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Alberta Energy Regulator

An Update to the Glacial Landforms Map of Alberta

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N. Atkinson, D.J. Utting and S.M. Pawley

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Alberta Energy Regulator
Alberta Geological Survey
4th Floor, Twin Atria Building
4999 – 98th Avenue
Edmonton, AB T6B 2X3
Canada

Tel: 780.638.4491
Fax: 780.422.1459
Email: AGS-Info@aer.ca
Website: www.ags.aer.ca

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Abstract

Alberta Geological Survey Map 604 and its accompanying digital dataset portrayed ~74 000 glacial landforms derived from previously published maps and reports, as well as new mapping based on a light detection and ranging (LiDAR) bare-earth digital elevation model (DEM) covering 46% of the province. The acquisition in 2017 of a 15 m LiDAR DEM for all remaining areas of Alberta, excluding federally controlled lands, has enabled Alberta Geological Survey mappers to provide an updated, comprehensive inventory of ~143 500 glacial landforms across the province. This report provides an overview of the methods and results of this updated dataset, particularly the morphology of each of the eleven landform feature classes. The report also highlights areas where significant revisions were required and what implications these have for future work. The mapping focus remained on landforms that constrain former ice margins (moraines, ice-marginal channels), ice sheet geometry and flow dynamics (streamlined subglacial bedforms, ice-thrust moraines, glacially overridden moraines, crevasse-fill ridges) and hydrology (meltwater channels and eskers). An additional thematic layer included in the updated digital dataset depicts the distribution of eolian dunes across Alberta.

Such work is of interest to the glaciological community, and also to those mapping glacial deposits to determine mineral dispersal patterns, as well as near-surface material properties, particularly relating to hydrogeology, geo-engineering, natural resources management, infrastructure planning, and environmental protection.

1 Introduction

Alberta Geological Survey Map 604 (Atkinson et al., 2014a) and the accompanying digital dataset (DIG; Atkinson et al., 2014b) portrayed 73 885 glacial landforms derived from previously published maps and reports, as well as new mapping based on a 306 624 km^2 light detection and radar (LiDAR) bare-earth digital elevation model (DEM) covering much of the Green Area (forested portion) of Alberta (46% of the province). Emphasis was placed on portraying landforms that provided insights into the configuration, flow geometry and dynamics of the Laurentide and Cordilleran ice sheets (LIS, CIS), which are critical components of understanding ice sheet evolution. Such work is not only of interest to the glaciological community, but also to those deciphering ice-flow histories as a means to interpret geochemical and mineralogical data collected in drift prospecting surveys to help identify mineral dispersal patterns that can be traced up-ice to their source.

The intent of this work was that as new data became available, particularly LiDAR coverage across the White Area (settled portion) of Alberta, the DIG would be updated to incorporate the most recent mapping information. Accordingly, the acquisition in 2017 of a 15 m LiDAR DEM for all remaining areas of Alberta, excluding federally controlled land such as National Parks and Canadian Forces Bases, has enabled AGS mappers to provide a more comprehensive inventory of glacial landforms across the province (Atkinson et al., 2018). This report provides an overview of the methods and results of this updated DIG, particularly the morphology of each of the landform feature classes mapped in this update. Additionally, the report highlights areas where significant revisions were required and what implications these have for future work.

2 Data Sources and GIS Compilation

This update utilizes interpreted information previously compiled for AGS Map 604 (Atkinson et al., 2014a) and is augmented with new map information based on interpretations of a seamless bare-earth LiDAR DEM across 86% (573 688 km^2) of Alberta (Figure 1). Based on the methods described by Atkinson et al. (2014c), this high-resolution (5 to 15 m) DEM enables published line features to be verified with greater accuracy than previously possible, with inconsistencies either being corrected, or removed from the GIS database. The mapping focus remained on landforms that constrain former ice margins (moraines, ice-marginal channels), ice sheet geometry and flow dynamics (streamlined subglacial bedforms, ice-thrust moraines, glacially overridden moraines, crevasse-fill ridges) and hydrology (meltwater channels and eskers). An additional thematic layer included in the updated DIG depicts the distribution of eolian dunes within Alberta.

