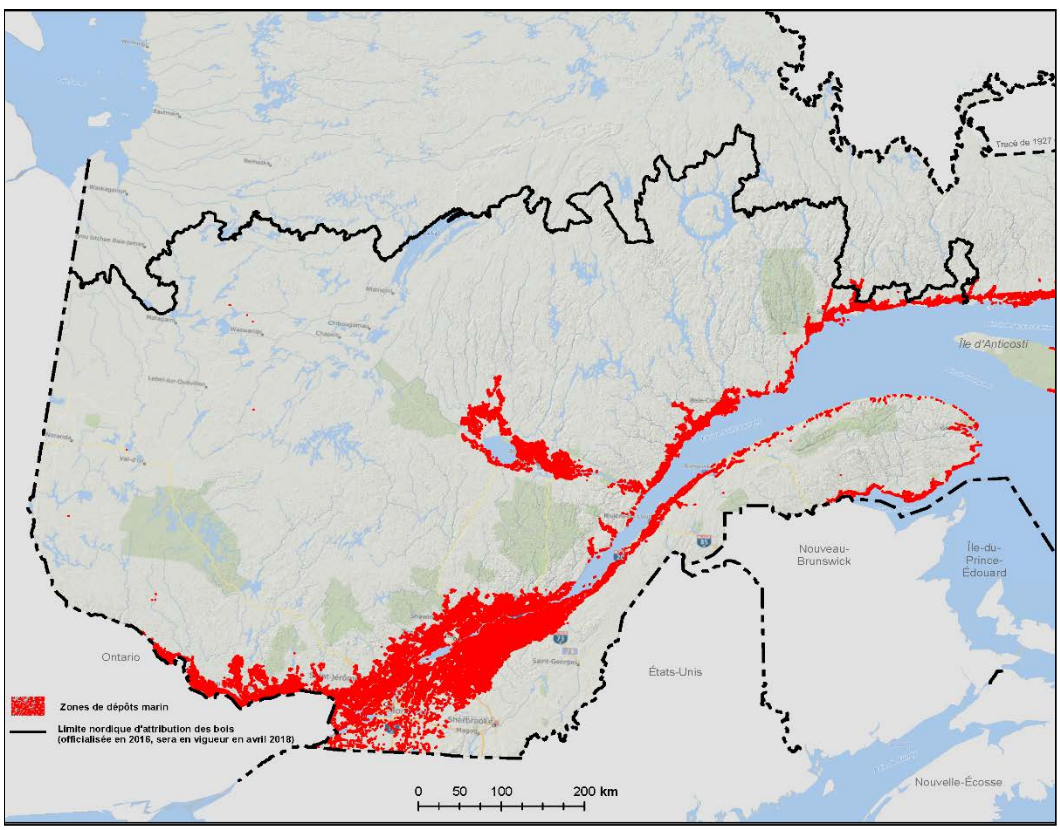


Figure 54. Marine deposit zones in Southern Québec, mapped by the MFFP (4th inventory)

## 3. Description of the Deposit

The characteristics of marine deposits differ according to their proximity to the sediment source and the depth of the water in which they formed. Generally speaking, their particles are finer further from the glacier front and in deeper water (Tranhaile 2013; Benn and Evans, 2010).

The Ministère des Forêts, de la Faune et des Parcs du Québec has identified three types of marine deposits and three types of coastal marine deposits (Table 9) (MFFP, 2014):

Table 9. Marine deposits and coastal marine deposits and their area as a percentage of Southern Québec

| Marine deposits | % | Coastal marine deposits | % |
|---|---|---|---|
| 5a – Marine, deep water facies | 0.5 | 6s – Raised beach | 0.4 |
| 5l – Marine, deep water facies[1] | <0.1 | 6a – Current beach | <0.1 |
| 5s – Marine, shallow water facies | 2 | 6g – Raised block field[2] | - |
| 5g – Glaciomarine[3] | <0.1 | | |

Marine deposits

1. Deep water facies marine deposits usually formed at some distance from the glacier front and are composed of very fine particles of clay and loam, sometimes containing stones and ice-rafted blocks. The factor that differentiates deposit 5l from deposit 5a is the higher percentage of loam in the former (5l). However, this difference alone is insufficient to differentiate them on either an aerial photograph or LiDAR.
2. Shallow water facies marine deposits were formed near the glacier front and are composed of sand and sometimes gravel. They are usually sorted.
3. Glaciomarine deposits were reshaped or formed by the action of water and drift ice, between the highest and lowest water marks. They are composed of clay, sand, gravel, pebbles, stones and blocks, usually rounded. Glaciomarine deposits are rarely mapped in southern Québec.

Coastal deposit

1. Raised beaches are deposits left behind by waves, and mark former sea levels. They are composed of sand, gravel and pebbles, and are sorted and layered. They sometimes contain ice-rafted blocks.
2. Existing beaches were formed by waves marking the upper level of the existing sea shore. Their composition is similar to that of a raised beach, i.e. sorted and layered sand, gravel and pebbles.
3. Block fields were formed by the action of drift ice. Their morphology resembles that of a spit or an offshore bar.

## 4. Identification Criteria

First, it is important to consult maps to make sure the area under study is in a region formerly covered by one of the five postglacial seas. In addition, it is essential to know the altitude reached by the sea's marine limit (Table 10).

All marine deposits are usually found on large plains covering areas of several square kilometres.

Deep water facies marine deposit (5a)

- LiDAR indicators

a) The surface is flat, uniform and may be dissected by gullies caused by erosion from runoff water (Figure 55).
b) The shape of the gulley beds may be an indicator of deposit composition. Flared, U-shaped entrenchment at the gulley head suggests a deposit composed of clay (Figure 56).
c) Gullies are oriented gradually from upstream to downstream of the watercourse (Figures 57 and 58).
d) Frequent signs of landslides suggests the presence of clay in a sector. Landslides are generally shaped in the form of a smooth semi-

[1] Deposit not mapped in Québec.
[2] Not mapped in Québec
[3] Deposit not mapped in Québec.

circle. Their presence increases the probability of a marine deposit, but does not necessarily mean that clay will be present at its surface. Often, the underlying surface of a landslide is composed of clay, while the surface of the plateau on which the landslide originated may be sandy.

e) A dendritic or feather-like hydrographic network with numerous branches on flat land often indicates the presence of a clay deposit (5a).

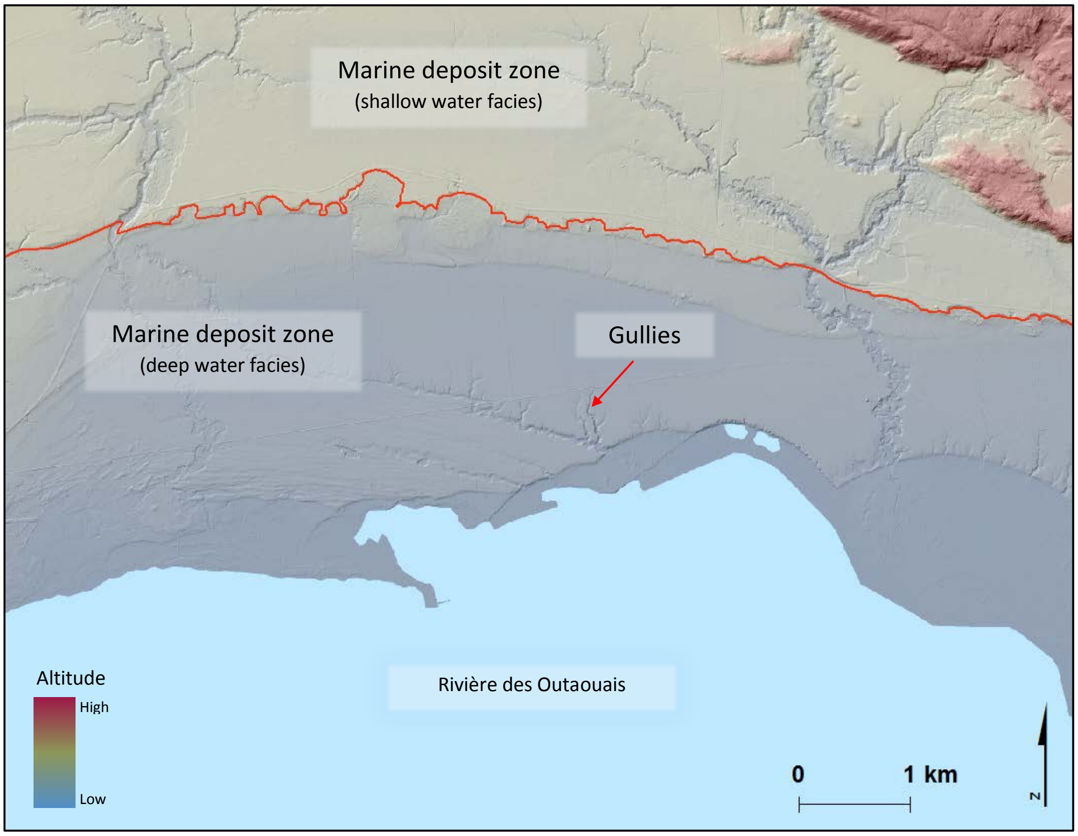


Figure 55. Example of a deep water facies marine deposit (5a), on LiDAR, in the Sugar Maple-Butternut Hickory ecozone

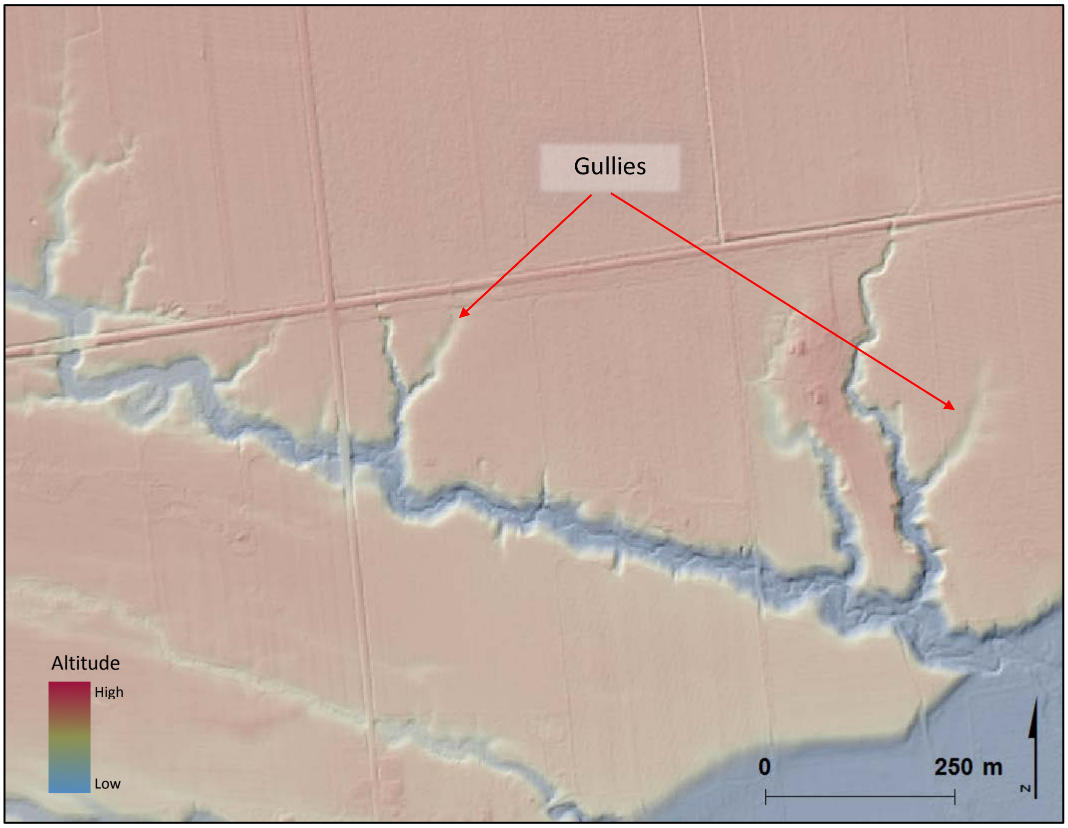


Figure 56. Example of gullies in a deep water facies marine deposit (5a), on LiDAR, in the Sugar Maple-Butternut Hickory ecozone

- Aerial photograph indicators

a) Some LiDAR indicators may also be visible on aerial photographs.
b) The pale coffee brown colour of the watercourses and lakes may indicate the presence of marine clay (Figure 4).
c) Where the soil is exposed (e.g. landslide talus slope or major watercourse erosion), soil colour is an indicator. Clay (5a) will be grey to blue-grey on the photograph (Figure 5). Once the maximum level of the clay has been identified, this altitude can be used as a reference for the entire sector. 5s will always be located at a higher level than 5a.

As for lacustrine deposits, shallow water facies marine deposits sometimes lie on top of deep water facies marine deposits. The identification criteria for these two deposits may therefore be superimposed.

## Shallow water facies marine deposits (5s)

- LiDAR indicators

a) The surface is flat, uniform and may be dissected by gullies created by erosion due to runoff water (Figure 57).
b) The shape of the gullies may be an indicator of surface deposit composition. Rapid, narrow, V-shaped entrenchment at the gulley head is indicative of a sandy deposit (Figures 57 and 58).
c) The gulley sides are striated and their slopes are more pronounced than in clay.
d) The gullies have fewer branches, and the branches are narrower than in clay.

