Surficial Mapping of the Eastern Cobequid Highlands, Nova Scotia, Canada: Insights from Lidar Imagery

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Introduction

During the 2019 field season surficial geological mapping and sampling were conducted in the Tatamagouche and Oxford map areas (NTS 11E/11 and 11E/12) as part of an ongoing surficial geology program initiated in the Eastern Cobequid Highlands in 2016 (Fig. 1). This year's field activities included surficial mapping, measurement of ice-flow indicators, clast lithology analysis, and till sampling.

The objectives of this program are to (1) conduct surficial geological mapping at the 1:50 000 scale; (2) conduct a till geochemistry sampling survey to provide regional background data on till composition and geochemistry, determine glacial dispersal distances and directions, and identify prospective areas and suitable sampling media for further geochemical exploration; and (3) refine the local glacial history of the map area based on mapping of ice-flow indicators and sediment-landform relationships. These activities will supplement those from recent work by the Nova Scotia Geological Survey in the area (Brushett and Smith, 2018), and complement concurrent and previous bedrock mapping and mineral deposit research in the area (e.g., Baldwin, 2018; MacHattie, 2018).

This report presents some key findings from lidar-based surficial mapping, and provides preliminary interpretations of Pleistocene glacial deposits and erosional features that have been identified to date, and how they inform our understanding of the deglaciation of the Cobequid Highlands.

Bedrock and Physiographic Setting

The study area comprises two physiographic regions: Cobequid Highlands and Cumberland-Pictou Lowlands (Grant, 1989). The Cobequid Highlands are predominantly composed of Late Neoproterozoic to Late Devonian to Early Carboniferous volcanic, sedimentary, and intrusive rocks that rise up to 365 m above the surrounding lowlands and mark the highest elevation point on mainland Nova Scotia (e.g., Murphy et al., 1997; Pe-Piper and Piper, 2002; MacHattie and White, 2014; Fig. 1). To the south, the southern boundary of the highlands is marked by the Cobequid-Chedabucto Fault Zone. To the north, the highlands are unconformably overlain by Late Carboniferous sedimentary rocks of the Cumberland Basin. Within the study area, the eastern Cobequid Highlands comprise, from west to east, gabbro-diorite of the Folly Lake Pluton, granitic rocks of the Hart Lake-Byers Lake Pluton, Late Devonian to Early Carboniferous bimodal volcanic rocks, consisting of the felsic (rhyolite and felsic volcaniclastic) Byer's Brook Formation and the overlying mafic (basalt and minor volcaniclastic) Diamond Brook Formation; and late diorite bodies and diabase dykes that cut both the Byers Brook Formation and Hart Lake-Byers Lake Pluton (MacHattie and White, 2014).

Quaternary History

The oldest documented ice-flow indicators on the Cobequid Highlands are recorded by east-southeast-trending striations, originating from a regional ice sheet in the northern Appalachians (Northumberland phase: ~190-130 ka). These striations are often crosscut by southeast-trending striations, originating from a regional ice sheet from New Brunswick (Caledonia phase: 75-50 ka; Stea et al., 2011). This phase of flow was followed by a major south to southwestward flow, which at its maximum extent reached the edge of the continental shelf (Escuminac phase: 25-20 ka; Shaw et al., 2006). During this phase fast-flowing ice streams stemming from the Escuminac ice center over the Magdalen Shelf crossed the province, entraining material from redbeds in the Cumberland Lowlands, depositing a distinctive reddish till, and forming extensive drumlin fields (Stea, 2004; Stea et al., 2011). Within the study area, this phase is recorded by a reddish-brown