3 New Mapping

In addition to verifying previous mapping, the updated DIG includes an additional 71 947 newly interpreted line features (Figure 2; Table 1) based on the most recent interpretations of the provincial LiDAR DEM. This represents an almost two-fold increase in mapped landforms now identified across Alberta. Updated features have been classified thematically using the standard AGS surficial geology legend (c.f., Atkinson et al., 2014a), with two new feature classes being added based on the identification of previously unmapped landforms. Following the convention of previous surficial geology maps, each landform is represented as a single line drawn along the entire length of the long axes of the feature. Due to the scale of mapping, less emphasis was placed on mapping small (<50 m long) features, particularly in areas where the inclusion of such features would not add to the interpretative value of the respective thematic layer.

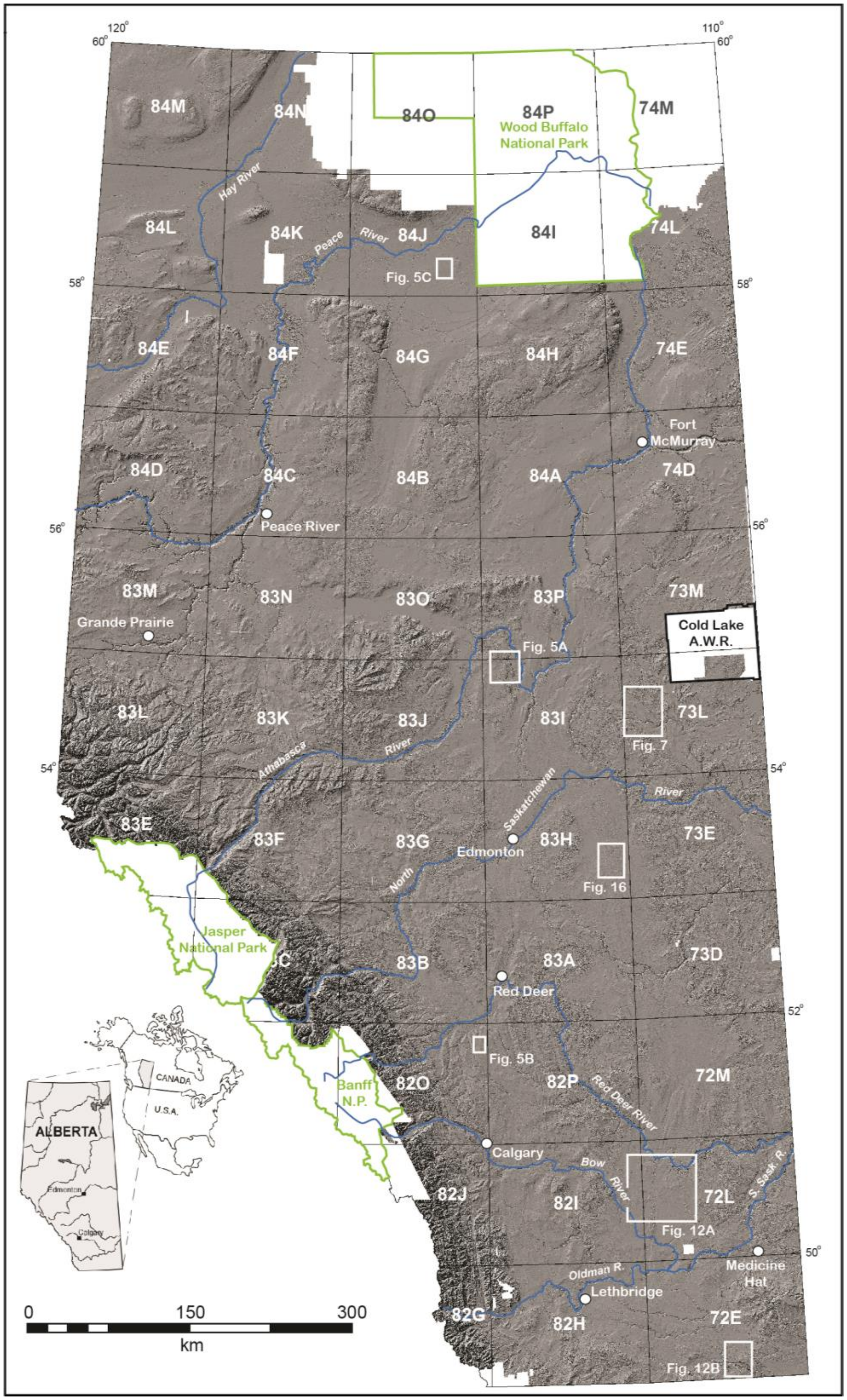

Figure 1. Spatial extent of current LiDAR coverage within Government of Alberta data holdings. A.W.R = Air Weapons Range; N.P. = National Park.