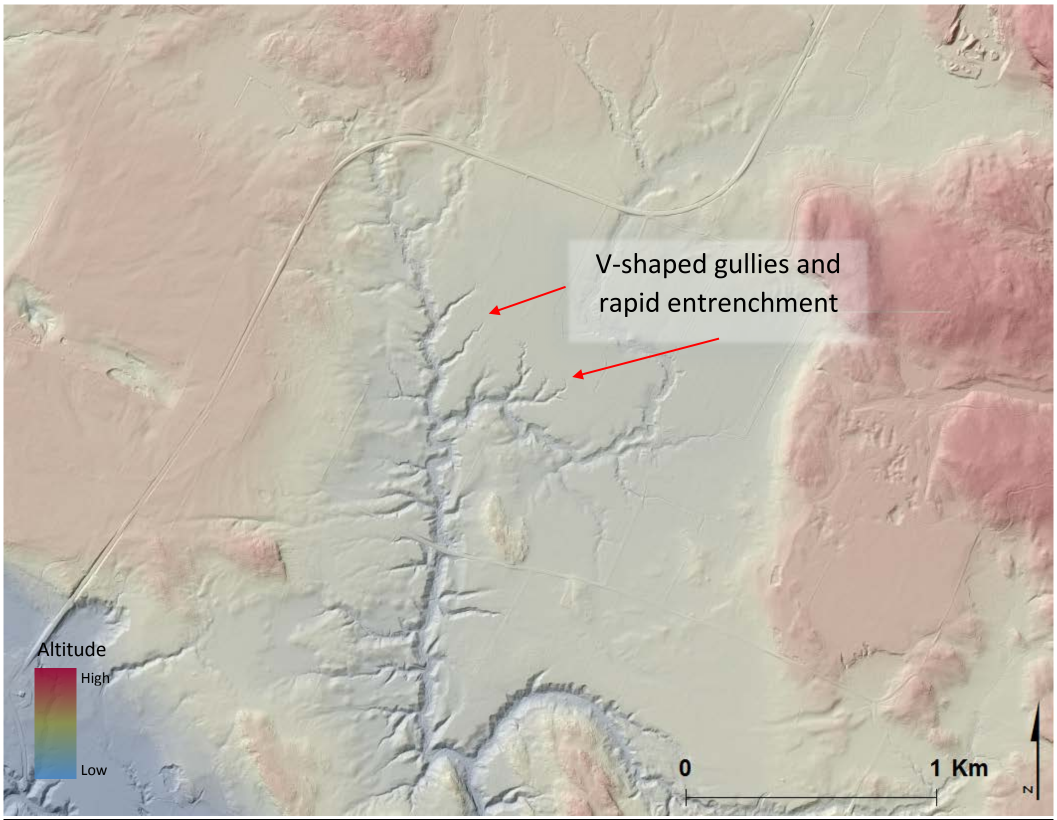


Figure 57. Example of a shallow water facies marine deposit (5s), on LiDAR, in the Sugar Maple-Butternut Hickory ecozone

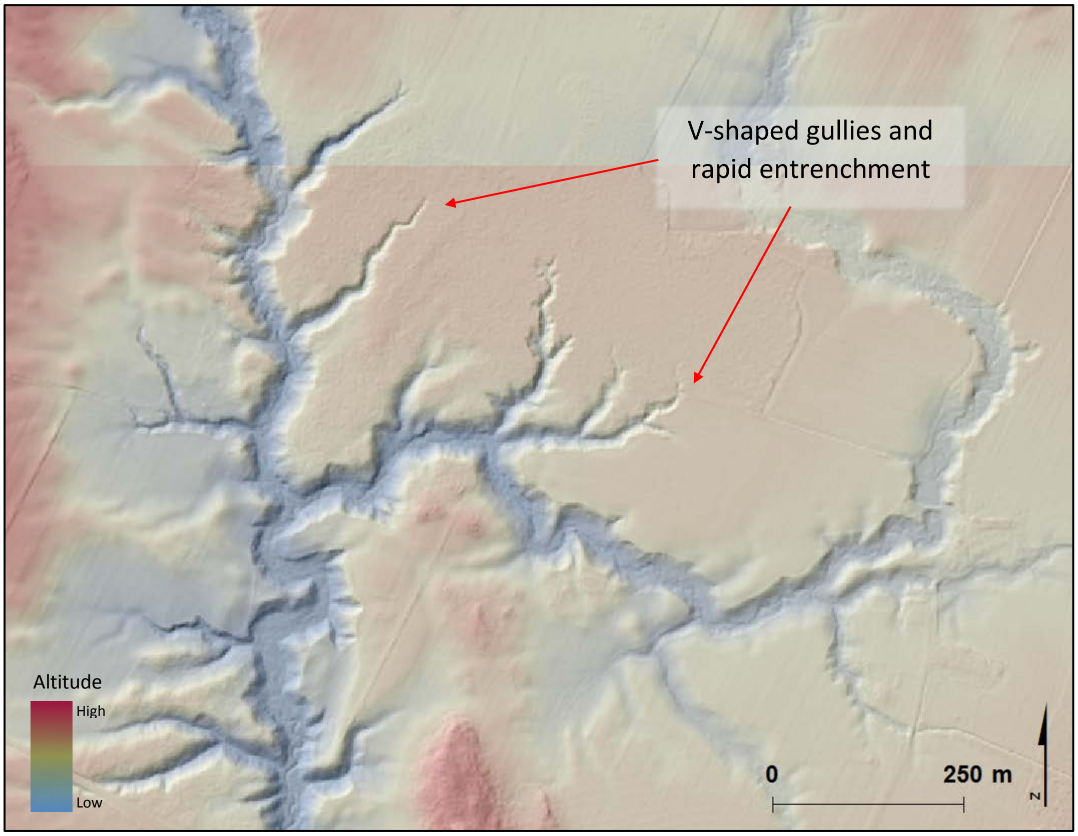


Figure 58. Example of gullies in a shallow water facies marine deposit (5s), on LiDAR, in the Sugar Maple-Butternut Hickory ecozone.

- Aerial photograph indicators

a) Some LiDAR indicators may also be visible on aerial photographs.

b) Where the soil is exposed (e.g. landslide talus slope or major watercourse erosion), soil colour is an indicator. Sand (5s) will be pale grey to yellowish grey on the photograph.


Figure 59. Example of water colour in a deep water facies marine deposit (5a), on an aerial photograph, in the Sugar Maple-Butternut Hickory ecozone


Figure 60. Example of water colour in a deep water facies marine deposit (5a), on an aerial photograph, in the Sugar Maple-Butternut Hickory ecozone

## Raised beach (6s)

- LiDAR indicators

a) Long ridges are visible, often in groups and running parallel to one another (Figures 61 and 62).
b) These ridges, whether continuous or broken, suggest the presence of an ancient shoreline.
c) They often have a stepped appearance on the slope (Figure 62).
d) They are usually located on slopes ranging from gentle to steep.

- Aerial photograph indicators

a) Some LiDAR indicators may also be visible on aerial photographs.
b) Since the ridges are convex and composed of sand, they are often drier and, in boreal environments, support the presence of lichens and limit vegetation density.

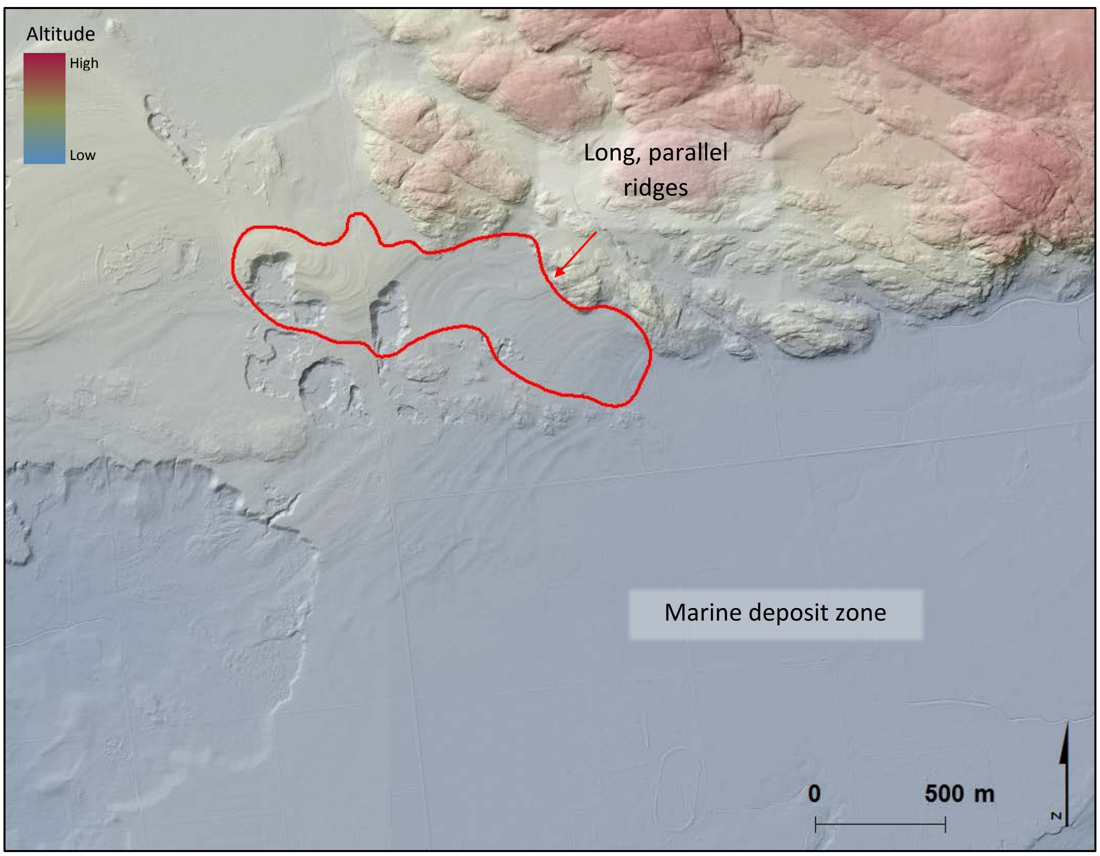


Figure 61. Example of a raised beach (6s), on LiDAR, in the Sugar Maple-Butternut Hickory ecozone

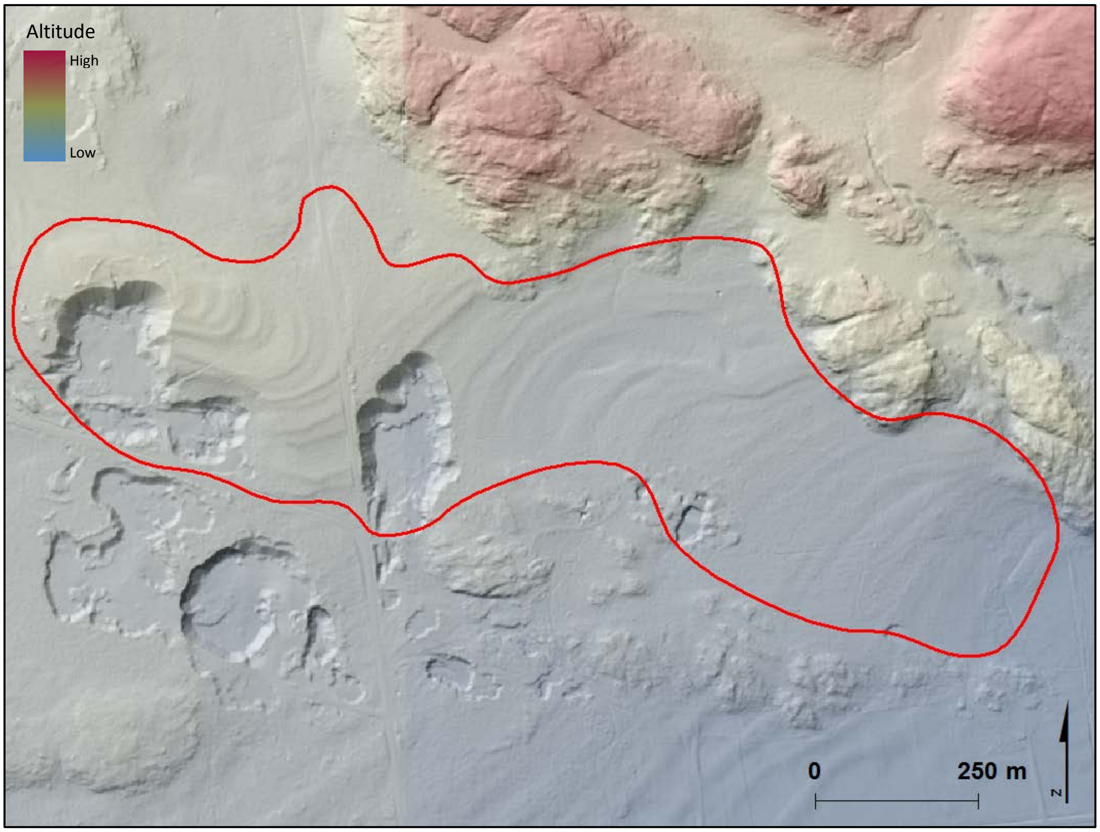


Figure 62. Example of a raised beach (6s), on LiDAR, in the Sugar Maple-Butternut Hickory ecozone

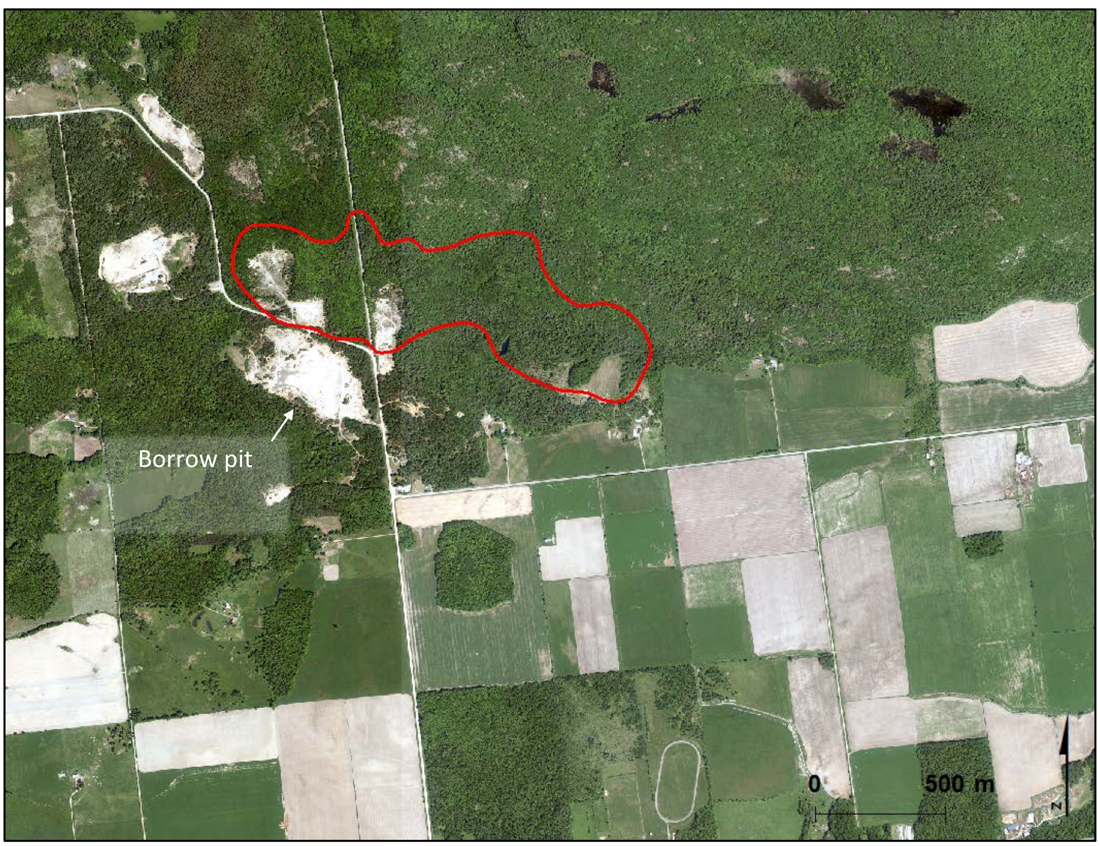


Figure 63. Example of a raised beach (6s), on an aerial photograph, in the Sugar Maple-Butternut Hickory ecozone

Existing beach (6a)

- LiDAR indicators

Aerial photographs provide the best means of identifying these beaches.