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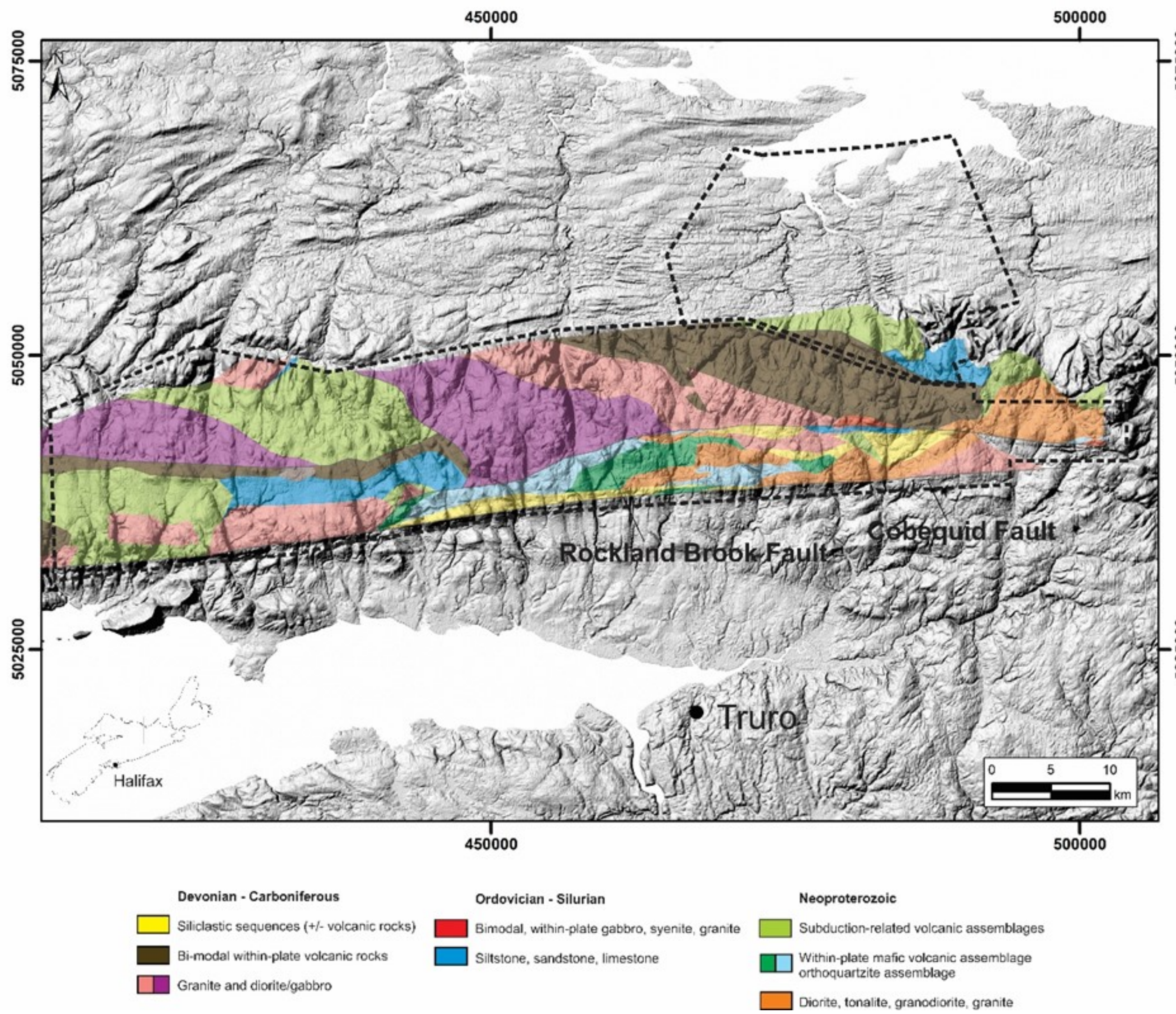

Figure 1. Simplified bedrock geology of the Cobequid Highlands (modified from MacHattie, 2018), overlain on provincial DEM (Fisher et al., 2004). Extent of lidar surveys are indicated by dashed lines.

silty clay till, termed Eatonville-Hants till, and southward-trending striations crossing earlier southeastward-trending striations at many sites on the upland regions of Nova Scotia and New Brunswick (Stea et al., 1986).

As ice thinned rapidly due to continued ice streaming into marine channels offshore Atlantic Canada, an ice divide (Scotian Ice Divide) formed over much of the province, changing ice-flow patterns dramatically such that there was northerly ice flow in northern Nova Scotia and south to southwestward ice flow in southern Nova Scotia (Scotian phase: 20-17 ka; Stea, 2004; Stea et al., 2011). In northern Nova Scotia this reversal in ice flow has been identified by northward-trending striations and crag and tail features across the region, and erratics from the Cobequid Highlands in the Cumberland-Pictou Lowlands to the north, first described by Chalmers (1895; Stea and Finck, 1984). Within the study area, this ice-flow phase is associated with a mostly locally derived, stony, greyish-brown hybrid till, termed the "Cobequid Till" which is commonly found as a veneer (<2 m) on the highlands, and also overlying the red Eatonville Till in some places (Stea and Finck, 1988).