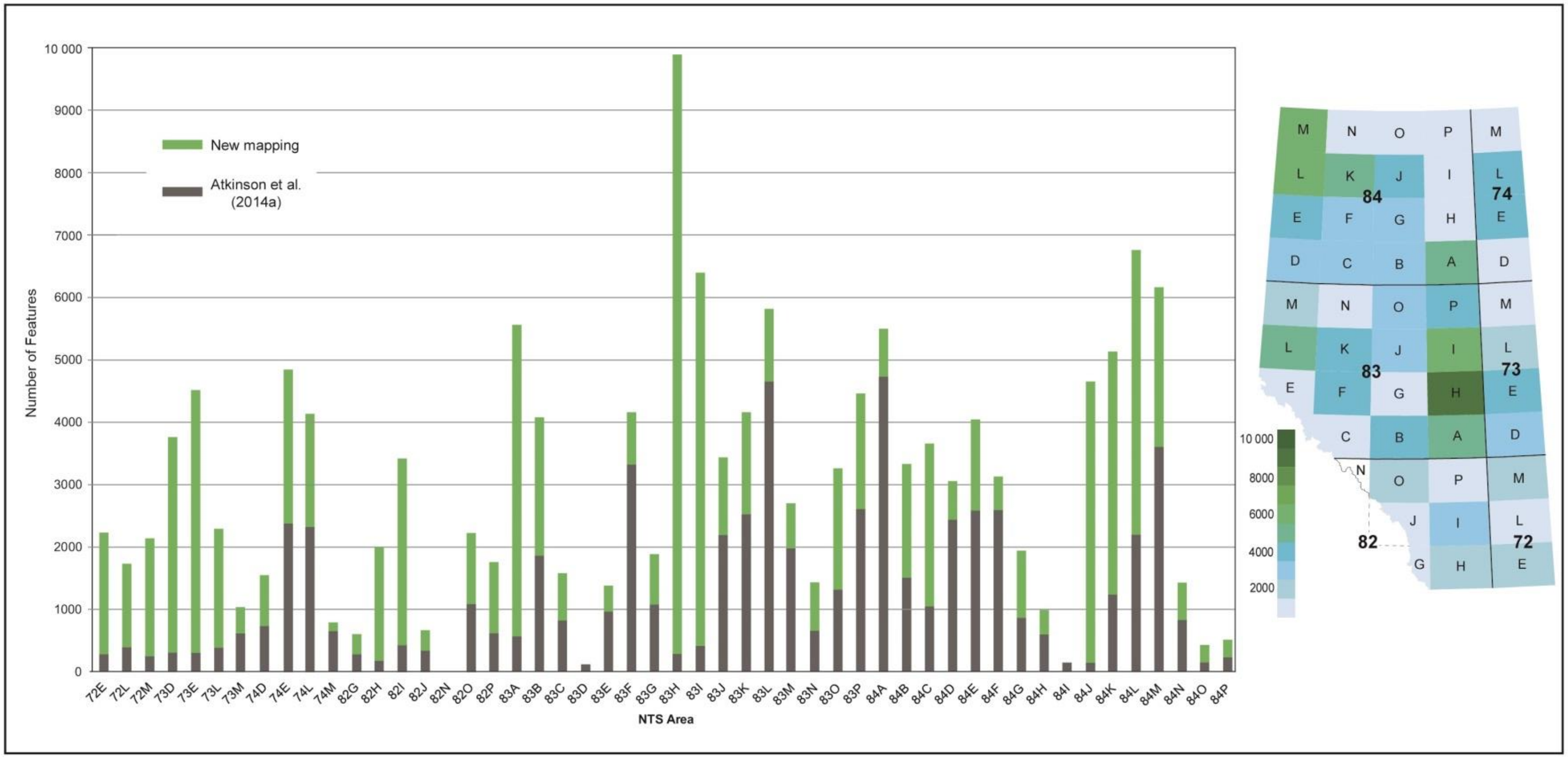

Figure 2. Total number of line features from each of the 1:250 000 NTS map sheet areas in Alberta.

Table 1. Total number of line features in the updated DIG, classified thematically and by source.