- Aerial photograph indicators

a) The beach is located near a body of water and is subject to the action of the tide.
b) There is little to no vegetation.


Figure 64. Example of an existing beach (6a), on an aerial photograph, in the Sugar Maple-Butternut Hickory ecozone

## 5. Borrow Pit Potential

The potential as a source of sand and gravel ranges from zero to moderate, for both marine deposits and coastal marine deposits.

Raised beaches (6s) offer moderate potential due to their composition of sorted, layered sand, gravel and pebbles (MFFP, 2014). A lot of gravel pits are located in this type of deposit.

All the other deposits in these categories offer zero to low potential due to their fine particles (fine sand and clay) or their proximity to the water table.

Table 10. Maximum altitude of the marine limits of Québec's main glacial seas (Taken from Ministère des Forêts, 1991 - 1998. Surface deposit maps. Working document. 1:50 000. Service des inventaires forestiers)

| Map sheets | Altitude (m) | Sources |
|---|---|---|
| 12G01 | 122 | Dubois (1977) |
| 12G03 | 122 | Dubois (1977) |
| 12G05 | 122 | Dubois (1977) |
| 12G06 | 122 | Dubois (1977) |
| 12G07 | 122 | |
| 12G08 | 122 | |
| 12G09 | 122 | |
| 12G11 | 122 | |
| 12K04 | 122 | Dubois (1977) |
| 12K05 | 122 | Dubois (1977) |
| 21G04 | 175 | |
| 21G05 | 200 | |
| 21G06 | 190 | |
| 21G10 | 205 | |
| 21G11 | 205 | |
| 21G12 | 205 | |
| 21G13 | 200 | Lasalle *et al.* (1977); Lasalle (1978) |
| 21G14 | 200 | Lasalle *et al.* (1977) |
| 21G15 | 185 | Lasalle *et al.* (1977) |
| 21G16 | 190 | Lasalle *et al.* (1977) |
| 21M01 | 200 | Lasalle *et al.* (1977) |
| 21M02 | 200 | |
| 21M03 | 200 | Lasalle *et al.* (1977) |
| 21M07 | 190 | Dionne (1977) |
| 21M08 | 190 (N) 167 (S) | Martineau (1977) |
| 21M09 | 190 | Dionne (1977) |
| 21N12 | 167 | Dionne (1977) |
| 21N13 | 188 (N) 166 (S) | Dionne (1972); Dionne (1977) |
| 21N14 | 166 | Dionne (1972) |
| 22A03 | 64 | |
| 22A04 | 45 | |
| 22A07 | 64 | |
| 22A08 | 64 | |
| 22A09 | 64 | |
| 22A15 | 45 | |
| 22A16 | 45 | |
| 22B01 | 61 | Lebuis and David (1977) |
| 22B02 | 61 | Dionne (1977) |
| 22B12 | 112 | Lebuis and David (1977) |
| 22B13 | 112 | Lebuis and David (1977) |
| 22B14 | 85 | Lebuis and David (1977) |
| 22B15 | 85 | Lebuis and David (1977) |
| 22C02 | 166 | Dionne (1972) |
| 22C03 | 166 | Dionne (1972) |
| 22C04 | 168 | Vincent (1989) |
| 22C07 | 155 | Locat (1978) |
| 22C08 | 155 | Locat (1978) |
| 22C09 | 155 | Locat (1978) |
| 22C11 | 152 | Vincent (1989) |
| 22C14 | 152 | Vincent (1989) |
| 22C15 | 152 | Vincent (1989) |
| 22D01 | 167 | Vincent (1989) |
| 22D05 | 167 | Lasalle and Tremblay (1988) |
| 22D06 | 167 | Vincent (1989) |
| 22D08 | 167 | Vincent (1989) |
| 22D11 | 167 | Vincent (1989) |
| 22D12 | 198 | Lasalle and Tremblay (1988) |
| 22D13 | 198 | Lasalle and Tremblay (1988) |
| 22F01 | 152 | Vincent (1989) |
| 22F02 | 152 | Vincent (1989) |
| 22F08 | 152 | Vincent (1989) |
| 22G01 | 64 | |
| 22G02 | 68 | Lebuis and David (1977) |
| 22G05 | 137 | Vincent (1989) |
| 22G06 | 137 | Vincent (1989) |
| 22G11 | 137 | Dredge (1976) |
| 22G14 | 137 | Dredge (1976) |
| 22G15 | 137 | Dredge (1976) |
| 22G15 | 137 | Dredge (1976) |
| 22H01 | 46 | |
| 22H02 | 30 | |
| 22H03 | 53 | |
| 22H04 | 46 | |
| 22I05 | 137 | Dubois (1977, 1980) |
| 22I06 | 140 | Dubois (1977) |
| 22I07 | 140 | Dubois (1977) |
| 22J01 | 137 | Dredge (1976) |
| 22J02 | 137 | Dredge (1976) |
| 22J03 | 137 | Dredge (1976) |
| 22J06 | 140 | Dubois (1977) |
| 22J07 | 140 | Dubois (1977) |
| 22J08 | 137 | Dubois (1977) |
| 22J10 | 140 | Dubois (1977) |
| 31F08 | 200 | Lajoie (1962) |
| 31F09 | 210 | Lajoie (1962) |
| 31F10 | 210 | Lajoie (1962) |
| 31F14 | 210 | Lajoie (1962) |
| 31F15 | 210 | Lajoie (1962) |
| 31F16 | 198 | Lajoie (1962) |

| Map sheets | Altitude (m) | Sources |
|---|---|---|
| 31G01 | 175 | Parent and Occhietti (1988); Elson (1969) |
| 31G02 | 175 | Parent and Occhietti (1988); Elson (1969) |
| 31G05 | 200 | Parent and Occhietti (1988); Elson (1969) |
| 31G08 | 175 | Prichonnet (1977); Richard (1976) |
| 31G09 | 175 | Prichonnet (1977); Richard (1976) |
| 31G10 | 198 | Lajoie (1962, 1967); Richard (1984) |
| 31G11 | 229 | Lajoie (1962, 1967) |
| 31G12 | 210 | Lajoie (1962, 1967) |
| 31G13 | 198 | Lajoie (1962, 1967) |
| 31G14 | 229 | Lajoie (1962, 1967) |
| 31G15 | 229 | Lajoie (1962, 1967); Richard (1984) |
| 31G16 | 230 | Prichonnet (1977); Elson (1969) |
| 31H02 | 175 | Parent and Occhietti (1988); Elson (1969) |
| 31H03 | 175 | Parent and Occhietti (1988); Elson (1969) |
| 31H04 | 175 | Parent and Occhietti (1988); Elson (1969) |
| 31H05 | 175 | Parent and Occhietti (1988); Elson (1969) |
| 31H06 | 175 | Parent and Occhietti (1988); Elson (1969) |
| 31H07 | 175 | Parent and Occhietti (1988); Elson (1969) |
| 31H09 | 175 | Parent (1987) |
| 31H10 | 175 | Parent and Occhietti (1988); Elson (1969) |
| 31H11 | 150 | Parent and Occhietti (1988); Elson (1969) |
| 31H12 | 175 | Prichonnet (1977); Elson (1969) |
| 31H13 | 228 | Prichonnet (1977); Elson (1969); Tremblay (1977) |
| 31H14 | 150 | Parent and Occhietti (1988); Elson (1969) |
| 31H16 | 175 | Prichonnet (1977) |
| 31I02 | 150 | Prichonnet (1977) |
| 31I03 | 175 | Prichonnet (1977) |
| 31I04 | 235 | Prichonnet (1977); Elson (1969); Tremblay (1977) |

| Map sheets | Altitude (m) | Sources |
|---|---|---|
| 31I05 | 229 | Parry and MacPherson (1964) |
| 31I06 | 183 | Parry and MacPherson (1964) |
| 31I07 | 185 | Occhietti, S. (1980) |
| 31I08 | 200 | Occhietti, S. (1980) |
| 31I09 | 198 | Occhietti, S. (1980) |
| 31I10 | 185 | Occhietti, S. (1980) |
| 31I11 | 183 | Allard (1978) |
| 31I15 | 183 | Occhietti, S. (1980) |
| 32A09 | 183 | Lasalle and Tremblay (1988) |
| 32A10 | 198 | Lasalle and Tremblay (1988) |
| 32A15 | 198 | Lasalle and Tremblay (1988) |
| 32A16 | 198 | Lasalle and Tremblay (1988) |
| 32G10 | 225 | Vincent (1989) |
| 32G15 | 225 | Vincent (1989) |
| 32G16 | 225 | Vincent (1989) |
| 32K13 | 240 | Vincent (1989) |
| 32N02 | 240 | Vincent (1989) |
| 32N03 | 240 | Vincent (1989) |
| 32N04 | 240 | Vincent (1989) |

# Organic Deposits

Organic deposits are deposits in which organic matter accumulates more quickly than it decomposes. They offer zero potential for borrow pits (sand and gravel).

## 1. Formation

These deposits form in areas where poor drainage conditions and weather are conducive to the accumulation of organic matter.

## 2. Location

Organic environments are found throughout Québec, mainly in areas where the topography around ponds or large plains does not allow for quick surface water runoff. The number of organic environments increases from south to north.

## 3. Deposit Description

Organic deposits are composed of organic matter from sphagnum, moss or ground vegetation litter, at various stages of decomposition. The wet environments in which they develop usually support only low vegetation, but occasionally host forest growth. The thickness of the organic layer can vary from a few centimetres to several metres.

The Ministère des Forêts, de la Faune et des Parcs du Québec has identified two types of organic deposits (Table 11) (MFFP, 2014; Robitaille and Dionne, 2007):

Table 11. Organic deposits and their area as a percentage of southern Québec

| Organic deposits | % |
|---|---|
| 7t – Thin organic | 4.9 |
| 7e – Thick organic | 7.8 |

1. In thin organic deposits, accumulations are less than one metre thick.
2. In thick organic deposits, accumulations are more than one metre thick.

## 4. Identification Criteria

The following criteria apply more to thin and thick organic deposits in the boreal forest, and less so to the sugar maple domains.

<u>Thin organic deposits (7t)</u>

- LiDAR indicators

a) LiDAR is useful for locating the boundaries of wetland areas, mostly when the wetlands are located in a glacial deposit set. In these cases, the deposit's topography is flat and contrasts with surrounding deposits (Figure 65).
b) However, aerial photographs provide all the indicators needed to identify these deposits.

- Aerial photograph indicators

a) The topography is flat (Figure 65).
b) The forest species that grow in these areas tolerate drainage conditions ranging from imperfect to very poor.
c) Generally speaking, tree vegetation is present but is not as tall and is also less dense (Figures 66 and 67). Heathland and sphagnum can usually be seen between the trees.
d) There may be outcrops of unconsolidated mineral deposits or rocks in some situations.

## Thick organic deposits (7e)

- LiDAR indicators

a) LiDAR is useful for locating the boundaries of wetland areas, mostly when the wetlands are located in a glacial deposit set. In these cases, the deposit's topography is flat and contrasts with the surrounding deposits (Figure 65).
b) However, aerial photographs provide all the indicators needed to identify these deposits.

- Aerial photograph indicators

a) The topography is flat (Figure 65);
b) There are usually no trees and the terrain is not rough (Figures 66 and 67).
c) Pools of water are common.

Thick organic deposits are usually covered in sphagnum and heath.

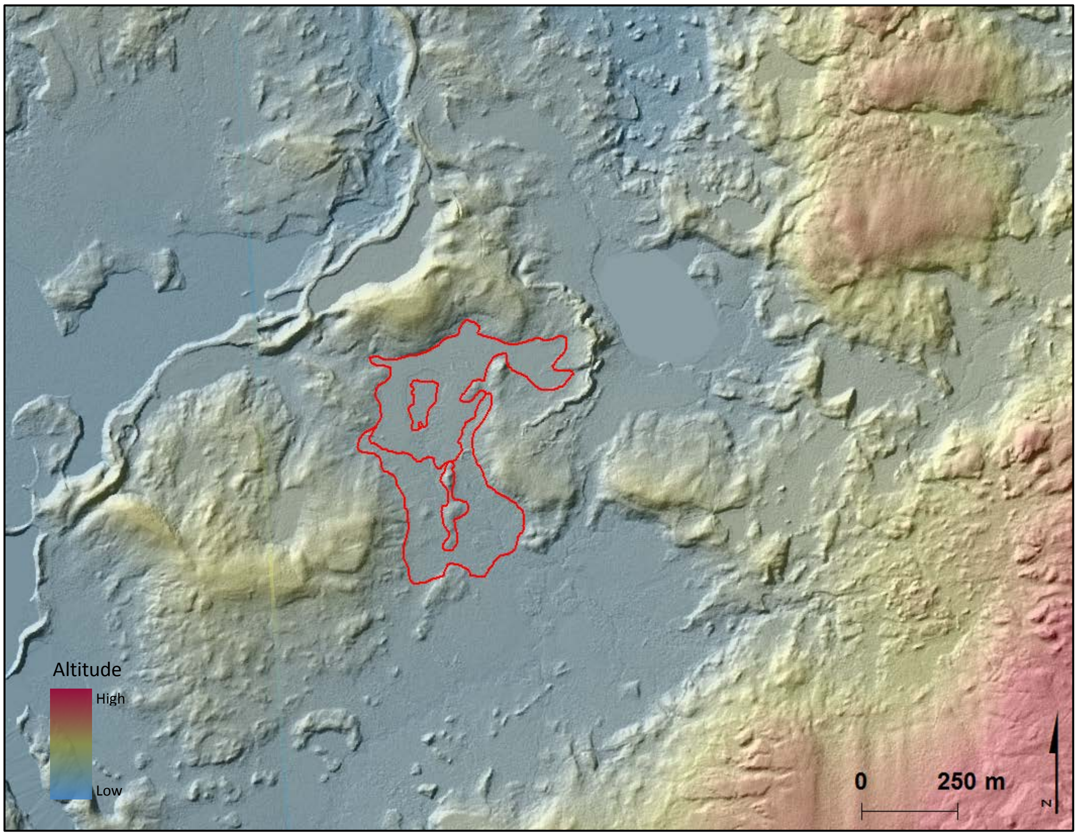


Figure 65. Example of thin and thick organic deposits, on LiDAR, in the Eastern Balsam Fir-White Birch ecozone