Residual ice likely persisted on the Cobequid Highlands in the ensuing deglacial phases: the Chignecto Phase, which included re-advance of several small ice caps (remnants of Scotian phase ice) in the Northumberland Strait and in the Antigonish Highlands in northern Nova Scotia, as a result of continued calving and drawdown of the Scotian Ice Divide (Stea et al., 2011; Stea and Finck, 2001); the Shulie Lake phase, another short-lived ice advance after the main Chignecto phase, related to an ice margin on the Chignecto Peninsula (Stea and Mott, 1998); and the Collins Pond phase (Younger Dryas), an abrupt climatic cooling ~10.8 ka, during which small glaciers developed or re-advanced over several hundred years, including an ice cap near PEI that advanced southward over northern Nova Scotia. Stea and Mott (1989, 1990) documented radiocarbon dates on glaciomarine deltas, and minimum dates on lake sediments and buried organic horizons, which imply that the final retreat of ice in northern Nova Scotia after 15 ka was slow or interrupted by several stillstands and possible re-advances. By 10 ka, Nova Scotia was ice free (Stea et al., 2011).

Lidar-based Surficial Mapping

During the last decade, lidar imagery in Nova Scotia has revealed new glacial features that inform our understanding of glacial events and further refine our regional conceptual models of glaciation (e.g. Utting, 2009, 2011). The lidar imagery has also been employed to identify and map geohazards associated with flooding, coastal erosion, karst topography, and abandoned mine openings (e.g. DeMont et al., 2010; Kennedy and Utting, 2011). Surficial mapping using lidar imagery will continue as lidar surveys become available for additional areas in the province. This knowledge is necessary for past glacial reconstructions, drift prospecting, geoengineering, and groundwater and aggregate resource investigations.

Data Sources

Lidar data for this project originated from a lidar survey flown over the Cobequid Highlands in 2010 with the financial support of the Geological Survey of Canada through the Targeted Geoscience Initiative (TGI-4) program, which produced a 1 m bare earth digital elevation model. Lidar data for the Tatamagouche area to the north are available through the Nova Scotia LiDAR Acquisition Project, currently funded by the Nova Scotia Department of Lands and Forestry (Forestry Division) and the Department of Internal Services (Geographic Information Services). Lidar data for many areas of the province are now available (and updated as more data are released) through the Nova Scotia Geospatial Infrastructure (NSGI) and their DataLocator application: https://nsgi.novascotia.ca/datalocator/elevation/.

Mapped Landforms

Landforms were digitized in ArcMap 10.3.1. The primary criteria for landform identification was morphology, identified by multiple DEMs and illumination angles to avoid azimuth bias. Where features are ambiguous, ground truthing and additional data from aerial photography and existing surficial geologic data were used to refine interpretations.

Subglacial landforms

Subglacial landforms include a range of longitudinal and transverse landforms produced at the base of a glacier as a result of active ice flow - these include flutes, drumlins, megaflutes, and ribbed moraine. These landforms typically occur in distinct and fairly well-defined fields, and different types such as drumlins and ribbed moraine are often found in close association with each other (Benn and Evans, 2010; Menzies and Hess, 2013). Streamlined landforms, including drumlins, flutes, and megaflutes, form parallel to the direction of ice movement. Megaflutes are highly attenuated with elongation (length:width) ratios >10:1, created by faster-flowing ice. Lower elongation ratios represent slower ice-flow velocities (Stokes and Clark, 1999, 2001). Ribbed moraines (terrain) are subglacially formed ridges that form transverse to ice-flow directions. There are several possible mechanisms for their formation, including: sluggish ice-flow velocities, generally under cold-based ice conditions; remoulding of pre-existing landforms; and active subglacial deformation into proto ridges (Lundqvist, 1989; Dunlop and Clark, 2006; Trommelen et al., 2014; Möller and Dowling, 2018).

Mapped landforms within the study area include drumlins, fluted terrain, megaflutes, and ribbed moraine. Lineations measured to date support previous mapping and add significant new detail. On the highlands, the majority of streamlined bedforms record the regional southward flow (~180°; Escuminac phase). These include drumlins (rock-cored), crag and tails, flutes, and ice-sculpted bedrock. Many areas in the eastern highlands are dominated by a rough bedrock-controlled