Thematic layer	Previous mapping[a]	New mapping	Total
Streamlined subglacial bedforms	22 007	12 106	34 113
Glacial grooves	22	1922	1944
Aligned rubble	0	83	83
Moraines	4250	3863	8113
Ice-thrust moraines	829	503	1332
Glacially overridden moraines	63	827	890
Major meltwater channels	322	10	332
Minor meltwater channels	6421	1653	8074
Eskers	1733	1419	3152
Crevasse-fill ridges	19 687	44 509	64 196
Dunes[b]	16 260	5052	21 312
Total	**71 594**	**71 947**	**143 541**

[a] Includes data from Atkinson et al. (2014a, b), previous LiDAR-based mapping, and verified non-LiDAR based mapping.

[b] Included in the GIS datasets (Atkinson et al., 2014b, c), but not portrayed on Map 604 (Atkinson et al., 2014a).

4 Results

There are eleven thematic landform layers, comprising 143 541 individual line features within the updated DIG (Table 1). The diagnostic criteria for classifying these landforms were described by Atkinson et al. (2014c), so in this report we focus on those landform classes and NTS map sheet areas that have been most significantly revised.

4.1 Streamlined Subglacial Bedforms

Collectively, mega-scale glacial lineations (MSGL), flutings, and drumlins represent the most widespread class of glacial landform in Alberta. They occur across most terrain elements in the province including flat-lying lowlands, moderate relief plains, locally isolated uplands, as well as dissected benchlands within the foothills and along valleys in the Rocky Mountains (Figure 3).

Of the ~34 000 streamlined bedforms identified in Alberta, 35% are newly mapped features (Table 1). In many areas, these refine ice-flow patterns identified by previous mapping (Gravenor et al., 1960; Shetsen, 1987, 1990; Ó Cofaigh et al., 2010; Evans et al., 2014; Atkinson et al., 2014c, 2016; Utting et al., 2016). However, the new mapping also identifies regions where ice-flow patterns were more complex than previously recognized, such as along the southern Alberta portion of the Rocky Mountain Foothills (NTS 82H, 82J, 82O), as well as across uplands in central and southern Alberta (e.g., NTS 83A, 73E, 73L; Figure 3). These bedforms are significant for understanding the glacial history of Alberta because they are a widely recognized geomorphic footprint of fast-flowing ice (Clark, 1993; Ross et al., 2009; Ó Cofaigh et al., 2010; Margold et al., 2015a, b, 2016; Stokes, 2018). When combined with information on the sedimentology of these bedforms, this update will significantly benefit the mapping of glacial deposits, particularly with respect to mineral exploration, hydrogeology and geo-engineering, as well as provide further details on paleoglaciology and temporal evolution of the southwest LIS and eastern CIS.