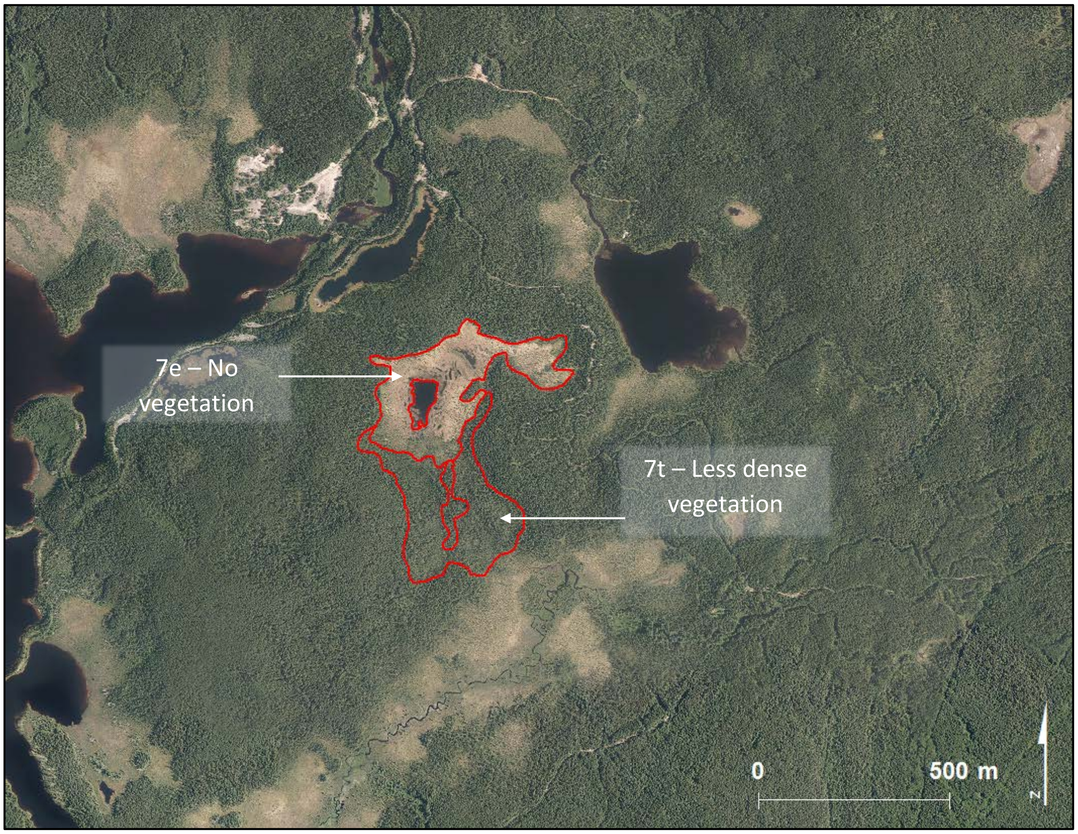


Figure 66. Example of thin and thick organic deposits, on an aerial photograph, in the Eastern Balsam Fir-White Birch ecozone

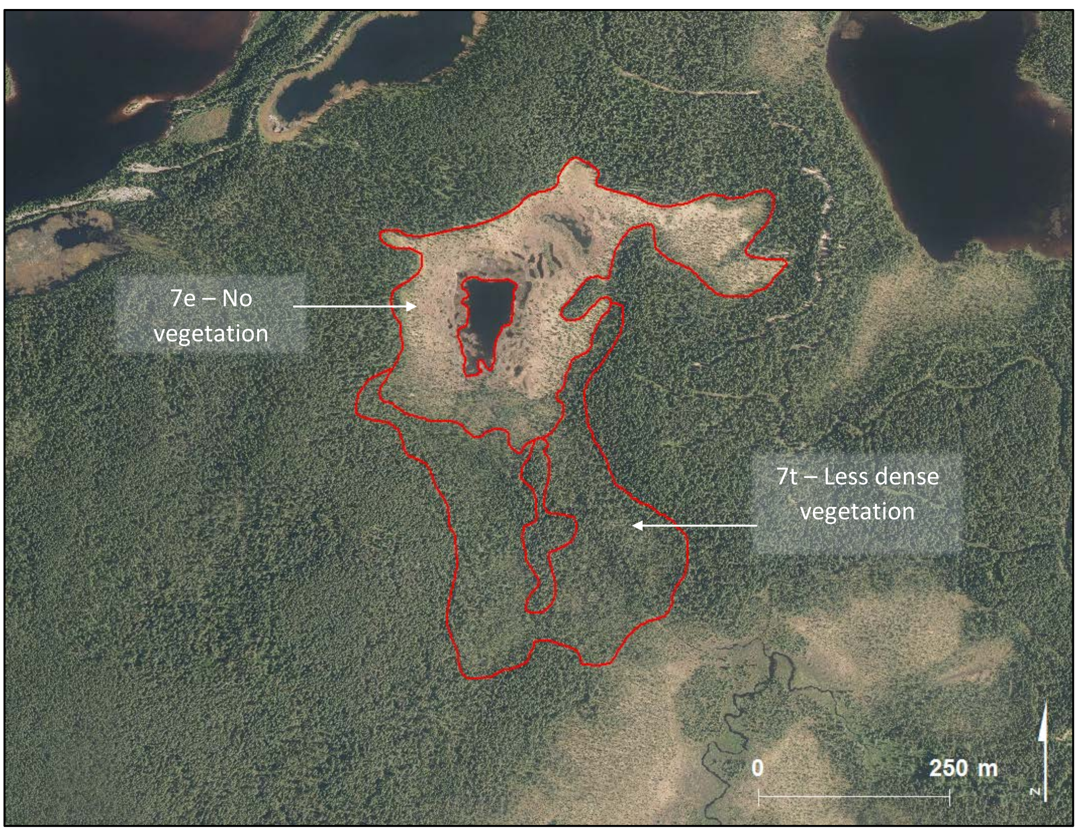


Figure 67. Example of thin and thick organic deposits, on an aerial photograph, in the Eastern Balsam Fir-White Birch ecozone

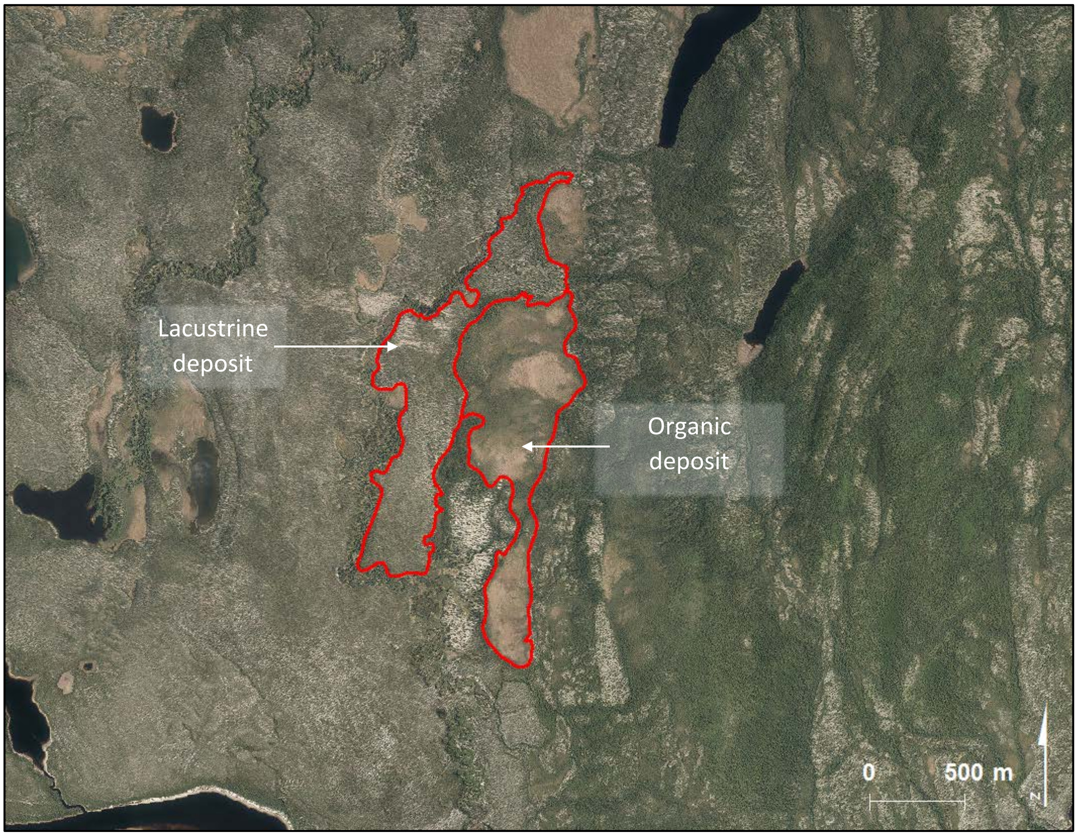


Figure 68. Example of an organic deposit adjacent to a lacustrine deposit, on an aerial photograph, in the Western Spruce-Moss ecozone

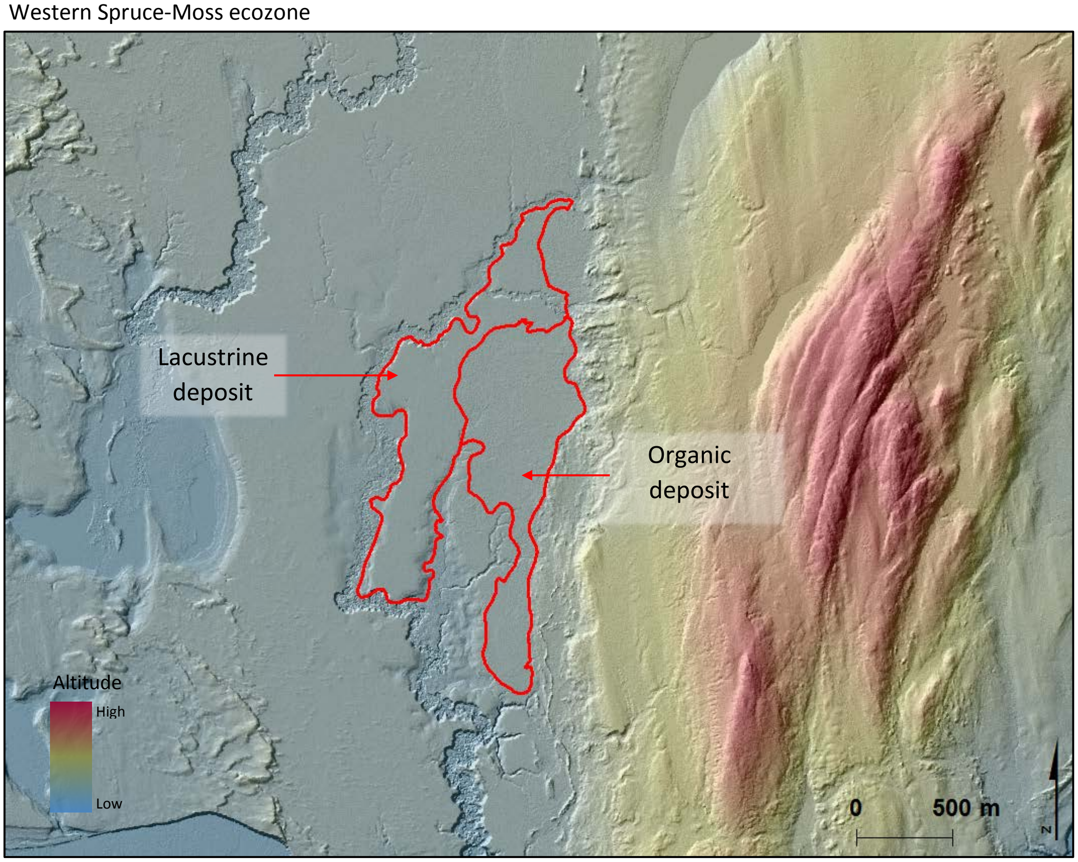


Figure 69. Example of an organic deposit adjacent to a lacustrine deposit, on LiDAR, in the Western Spruce-Moss ecozone

## 5. Borrow Pit Potential

These deposits offer zero potential for as an aggregate source.

# Slope Deposits and Altered Deposits

Slope deposits and altered deposits were formed by alteration of the rock base, surface water runoff or gravity. Their Borrow Pit Potential (sand and gravel) is zero.

## 1. Formation

Slope deposits and altered deposits were formed by different processes. Alteration of the rock base is a slow process that involves disintegration of the basement rock surface. There are many chemical, physical or biological causes of this type of erosion (Gutiérrez, 2013). Surface water runoff and gravity can also lead to the formation of slope and alteration deposits (MFFP, 2014).

## 2. Location

Slope deposits (Table 12) can be found throughout Québec, in locations where steep slopes and rock escarpments are present, and also in areas with large expanses of sand or clay conducive to landslides.

Alteration deposits (Table 12) are more likely to be found in certain regions of Québec, including Gaspésie, due among other things to the nature of the geological foundation, which is composed mainly of sedimentary and metasedimentary rock (sandstone, limestone, mudrock and shale) (Thériault, 2012).

Table 12. Slope and alteration deposits and their area as a percentage of southern Québec.

| Slope deposits | % | Alteration deposits | % |
|---|---|---|---|
| 8e – Rock scree | <0.1 | 8a – Alteration materials | 4.2 |
| 8c – Colluvium | 0.8 | 8f – Felsenmeers | <0.1 |
| 8g – Landslides | <0.1 | | |
| 8p – Translational slides | <0.1 | | |

## 3. Deposit Description

Particle sizes in slope and alteration deposits differ widely due to the different formation processes. The most common slope and alteration deposits are listed below (MFFP, 2014).

Slope deposits:

1. Scree is found over all or part of a steep flank. It is created by gravity, following mechanical alteration of the bedrock (mainly by gelifraction). It is composed of stones and angular boulders. The coarser sediment is found at the bottom of the slope.
2. Colluviums are formed on steep slopes by the action of runoff and gravity. They can occur in all types of sediment, including on the surface of friable bedrock. They are often responsible for recesses at the bottom of slopes. Colluviums can be differentiated from scree by particle size. They are usually composed of fine, sometimes bedded sediment accumulated at the bottom of a flank.
3. Landslides are caused by ground movements on flanks composed of unconsolidated sediment. They can be recognized by their distinctive spoon shape and the presence of a chaotic heap of sediment at the bottom of a slope. They comprise different types of sediments, usually clay, loam or sand.
4. Translational slides occur on steep slopes covered by thin deposits. A portion of the unconsolidated deposit separates from the wall and slides over the rock to the bottom of the slope, carrying with it any unconsolidated materials and vegetation in its path. The resulting debris is composed of a variety of elements (e.g. mineral soil and plant debris) (Dionne and Fillion, 1984).