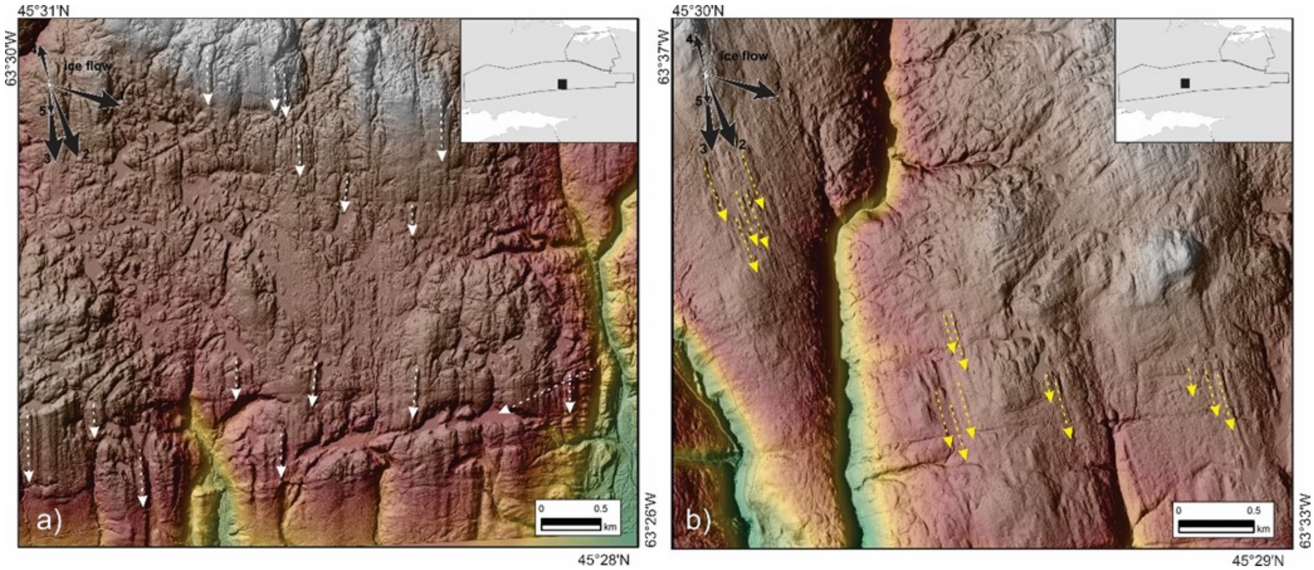

Figure 2. Examples of streamlined landforms on the Cobequid Highlands. Many areas in the eastern Cobequid Highlands have a discontinuous till veneer and bedrock-controlled topography. In many areas, crag and tail landforms (a; select landforms indicated by white dashed arrows) indicate southward-flowing ice crossing relatively thin sediment cover during the Escuminac phase. In other areas, drumlins (rock-cored) and fluted terrain (b; yellow dashed arrows) were identified over areas of thin till veneer and indicate southeast-flowing ice being funnelled into the Bay of Fundy.

topography, where sediment cover is generally thin and in places occurs as a discontinuous till veneer (<2 m). Many crag and tail landforms were identified in these areas. These streamlined hills result from glacial erosion and consist of a “crag” of resistant bedrock on the up-ice side, with an elongate “tail” of more erodible bedrock, till, or both, on its lee side pointing in the down-ice direction. They commonly occur in the lee of west-east bedrock ridges and indicate southward flowing ice crossing relatively thin sediment cover (Fig. 2a). Several highly attenuated fields of fluted terrain were also documented. They consist of small streamlined ridges, tens of centimetres to a few metres high and wide, and tens of metres in length, that likely formed in the lee of boulders and low lying, west-east bedrock ridges. The fields of fluted terrain indicate southeastward ice flow across the highlands (Fig. 2b). Their southeastward trend is likely the result of ice being funnelled into the Bay of Fundy-Chignecto Bay.

On the lowlands, extensively drumlinized terrain was identified, within which drumlins, megaflutes, and ribbed moraine occur. The latest drumlin-forming phase is to the south with most landforms exhibiting a strong southward trend (~180º), and their more gently sloping lee end facing down-ice (Fig. 3). Elongation ratios range from 2:1 (drumlins on highlands) and up to 12:1 (megaflutes on lowlands). Megaflutes are highly attenuated, strongly parallel and usually of low relief (<10 m high). This terrain is associated with southward flow during the Escuminac phase. Areas of ribbed moraine also occur, and in places they transition to drumlins (Fig. 4). Individual ridges are typically characterized by anastomosing to curved ridges with intervening troughs. In the easternmost extent of lidar coverage, ribbed moraine features were likely the result of remoulding of pre-existing drumlins by later westward-flowing ice. Further investigation will continue pending the release of additional lidar imagery in this area.

Meltwater Features

As deglaciation proceeded, downwasting and recession of ice from the highlands resulted in increased meltwater activity and the development of glaciofluvial landform assemblages in many of the valleys of the highlands, which acted as conduits for meltwater. One of the most predominant meltwater features on the highlands are meltwater channels. These channels form when meltwater cannot easily penetrate to the subglacial environment, as would be the case if ice was largely frozen to its bed (cold-based glacier). In this case, meltwater will flow toward the ice margin and drain along it, incising sediment and/or bedrock on adjacent slopes and forming meltwater channels (Dyke, 1993; Evans et al., 2017).