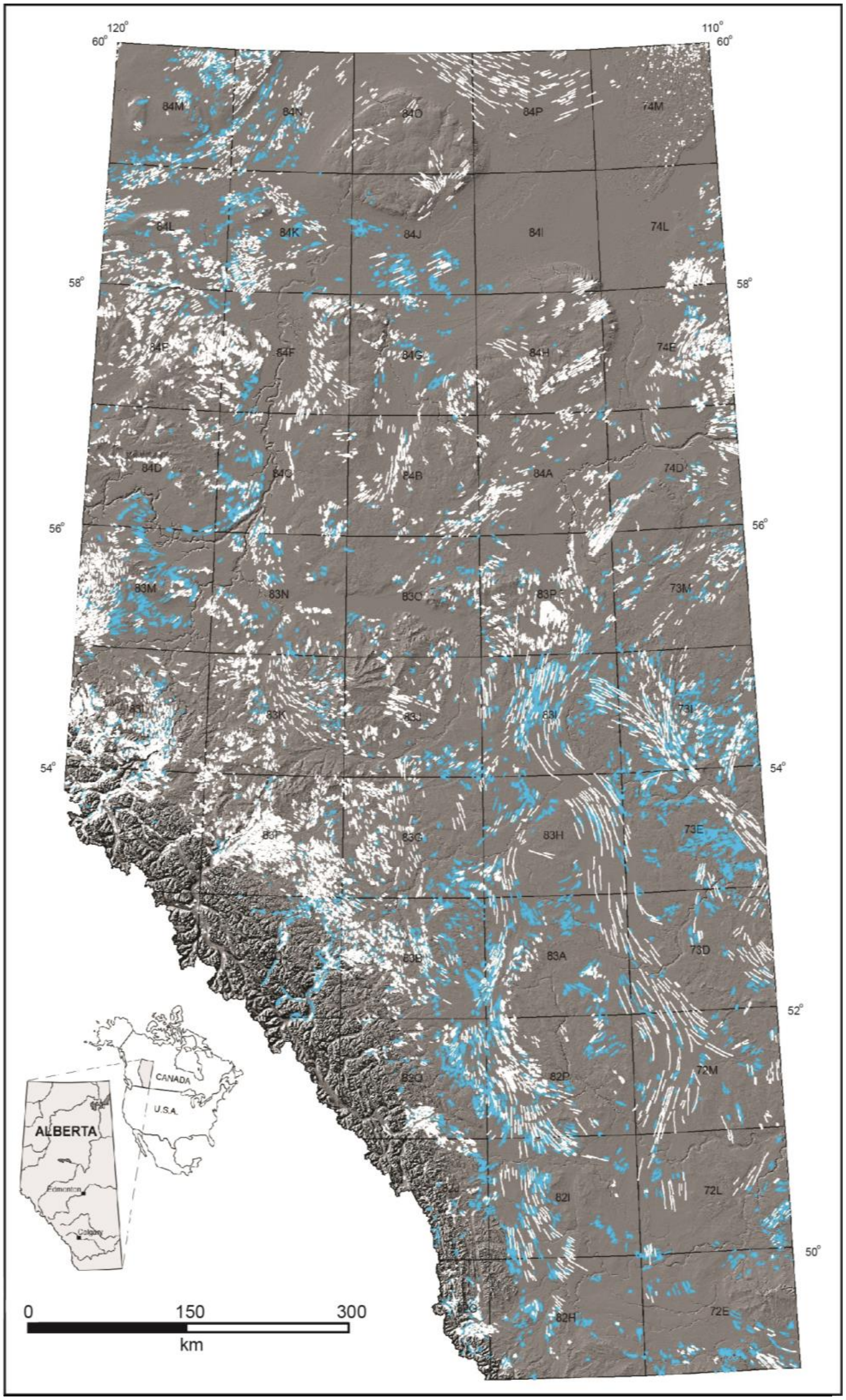

Figure 3. Distribution of previously compiled (white lines; Atkinson et al., 2014a, b) and updated (blue lines) streamlined subglacial bedforms across Alberta.

4.2 Glacially Scoured Grooves

Atkinson et al. (2016) previously described linear grooves across west-central Alberta, although such landforms were not mapped as a discrete feature class on Map 604 (Atkinson et al., 2014a). Instead, the relatively small number of closed-ended grooves, as well as the more common open-ended grooves, was amalgamated as a subclass of streamlined subglacial bedforms. However, landform associations that are now observable across large areas of recently acquired LiDAR necessitate glacial grooves being recognized as a separate feature class (Table 1, Figure 4) that provide new details on the interaction between the southwest LIS and its bed. These grooves occur at a range of scales, and comprise up to three distinct landform associations. For example, till-mantled bedrock in central and southern Alberta exhibit a number of erosional and constructional landforms associated with the ploughing of detached blocks of bedrock and/or consolidated sediment through the substrate. These include isolated bedrock plough marks, the largest of which is 2 km wide and extends for 23 km (Figure 5a), as well as tracts of shallow grooves flanked by sediment piled up in paraxial ridges (Figure 5b). Collectively, this new class of glacial landform provides further indication of former ice-flow trajectories, as well as improves our understanding of the genesis of streamlined subglacial bedforms vis-à-vis the ploughing of bedrock and/or sediment blocks through soft subglacial materials. These landform associations emphasize plough marks where the block remains in place, clearly demonstrating the linkage between longitudinally eroded grooves and the lateral deformation/displacement of material to form the paraxial ridges. Although groove ploughing is invoked to explain only a small number of streamlined subglacial bedforms in Alberta, this process may have been more widespread than currently recognized, particularly in cases where the terminal block was lifted off the bed or disaggregated down-ice, leaving only the ridges evident on the landscape. In such cases, the ridges would be classified as flutings, likely leaving the intervening groove unmapped.

Evidence of groove-ploughing also occurs across proglacial lake sediments in northern Alberta (e.g., NTS 84J, 84K), where tracts of flat-bottomed grooves extend alongside and parallel to 2–6 km long ridges, although in these cases, grooves terminate at arcuate frontal sediment prows rather than terminal bedrock blocks, suggesting a subaqueous origin resulting from iceberg ploughing (Figure 5c).