Altered deposits:

1. Altered material is produced by the action of atmospheric agents, such as disintegration, dissolution or chemical alteration of the bedrock. It is composed of angular sediment particles of varying sizes, and is usually made up of fine materials (from clay to gravel) when it is derived from sedimentary

bedrock, and of coarser materials (from sand to pebbles) in crystalline environments.

2. Felsenmeers or block fields are formed by the action of weather. They occur in non-glacial environments as a result of frost-related processes and reliefs. In southern Québec, they are found on the high peaks of Gaspésie. They are composed of relatively unconsolidated angular boulders and stones, and may include striated and polygonal soils.

## 4. Identification Criteria

Scree (8e)

- LiDAR indicators

a) Scree is found at the bottom of the cliff wall from which the rock fell, at the point where the angle of the slope changes abruptly (shallower slope) (Figures 70 and 71).
b) The surface appears rough, uneven and rugged where the boulders are large (Figure 72).

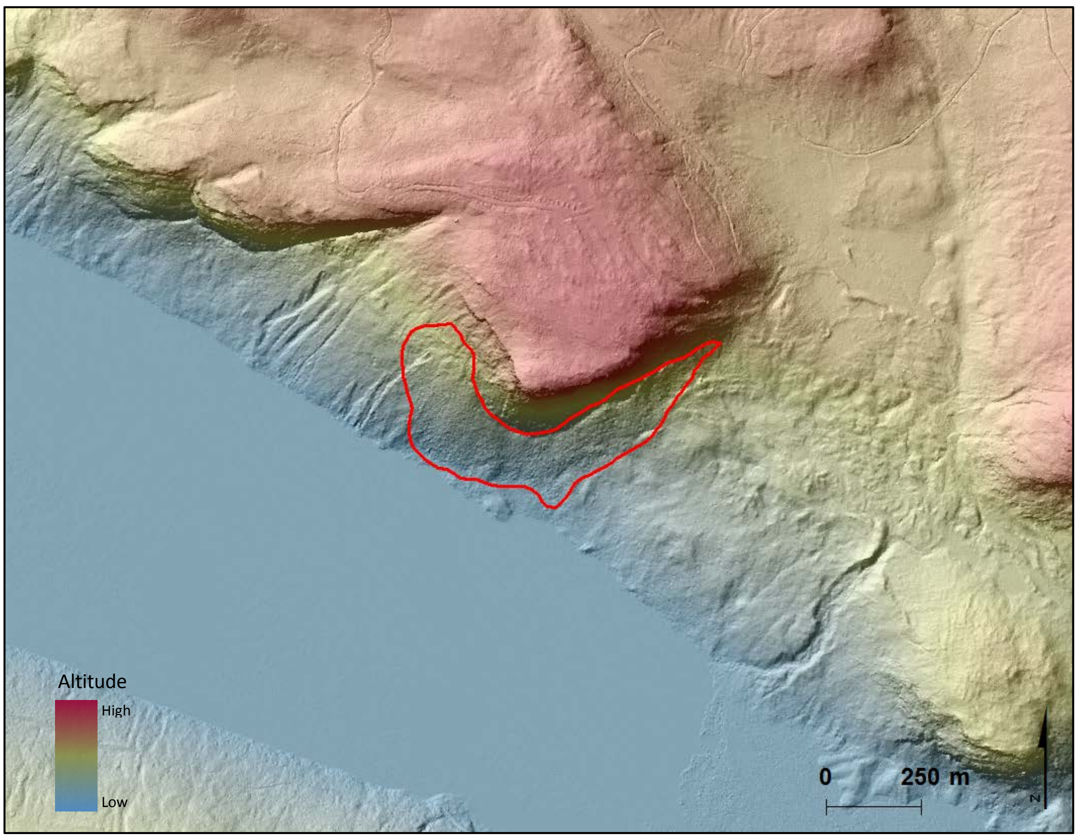


Figure 70. Example of scree (8e), on LiDAR, in the Eastern Balsam Fir-White Birch ecozone

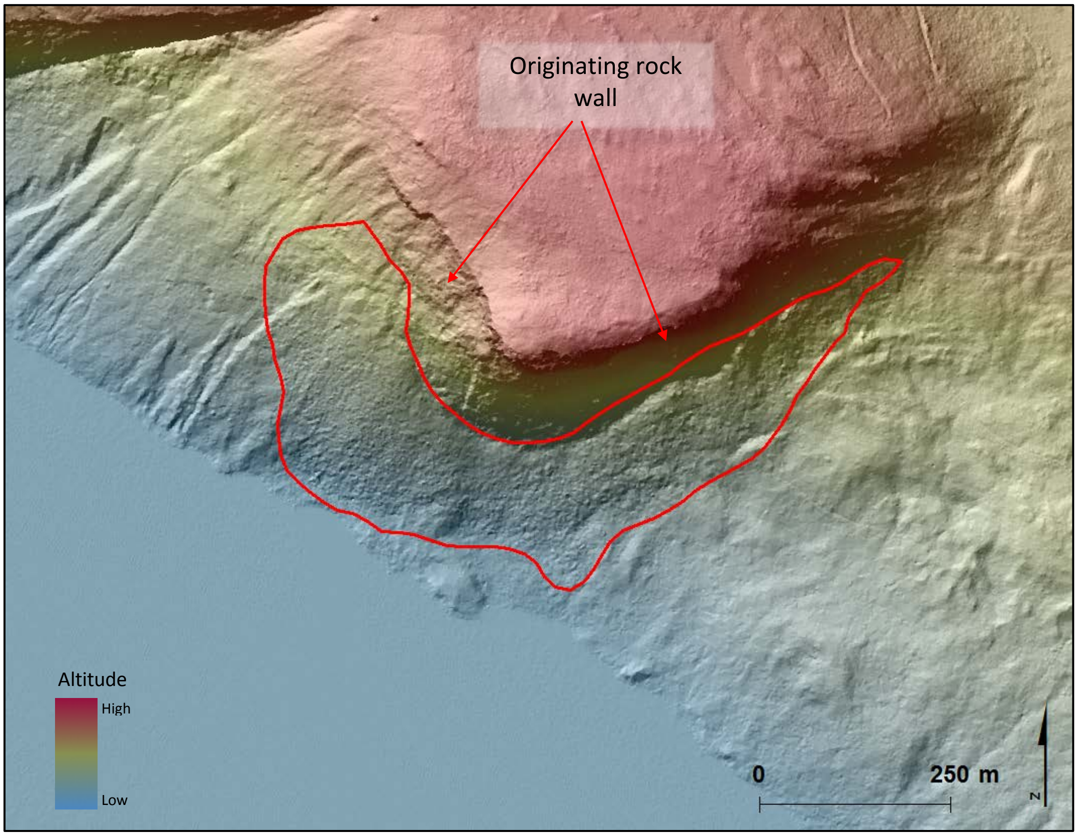


Figure 71. Example of scree (8e), on LiDAR, in the Eastern Balsam Fir-White Birch ecozone

- Aerial photograph indicators

a) LiDAR indicators may also be visible on aerial photographs if they are not hidden by vegetation.
b) There is an originating rock wall that is usually vegetation-free because it is too steep (Figure 72).
c) In the scree, it is possible to see piles of rock fragments or very rugged ground through the vegetation.

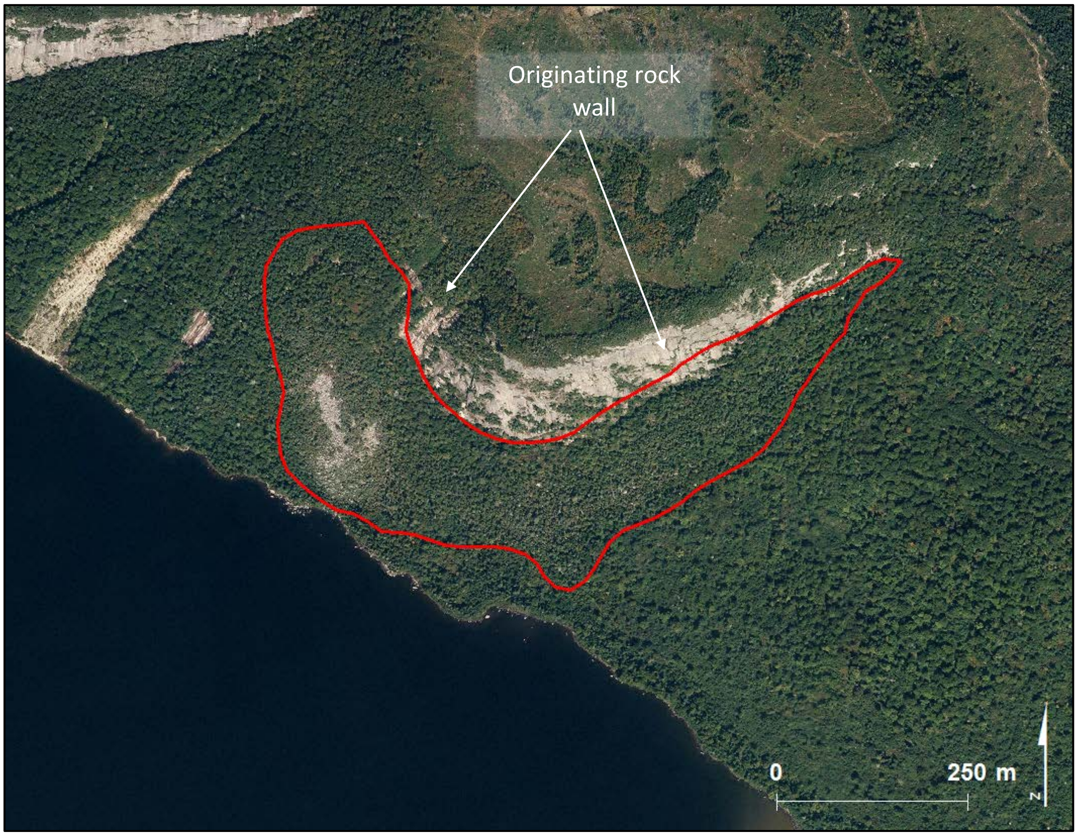

Figure 72. Example of scree (8e), on an aerial photograph, in the Eastern Balsam Fir-White Birch ecozone

## Colluviums (8c)

- LiDAR indicators

a) These deposits originate on steep slopes covered with unconsolidated material such as till or altered bedrock fragments. They are often found at the bottom of slopes, where the angle of the slope changes. In Québec, colluviums are found mainly in Gaspésie, in the high peak sectors, on steep gulley walls (Figure 73).

b) Generally speaking, the presence of colluviums is deduced rather than identified on both LiDAR and aerial photographs.

- Aerial photograph indicators

LiDAR indicators may also be visible on aerial photographs if they are not hidden by vegetation.

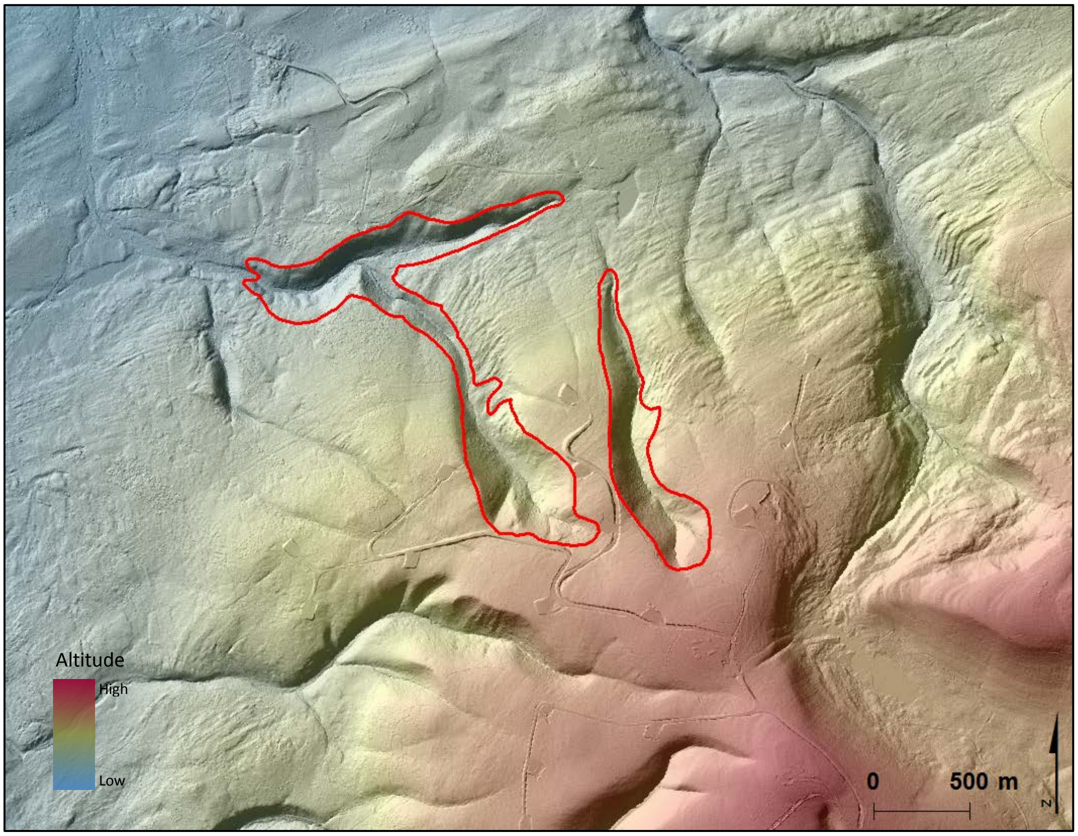


Figure 73. Example of colluviums (8c), on LiDAR, in the Eastern Balsam Fir-White Birch ecozone

<u>Landslides (8g)</u>

- LiDAR indicators

a) Landslides are usually seen on the edges of plains and plateaus composed of thick unconsolidated materials, alongside entrenched watercourses and large expanses of water (Figure 74).
b) A landslide is an accumulation of material at the bottom of a gash in the landscape.
c) In clay areas, the gash may look as though it was scooped out by a giant spoon.
d) The gash curves away from the landslide (Figure 75).
e) The material accumulated by this type of slide often looks like a series of undulating parallel lines, similar to the steps of a staircase, ending with the main hump at the bottom of the slide.

- Aerial photograph indicators

LiDAR indicators may also be visible on aerial photographs if they are not hidden by vegetation.