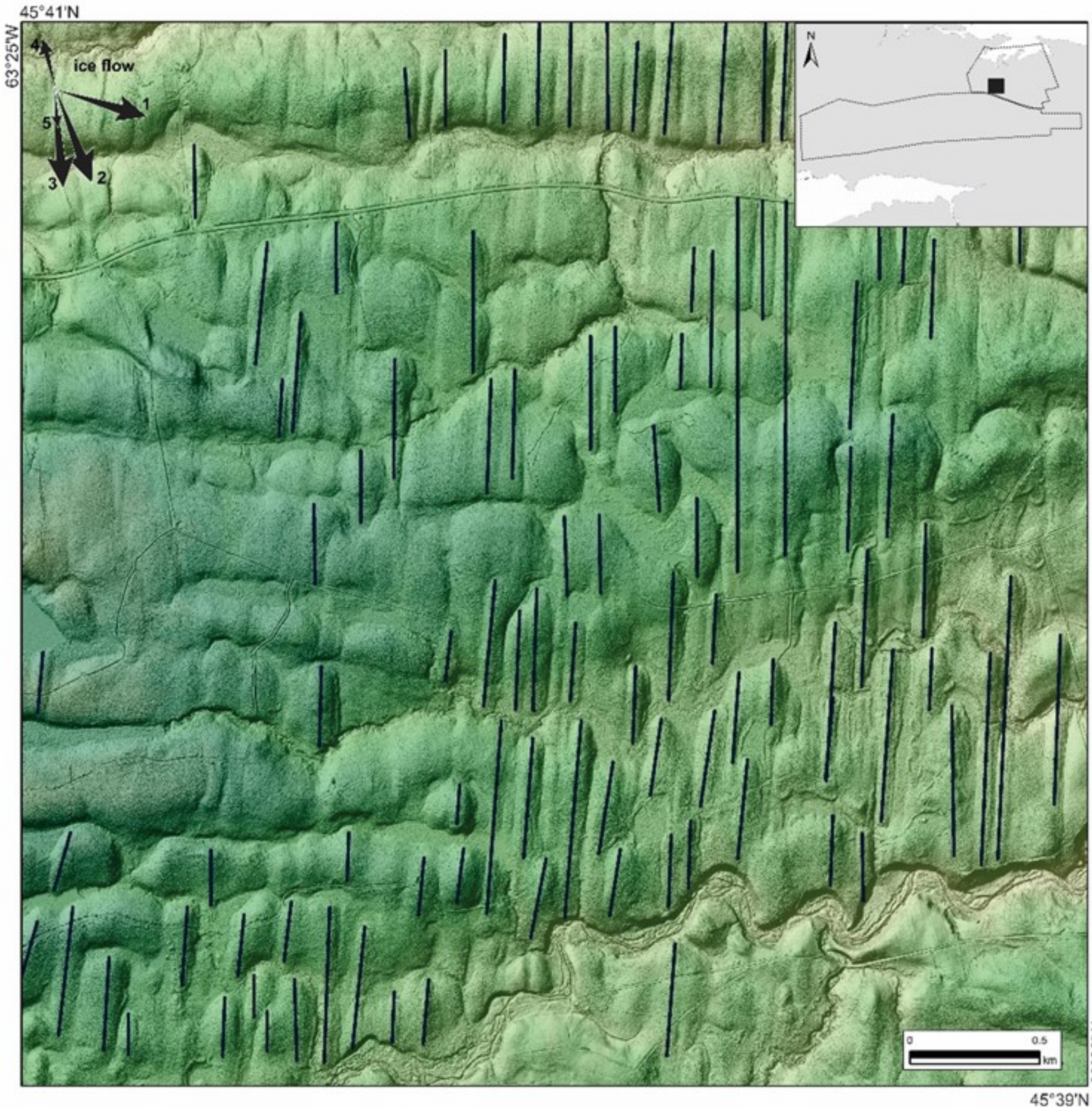

Figure 3. Extensive drumlinized terrain in the Cumberland-Pictou lowlands, including drumlins, flutes, and megaflutes, indicating that southward ice flow was the most recent to have modified this landscape.