4.3 Aligned Rubble

This class of glacial landform was originally mapped as rubble moraine in east-central Alberta (NTS 73L; Andriashek and Fenton, 1989) and comprises disaggregated blocks of bedrock or pre-existing sediment that occur within narrow dispersal trains, typically proximal to other ice-flow features such as flutings and grooves (Figure 6). To avoid confusion with other forms of previously mapped rubble moraine (e.g., Campbell et al., 2001) which parallel former ice-marginal positions, we have adopted the term aligned rubble to describe lineaments of disaggregated blocks that extend along former ice-flow trajectories (Figure 7). Spatially, aligned rubble is most common along the lateral margins of confluent fluting fields, as well as areas where bedrock occurs at, or close to, the modern land surface (MacCormack et al., 2015), such as down-ice from escarpments.

4.4 Moraines

Atkinson et al. (2014a) delineated moraines as single lines drawn along the crest of topographically distinct ridges of ice-marginal sediment (Figure 8). Such moraines were deposited during the quasi-steady-state retreat and/or stabilization of ice margins, and have been mapped across much of Alberta, although in areas of lower resolution data coverage, mapping was restricted to the identification of larger features. However, new interpretations of the 15 m LiDAR DEM reveal that moraines are more common than previously identified, resulting in a 47% increase in the total number of features mapped across the province (Figure 8).

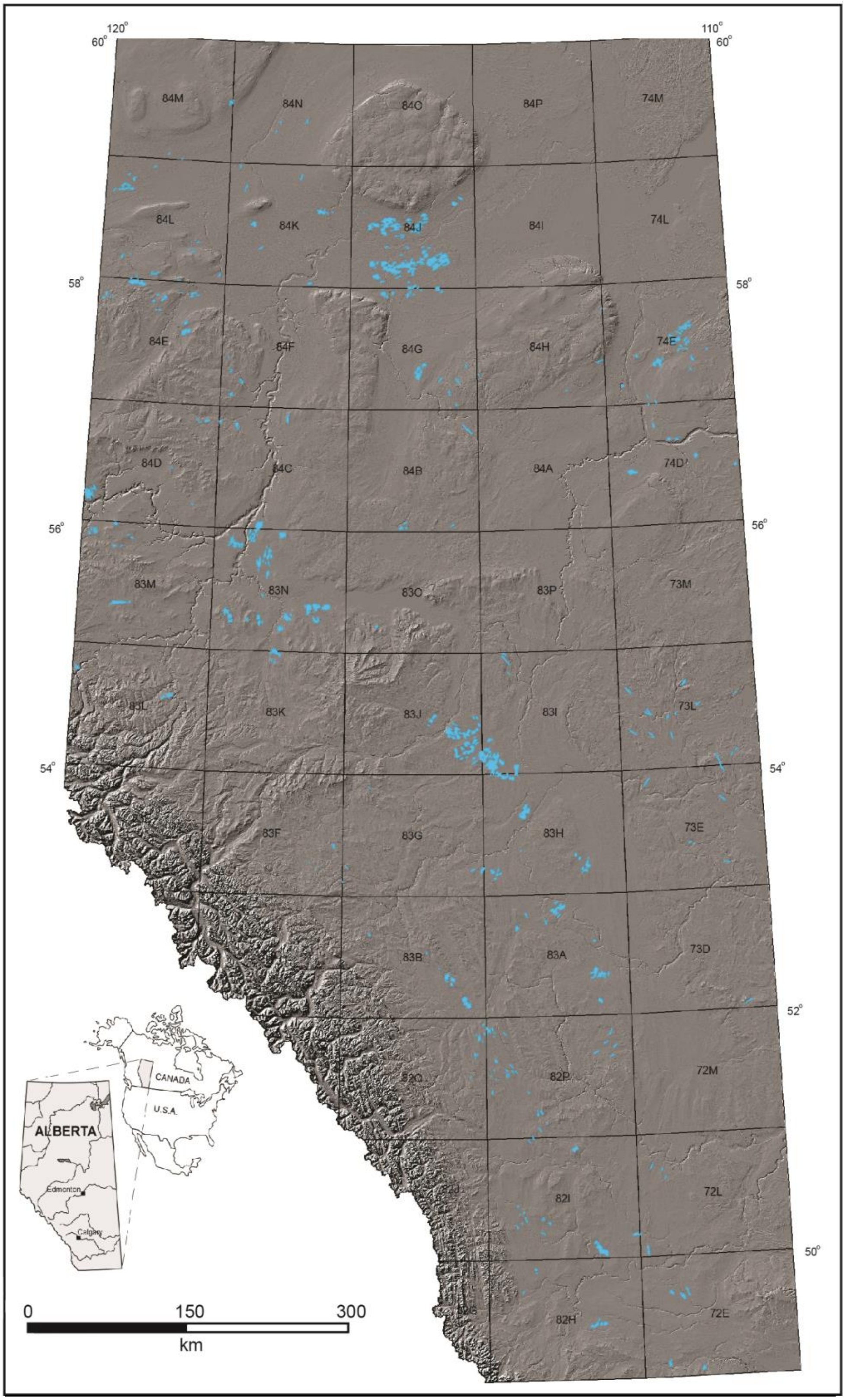

Figure 4. Distribution of glacially scoured grooves (blue lines) across Alberta.