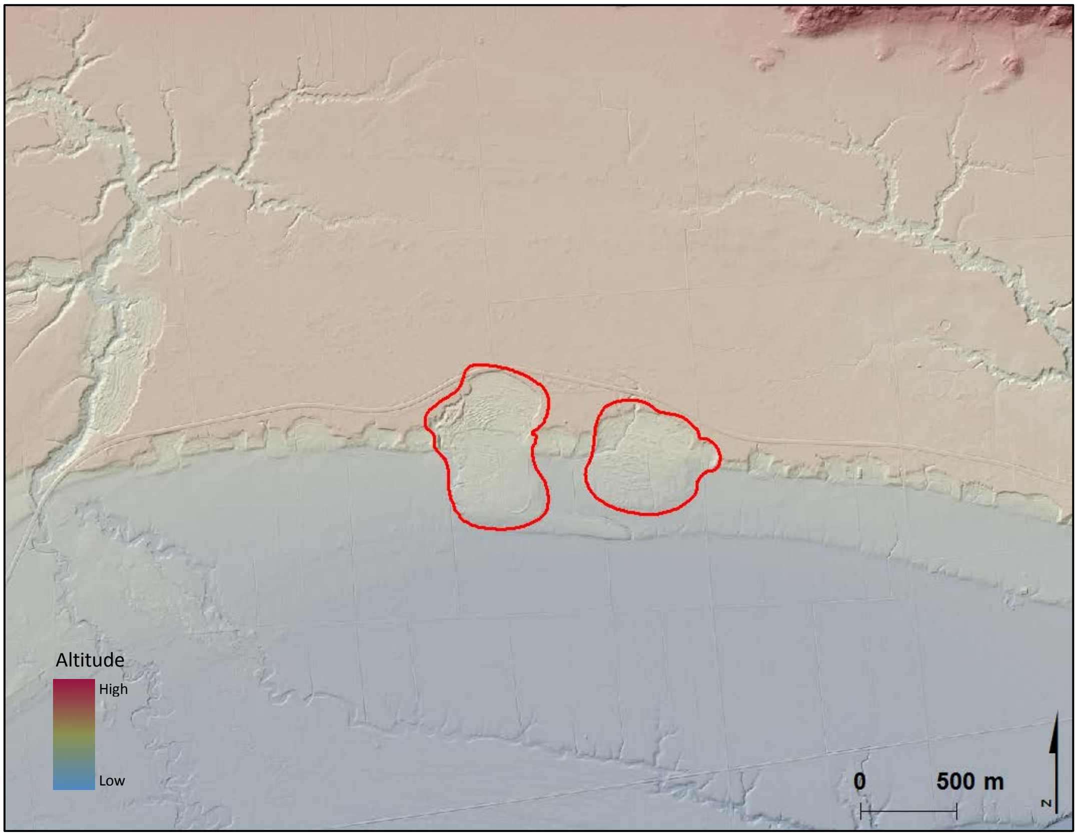


Figure 74. Example of a landslide (8g), on LiDAR, in the Sugar Maple-Butternut Hickory ecozone

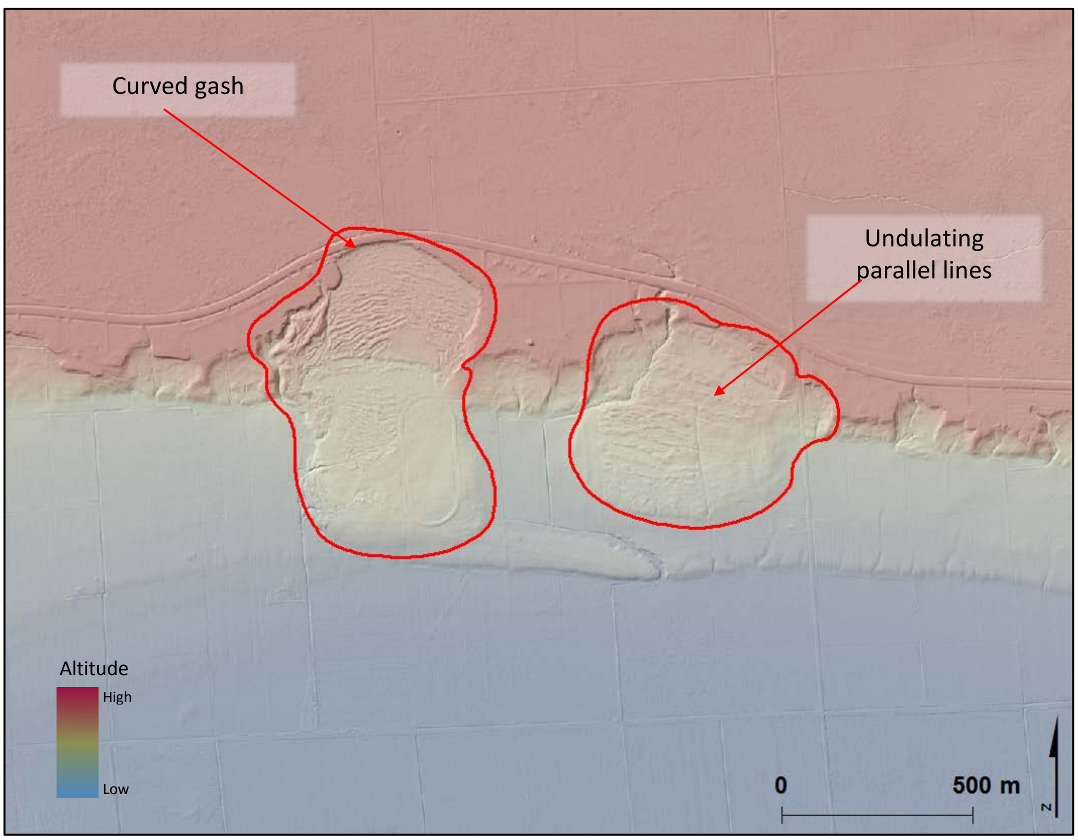


Figure 75. Example of a landslide (8g), on LiDAR, in the Sugar Maple-Butternut Hickory ecozone

## Translational slides (8p)

- LiDAR indicators

a) These elements are usually located on steep slopes of hills or mountains (Figure 76).
b) They are found mainly at the top of the slope and mid-slope.
c) They look like narrow linear cracks in the unconsolidated material, following the direction of the slope (Figures 76 and 77).

- Aerial photograph indicators

a) LiDAR indicators may also be visible on aerial photographs if they are not hidden by vegetation.
b) A narrow linear crack is seen, exposing the rock at the point where the layer of unconsolidated material detached and slid to the bottom of the slope, forming a debris pile (Figure 78).

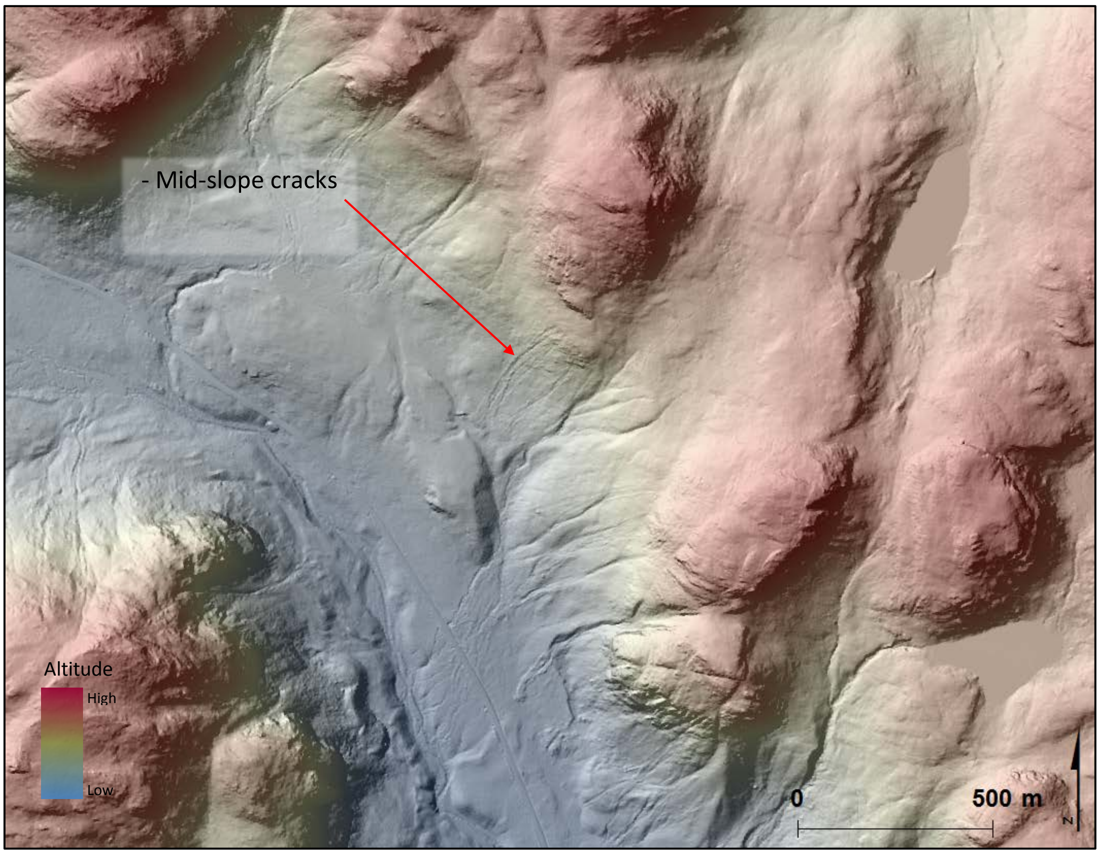


Figure 76. Example of a translational slide (8p), on LiDAR, in the Eastern Balsam Fir-White Birch ecozone

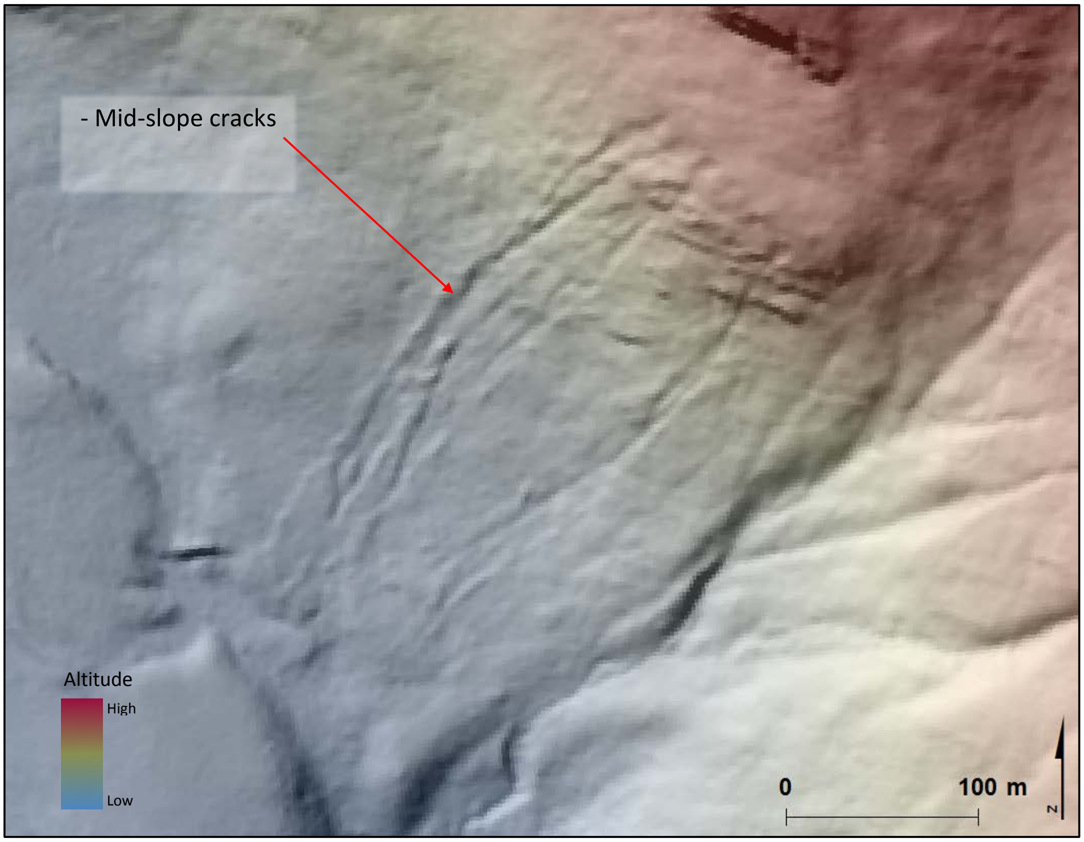


Figure 77. Example of a translational slide (8p), on LiDAR, in the Eastern Balsam Fir-White Birch ecozone


Figure 78. Example of a translational slide (8p), on an aerial photograph, in the Eastern Balsam Fir-White Birch ecozone

## Altered materials (8a)

- LiDAR indicators

a) There are few criteria that can be directly observed on aerial photographs or LiDAR. Geographical location is the best indicator.
b) These materials are found mainly on the high peaks of Gaspésie and on Anticosti Island.
c) Soil texture on hillshaded models appears smooth with virtually no roughness (Figure 79).
d) In some cases till can be detected from its position on the slope and its rough texture. Altered material is found at the tops of slopes and on plateaus, and appears to have a smoother texture than till.