Lateral meltwater channels were identified nested along numerous valley slopes and most prevalent along the northern slopes of the eastern highlands (Fig. 5). They are assumed to have originated from the most recent glacial phase (Collins Pond phase) and consist of relatively small channels that descend the slopes at an oblique orientation relative to the regional drainage slope, and in places, inset within one another forming an *en echelon* pattern. Ice-marginal meltwater channels such as these document the former slope of the ice surface, and mark the ice margin at the time of their formation, thus providing important information on the style and pattern of ice retreat (Margold et al., 2013; Evans et al., 2017). They have been documented elsewhere as relating to the retreat of cold-based ice (e.g. Dyke, 1993).

In other studies from similar topographic settings, a range of meltwater channel types has been documented, including lateral (marginal), sub-marginal, and subglacial channels, which reflect changes in both glacial hydrology and thermal regime. A similar transition is recorded in the

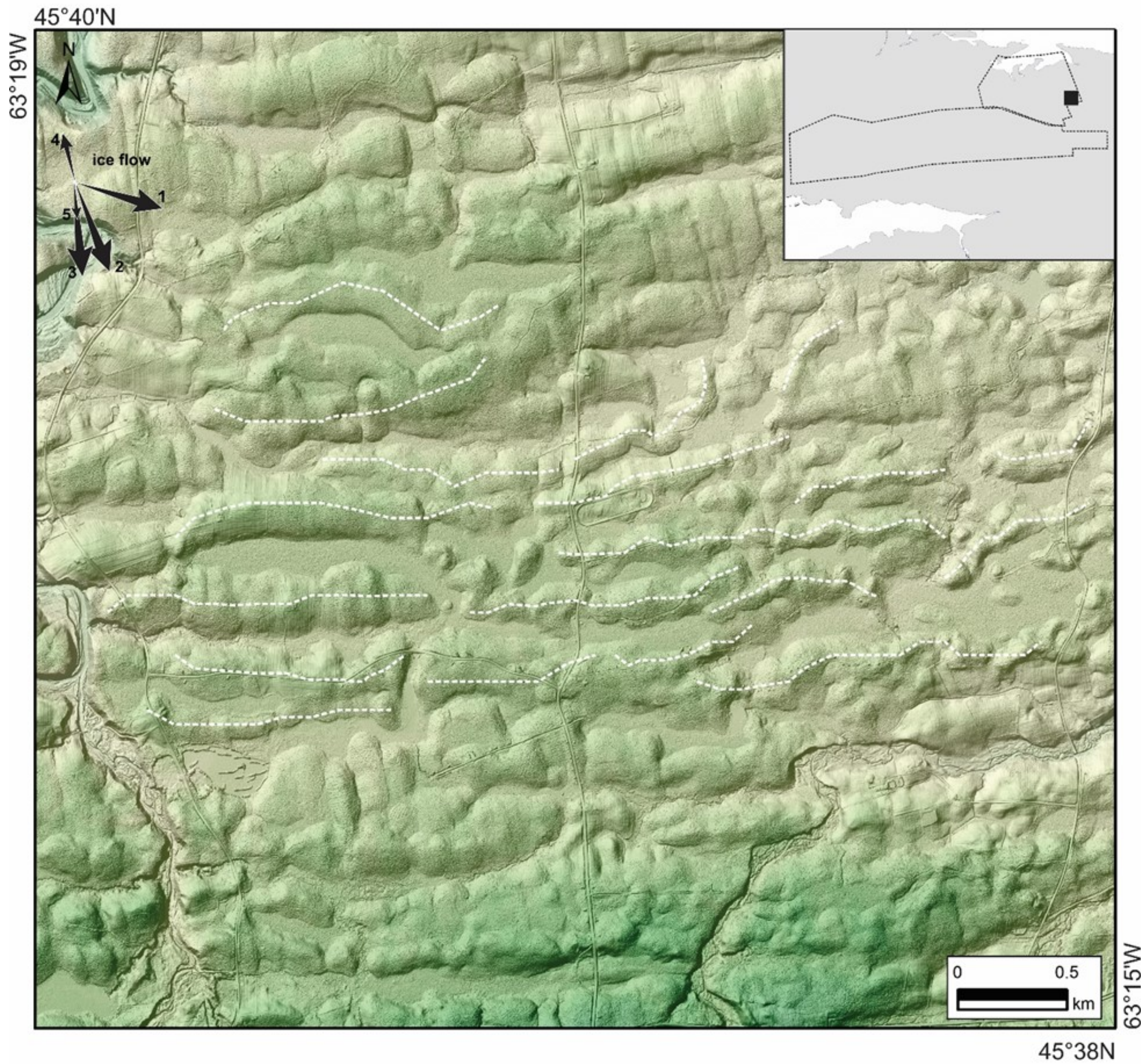

Figure 4. Ribbed moraine (ridge crests outlined by white dashed lines) in the Cumberland-Pictou lowlands transitions to drumlins and hummocky moraine. In places the ridges are also drumlinized.