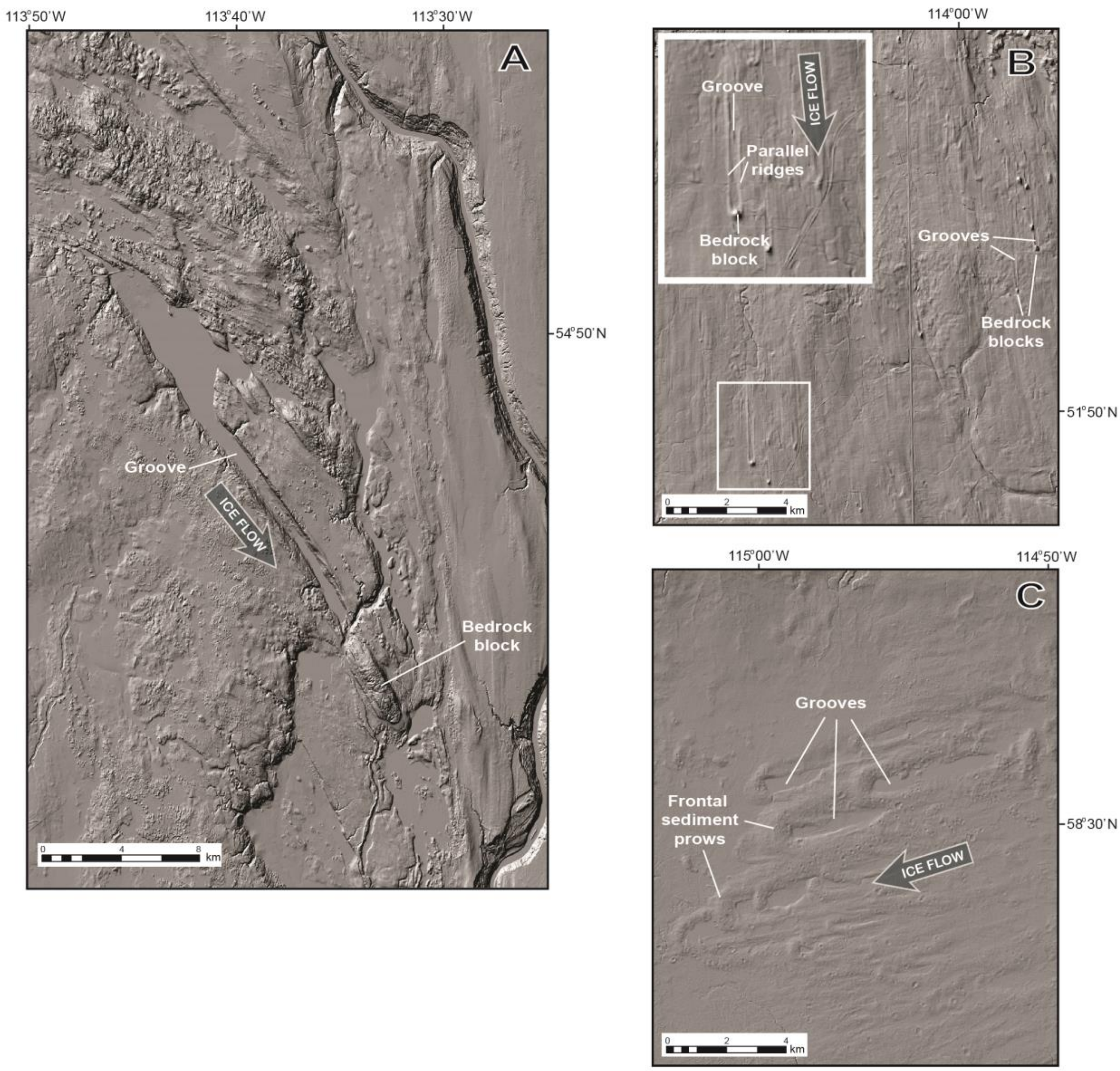

Figure 5. Examples of large-scale glacial grooves in Alberta. A) Isolated bedrock groove ploughed by a glaciotectonically displaced block. Note the absence of longitudinal paraxial ridges. B) Erosional and constructional landforms associated with detached blocks being ploughed through the substrate. C) Flat-bottomed grooves and longitudinal ridges terminating at frontal sediment prows. Note the depression and absence of a bedrock/consolidated sediment block on the proximal side of the sediment prow. See Figure 1 for locations.