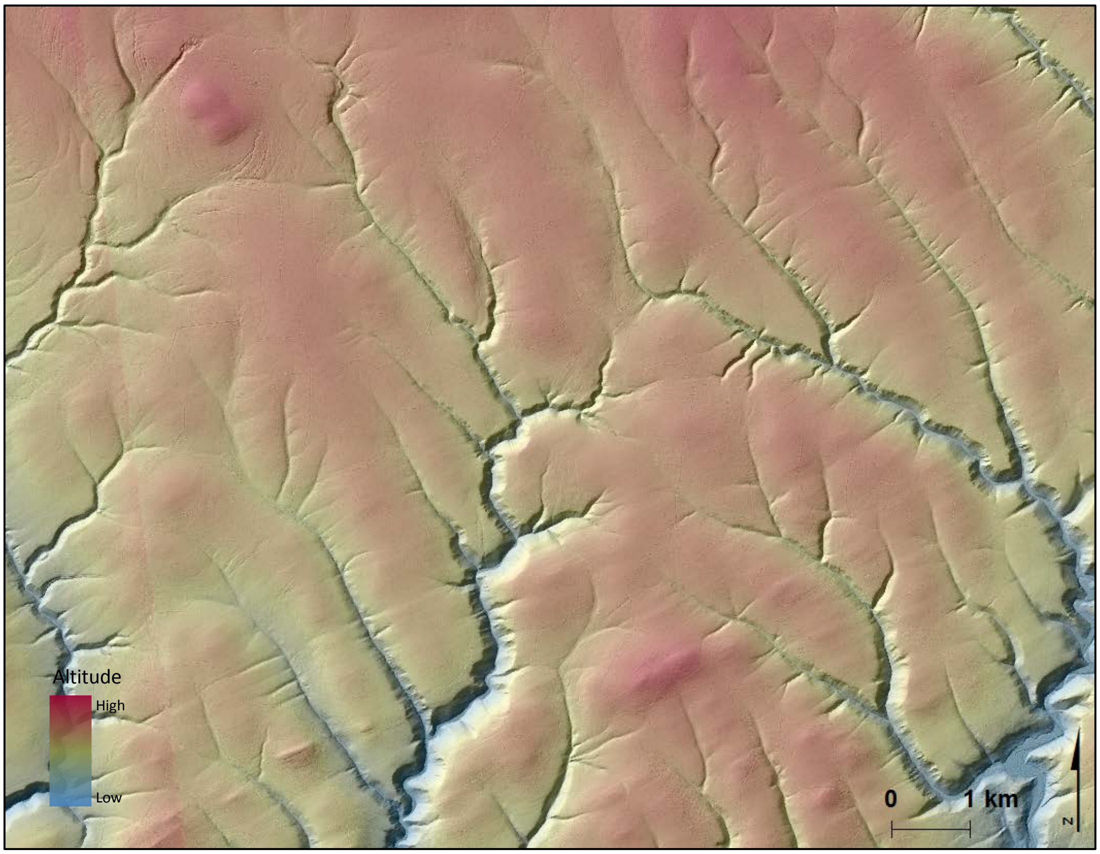

Figure 79. Example of altered material (8a), on LiDAR, in the Eastern Balsam Fir-White Birch ecozone

## Felsenmeer (8f)

- LiDAR indicators

The current spatial resolution of hillshaded models cannot currently distinguish these features.

- Aerial photograph indicators

a) There is little to no vegetation (Figure 80).
b) The soil appears grey in colour because of its stoniness and the absence or lack of matrix.
c) The soil looks rough because of its fragmented stoniness and the fact that it is exposed to the weather.

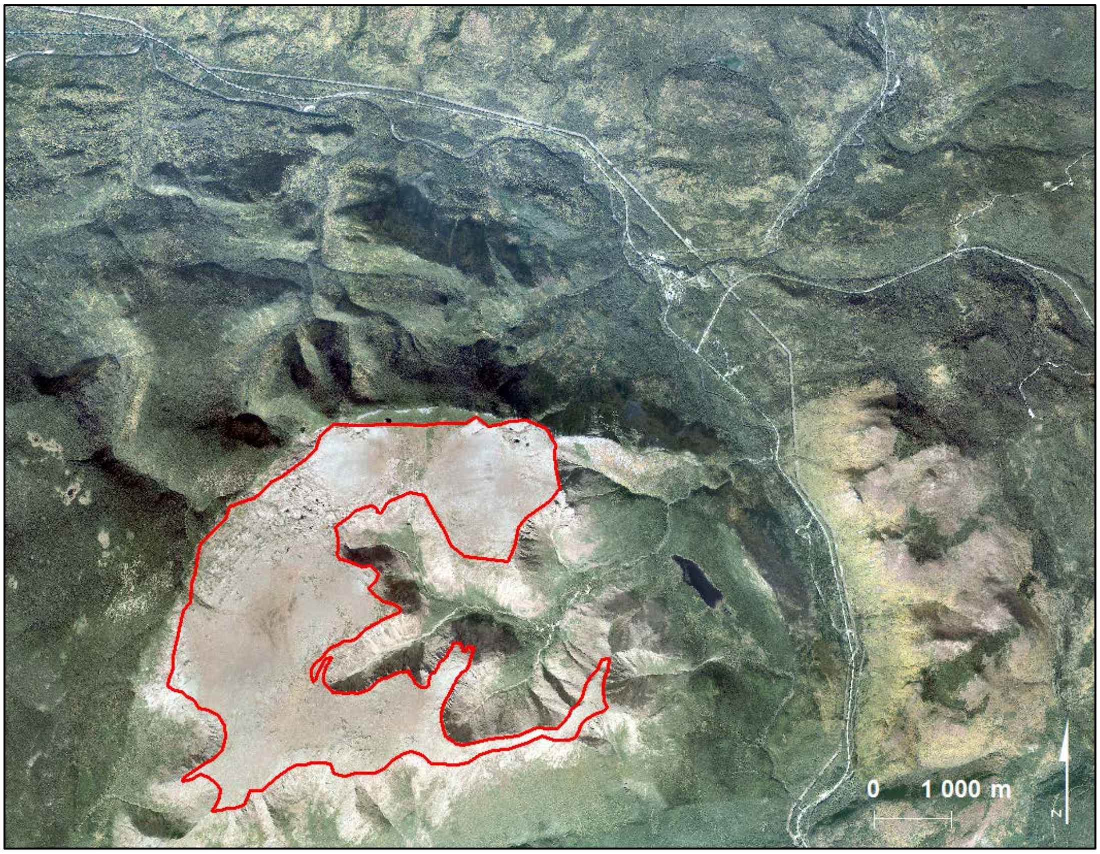


Figure 80. Example of a felsenmeer (8f), on an aerial photograph, in the Eastern Balsam Fir-White Birch ecozone

## 5. Borrow Pit Potential

These deposits offer zero potential as aggregate sources.

# Eolian Deposits

Eolian deposits are dunes formed by the wind. They are composed of fine to moderate sand that offer some potential for forest road repairs. However, their potential as an aggregate source is zero.

## 1. Formation

Wind, like water and glaciers, can act as an agent of erosion, transportation or sedimentation (Gutiérrez, 2013). Eolian deposits are accumulations of sand formed by the wind. They reflect the balance between erosion and sedimentation, both of which affect the shape of the dune (Lancaster, 1995). They are shaped in the form of long humps or crescents, known as longitudinal or parabolic (U-shaped) dunes. Since the wind is only able to transport fine particles of sand, the dunes are composed of glaciofluvial, glaciolacustrine or marine sand (MFFP 2014; Robitaille and Allard, 2007; Trenhaile, 2013).

## 2. Location

Eolian deposits are found throughout Québec. The dunes are associated with sandy deposits in glaciofluvial, lacustrine or marine plains and valleys. They occasionally overlap onto bordering till or rock walls.

## 3. Deposit Description

Eolian deposits can be several metres thick and several dozen metres long. They are bedded, sorted and usually composed of fine to moderate sand particles (MFFP 2014; Robitaille and Allard, 2007).

The Ministère des Forêts, de la Faune et des Parcs du Québec has identified two types of eolian deposits (Table 13) (MFFP, 2014):

Table 13. Eolian deposits and their area as a percentage of southern Québec

| Eolian deposits | % |
|---|---|
| 9a – Active dune | <0.1 |
| 9s – Stabilized dune | 0.16 |

1. An active dune is reshaped constantly by the wind (dynamic dune), meaning that it cannot be colonized by vegetation.
2. A stabilized dune is no longer affected by the wind and has been stabilized by vegetation growth.

## 4. Identification Criteria

Active dune (9a)

- LiDAR indicators

a) The dune is located in an extensive sector of sandy deposits (outwash plain, lacustrine plain, marine plain, etc.).
b) The land is relatively flat.
c) The dune's shape is curved or sinuous. The deflation basin is visible inside the curve of the dune.
d) If several dunes are grouped together, most of the curves are oriented in the same direction.
e) Aerial photographs are required to identify active dunes, since the absence of vegetation is a key factor.

- Aerial photograph indicators

a) LiDAR indicators may also be visible on aerial photographs if they are not hidden by vegetation.
b) The dune's surface is bare.

## Stabilized dune (9s)

- LiDAR indicators

a) The dune is located in an extensive sector of sandy deposits (outwash plain, lacustrine plain, marine plain, etc.) (Figure 81).
b) The land is fairly flat.
c) The dune's shape is curved or sinuous. The deflation basin is visible inside the curve of the dune (Figure 82).
d) If several dunes are grouped together, most of the curves are oriented in the same direction.

- Aerial photograph indicators

a) LiDAR indicators may also be visible on aerial photographs if they are not hidden by vegetation.
b) The dune's surface is covered in vegetation (Figure 83).

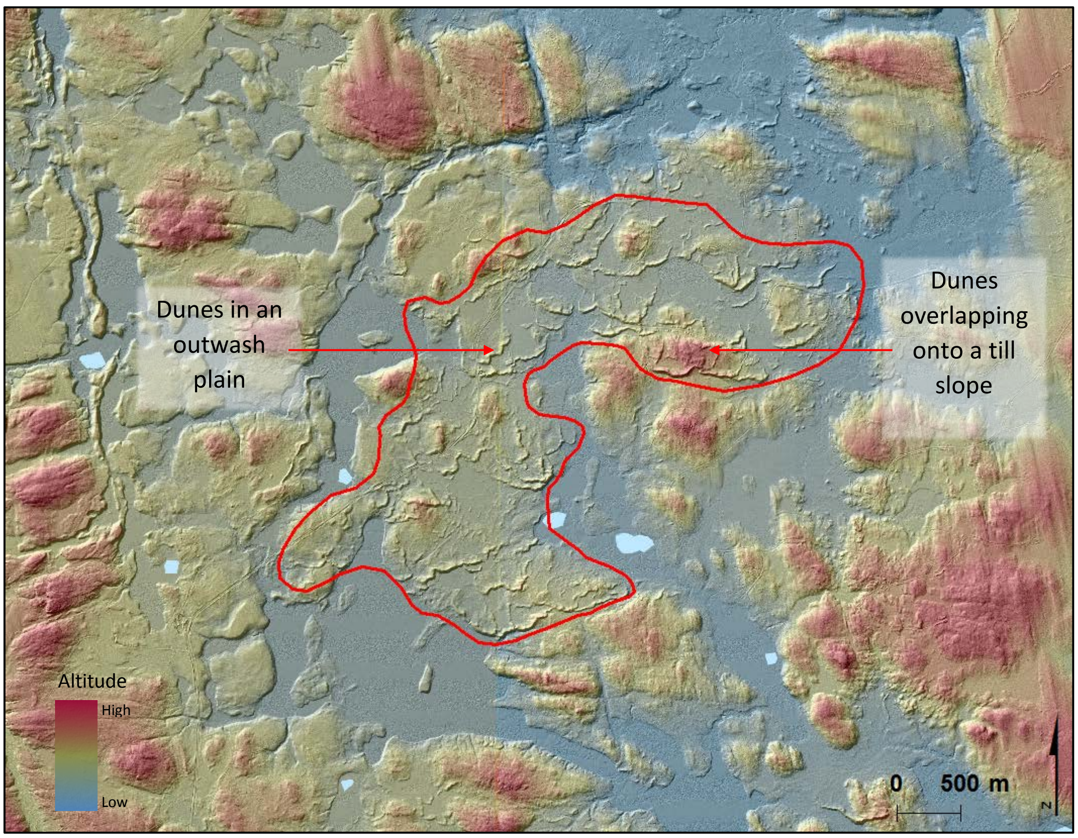

Figure 81. Example of stabilized dunes (9s), on LiDAR, in the Western Balsam Fir-Yellow Birch ecozone

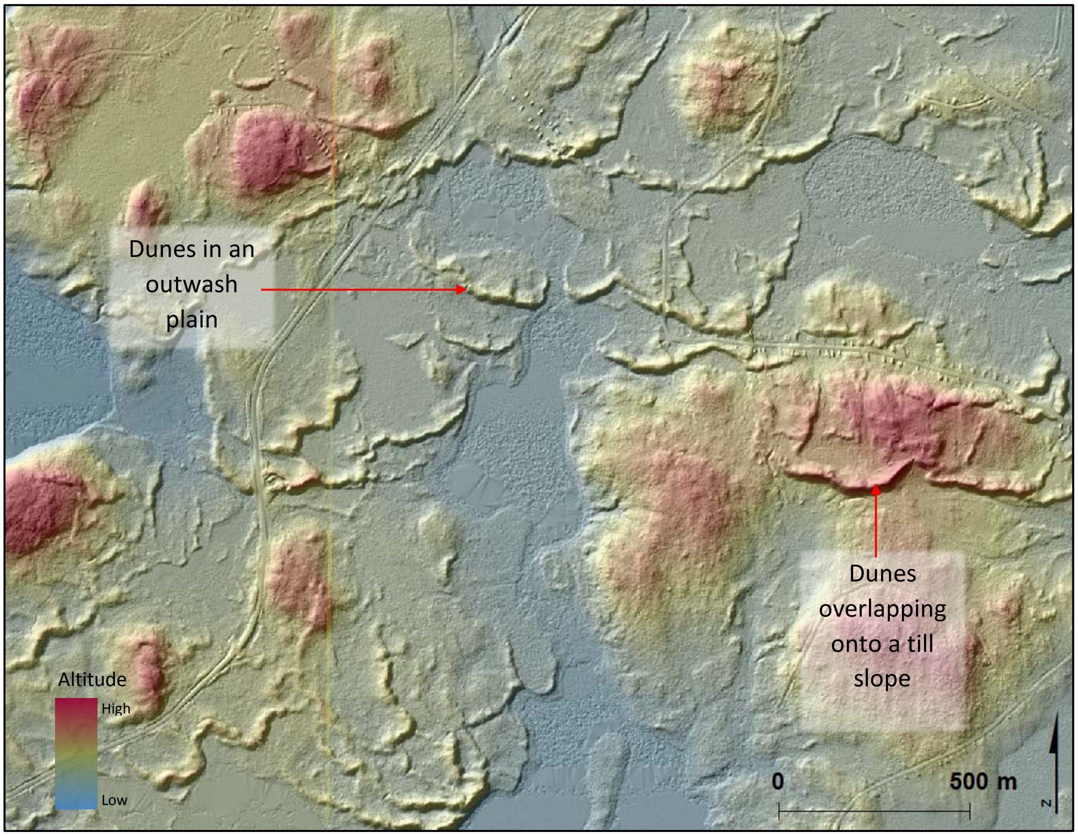


Figure 82. Example of stabilized dunes (9s), on LiDAR, in the Western Balsam Fir-Yellow Birch ecozone (Enlarged section of Figure 81)