Cobequid Highlands with lateral channels on the upper slopes grading downslope into sub-marginal and subglacial channels as the thermal regime of the ice warms (Livingstone et al., 2008; Evans et al., 2017). Lateral meltwater channels on slopes of the highlands give way to glaciofluvial deposits in the valleys. Common along the valley sides are kame terraces that mark the former positions of ice-marginal riverbeds (Fig. 6a). At the time of their formation, they tend to appear terrace-like, but with meltout of ice within them the terraces collapse, resulting in complex, irregularly shaped surfaces. Eskers are also common features on the highlands and in many of the valleys. They occur as single, straight to sinuous sand and gravel ridges, and as networks of multiple ridges, often fed by smaller tributary eskers (Fig. 6b). They provide a record of meltwater drainage patterns and generally trend parallel to the final direction of ice flow (Boulton et al., 2009; Menzies and Hess, 2013).

Future Work

To date, mapped landforms and flow patterns reproduce much of what has been reported by previous studies. In many places, however, lidar data have added new details on the ice dynamics on the Cobequid Highlands. For example, the

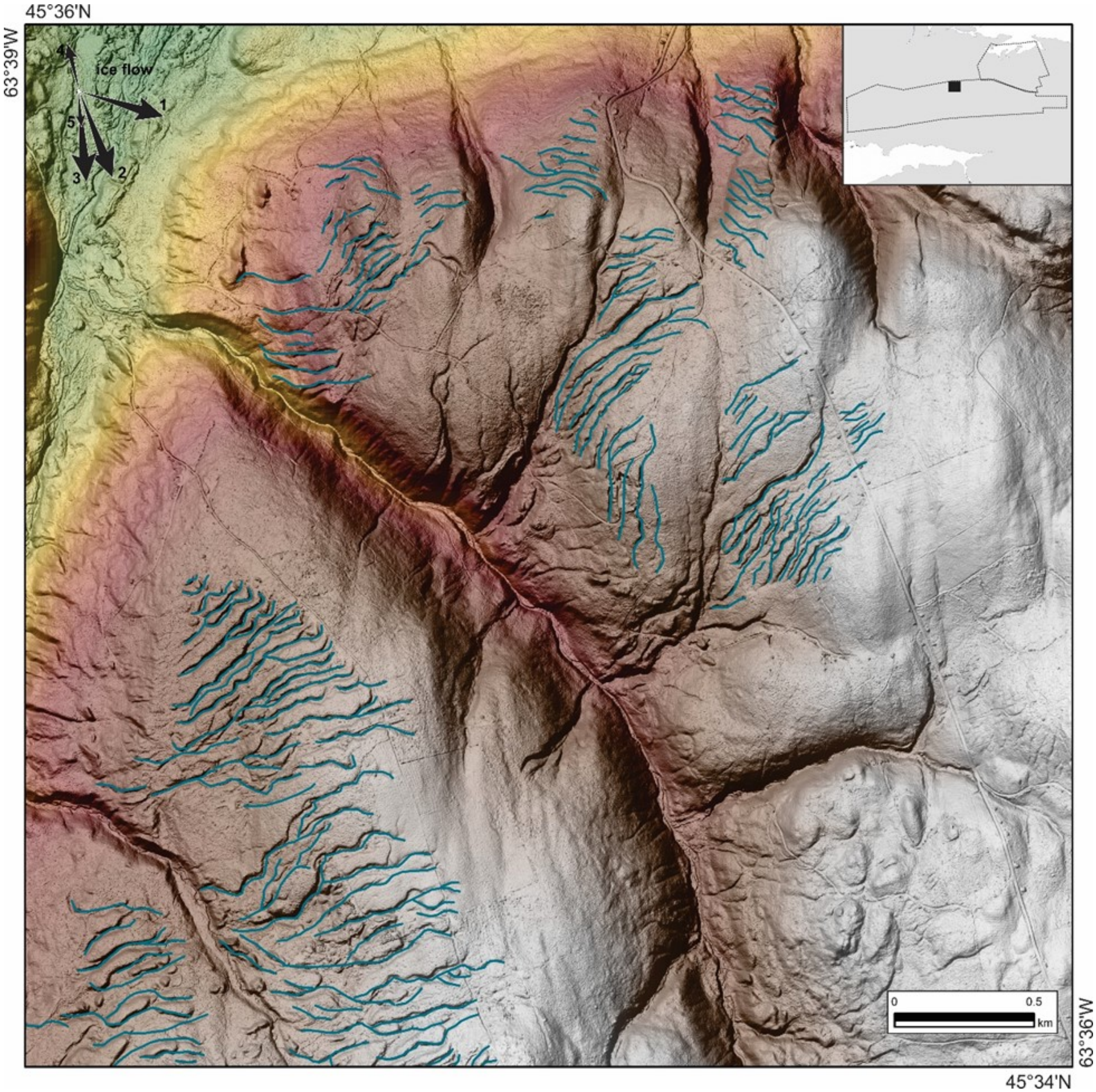

Figure 5. Lateral meltwater channels (indicated by blue lines) in the northern Cobequid Highlands.

widespread occurrence of lateral meltwater channels records the recession of ice and support the idea of a period of cold-based ice during deglaciation as proposed by previous studies. Drumlins, ribbed moraine, and megaflutes in lowland areas demonstrate fast-flowing ice during the regional southward Escuminac phase, and remoulding by later westward-flowing ice. Fieldwork will continue in 2020 with additional surficial mapping, till sampling, and analyses, and detailed surficial studies. A synthesis of glacial and deglacial events will be provided following further surficial mapping in the western Cobequid Highlands and surrounding Cumberland-Pictou lowland regions. It is anticipated that further mapping in these areas will provide more details on the nature and extent of both the northward Scotian phase ice and the final southward Collins Pond phase ice, and how they relate to deglaciation of the Cobequid Highlands. The results of this work will be included in a 1:50 000 scale surficial geology map of the eastern Cobequid Highlands, anticipated to be released in early 2021.

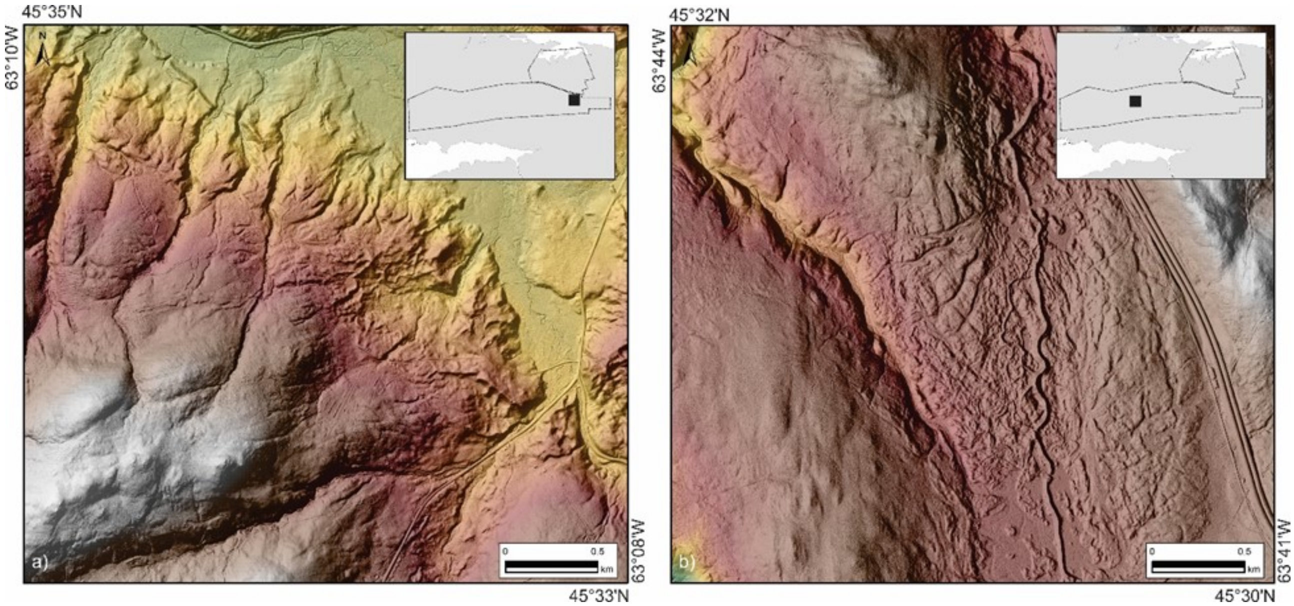

Figure 6. Kame terrace (a) and eskers (b). Tributary eskers of main eskers form esker networks in numerous areas on the highlands and in the valleys.

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