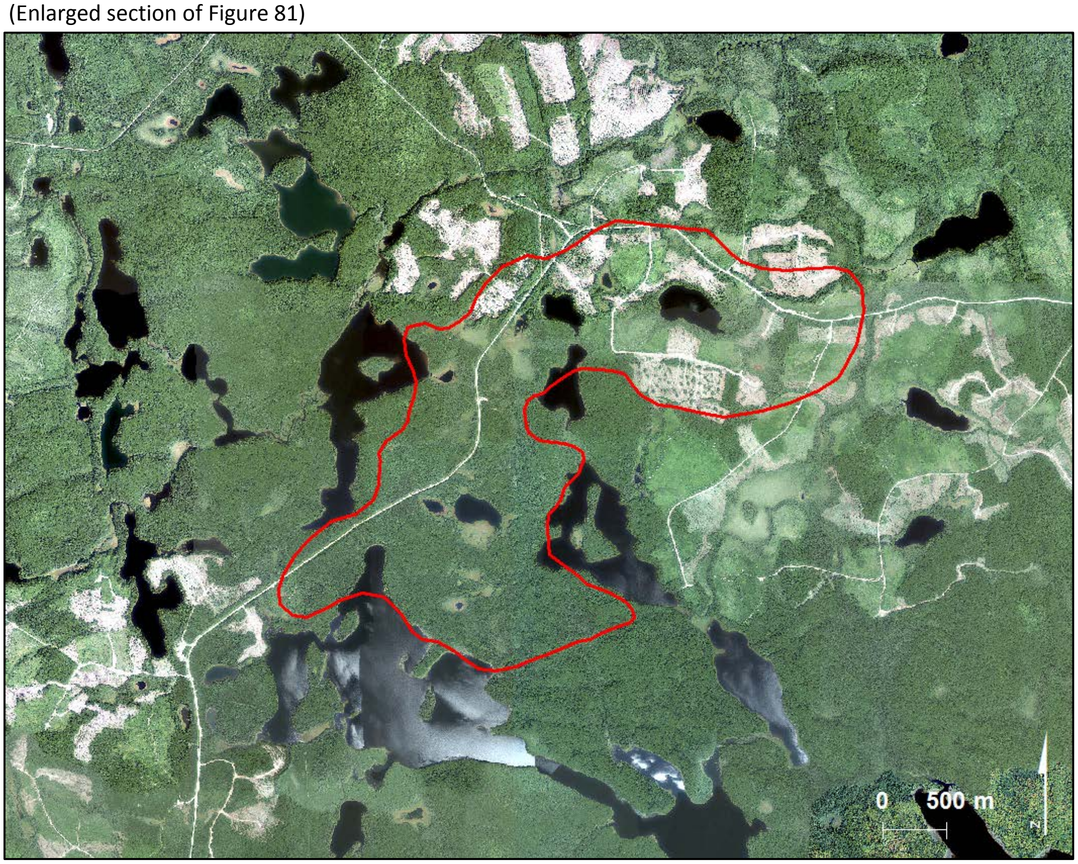


Figure 83. Example of stabilized dunes (9s) on an aerial photograph, in the Western Balsam Fir-Yellow Birch ecozone

## 5. Borrow Pit Potential

Eolian deposits offer zero potential as a source of aggregate (sand and gravel) because they are composed of fine to moderate particles that offer very little support.

# Bedrock

Bedrock occupies sites where there is little to no surface deposit. It offers zero potential as an aggregate source.

## 1. Formation

Bedrock is the rock that usually lies below the mineral or organic layer. Depending on location, it will have been formed thousands or even millions of years ago. It may be composed of igneous, metamorphic or sedimentary rock. In this document, the term *bedrock* is used to refer to sectors where more than 50% of the surface is bare (i.e. not covered by unconsolidated materials), meaning that the rock substrate is visible.

## 2. Location

Rock is present throughout Québec. It is found in sectors with no glacial sedimentation and on sites formerly covered by thin deposits that have been eroded by wind and runoff.

Bedrock is seen most frequently on convex peaks and basement escarpments.

## 3. Description of the Deposit

The Ministère des Forêts, de la Faune et des Parcs du Québec has identified three types of bedrock (Table 14) (MFFP, 2014; Robitaille and Dionne, 2007).

Table 14. Bedrock and its area as a percentage of Québec

| bedrock | % |
|---|---|
| R – Rock | 0.13 |
| Rs – Sedimentary rock[1] | - |
| Rc – Crystalline rock[1] | - |

## 4. Identification Criteria

<u>Bedrock (R)</u>

- LiDAR indicators

a) The sector's relief is mostly pronounced and convex in shape (Figures 84 and 85).
b) Soil texture is rugged.
c) A large number of fracture lines can be seen in a small area.
d) The fracture lines are straight and laid out like a staircase (stepped) (Figure 85).
e) The rock escarpments (steps) are usually between two to several dozen metres high.

- Aerial photograph indicators

a) LiDAR indicators may also be visible on aerial photographs if they are not hidden by vegetation.
b) There are numerous pale grey patches associated with exposed rock (Figure 86).
c) In some regions of Québec, there may be numerous white patches associated with bare rock that has been colonized by lichen.
d) In the hardwood and mixed bioclimatic domains, a drastic change in the type of cover can be seen (e.g. from hardwood to softwood or mixed softwood).
e) The vegetation may be less dense and not as tall as the surrounding vegetation.

[1] Deposit not mapped in Québec.

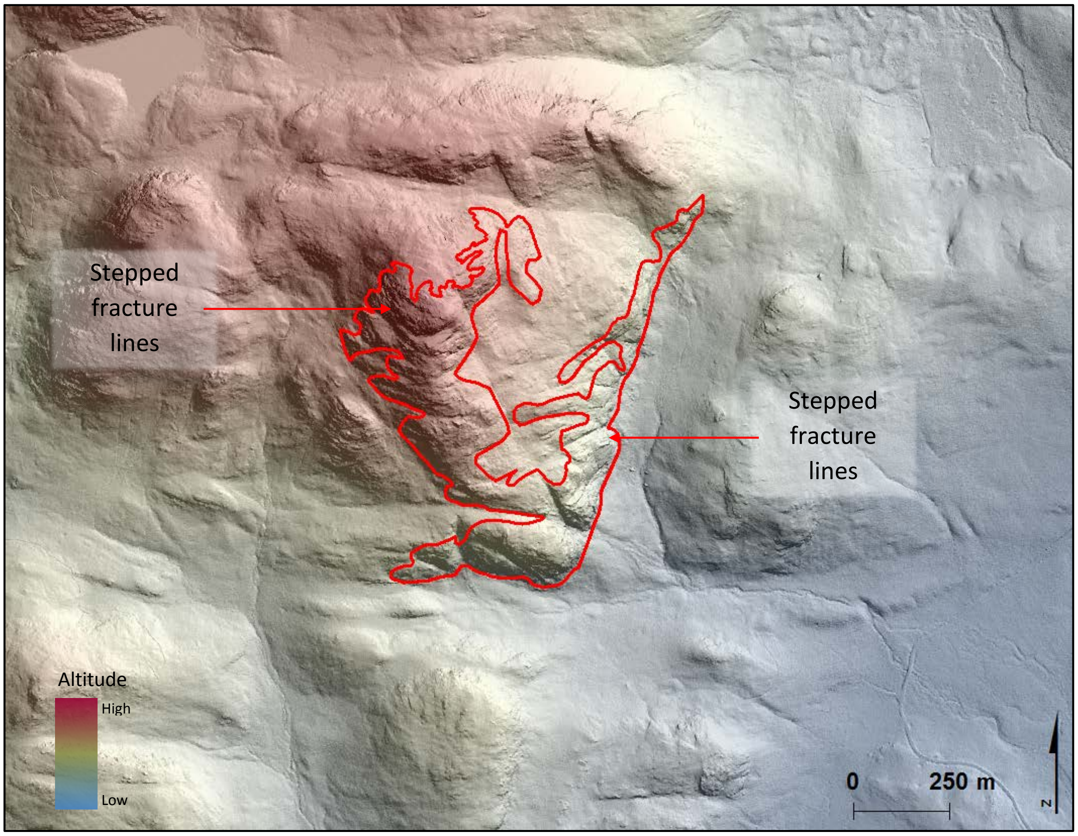


Figure 84. Example of bedrock (R), on LiDAR, in the Eastern Balsam Fir-White Birch ecozone


Figure 85. Example of bedrock (R), on LiDAR, in the Eastern Balsam Fir-White Birch ecozone

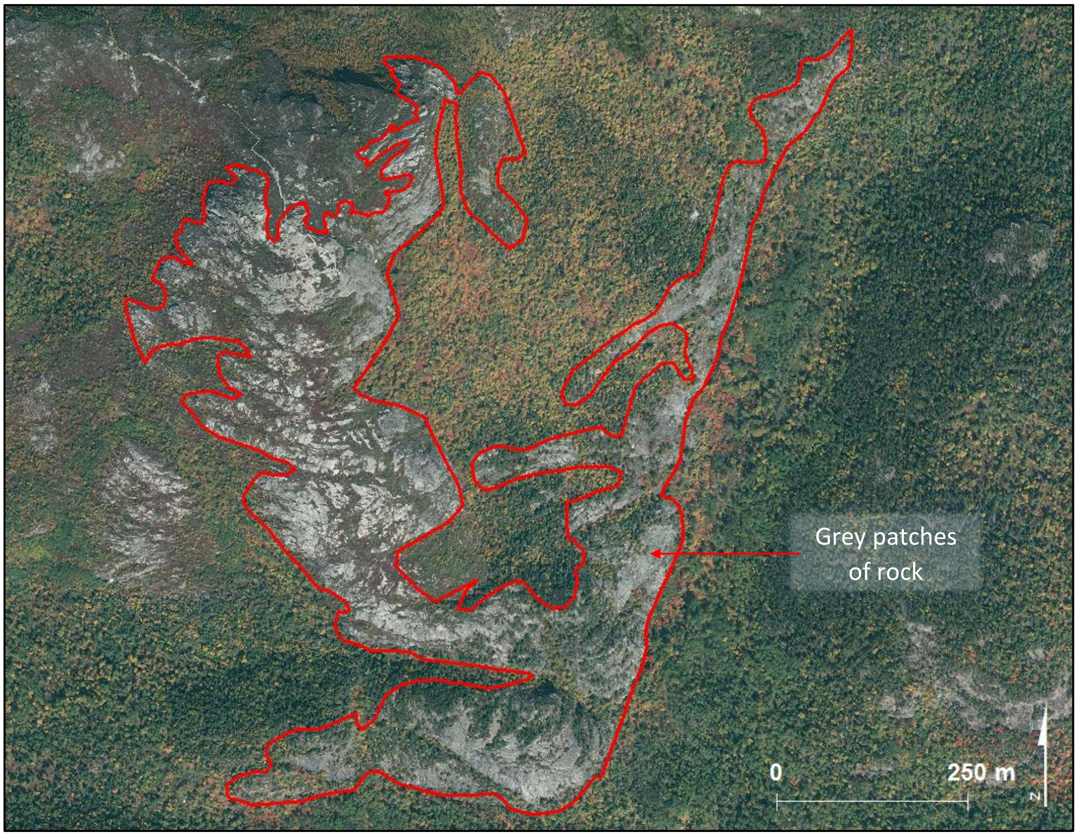


Figure 86. Example of bedrock (R), on an aerial photograph, in the Eastern Balsam Fir-White Birch ecozone

## 5. Borrow Pit Potential

Bedrock offers zero potential as a source of aggregate (sand and gravel).

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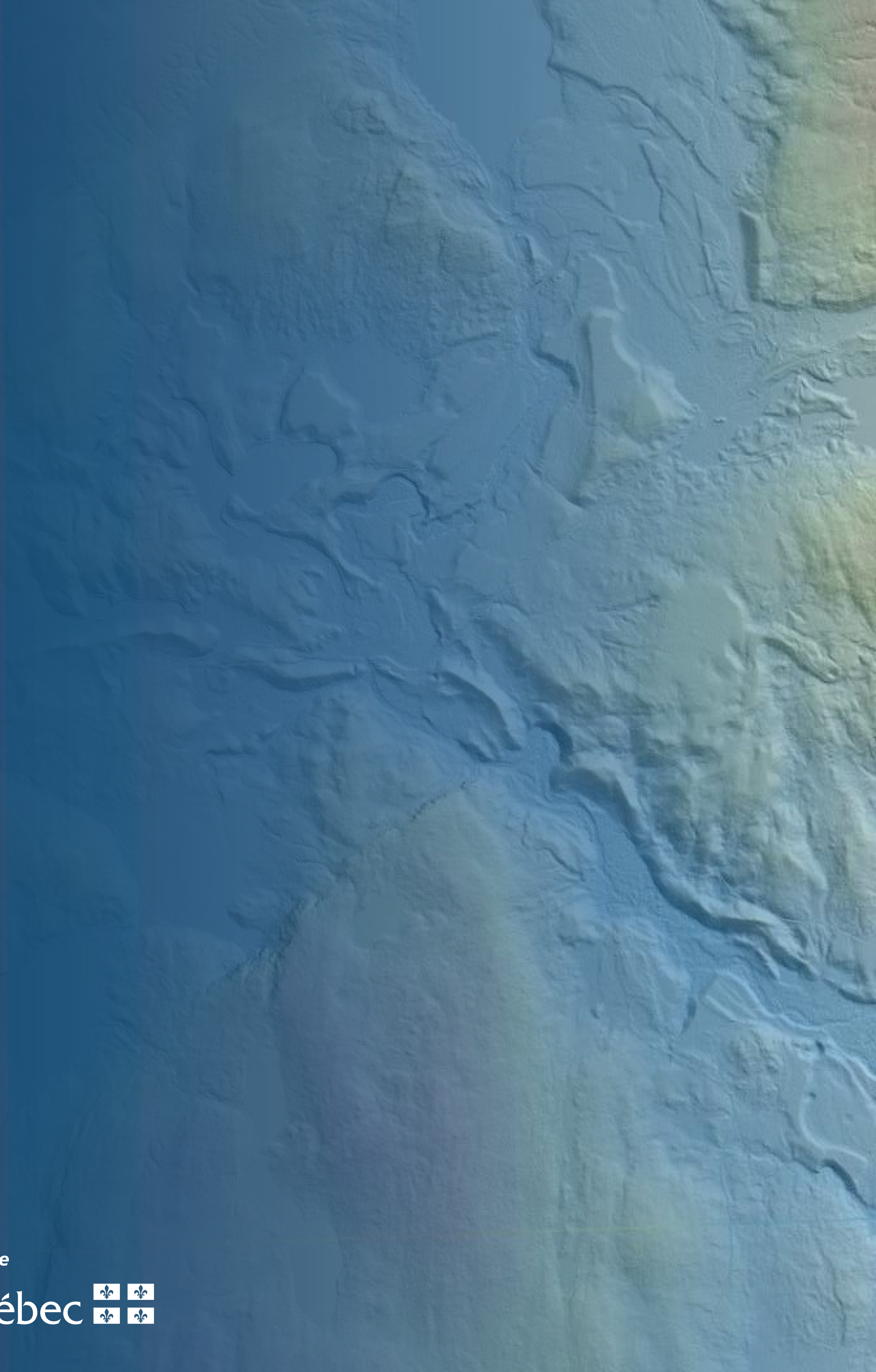

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