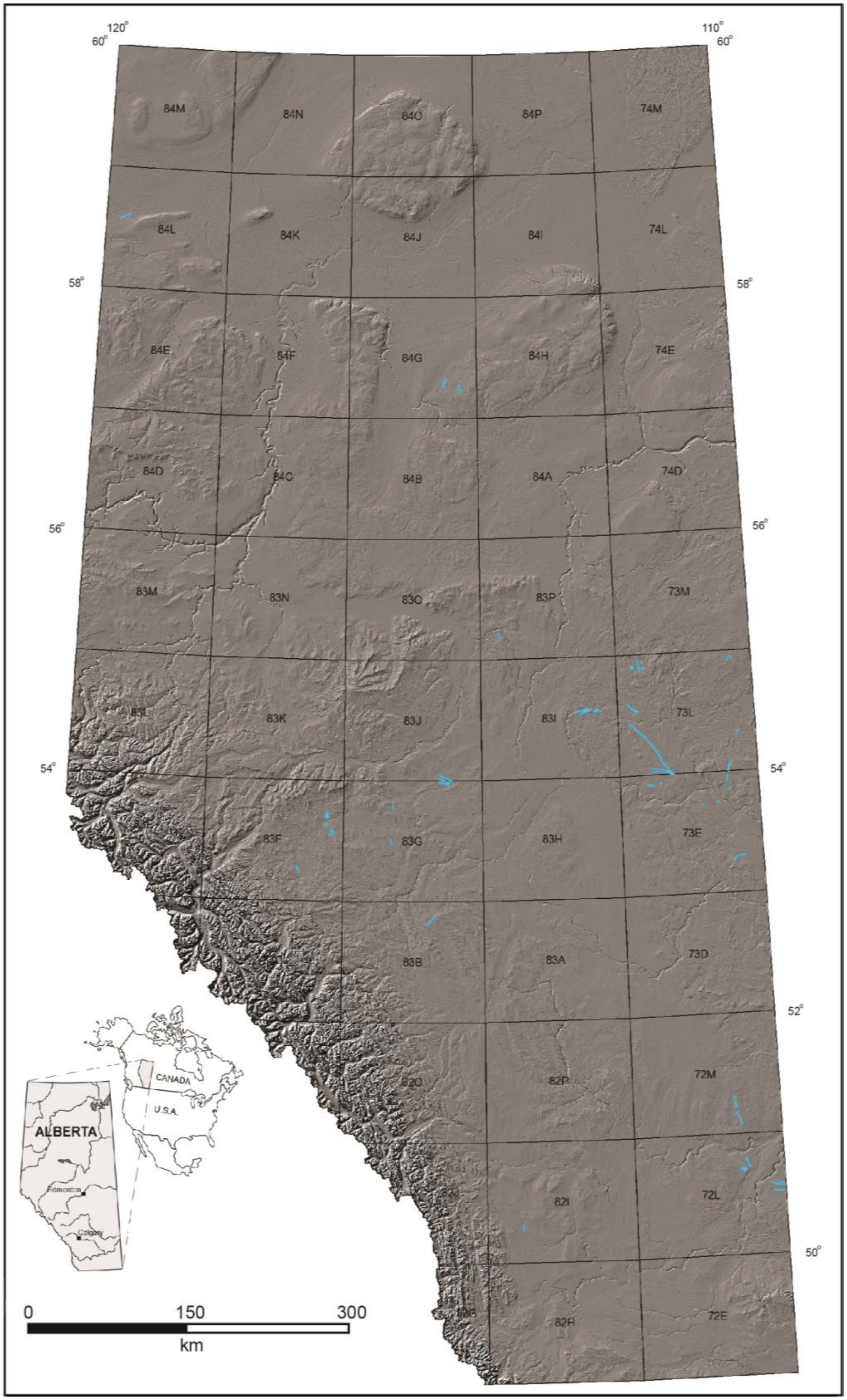

Figure 6. Distribution of aligned rubble (blue lines) across Alberta.

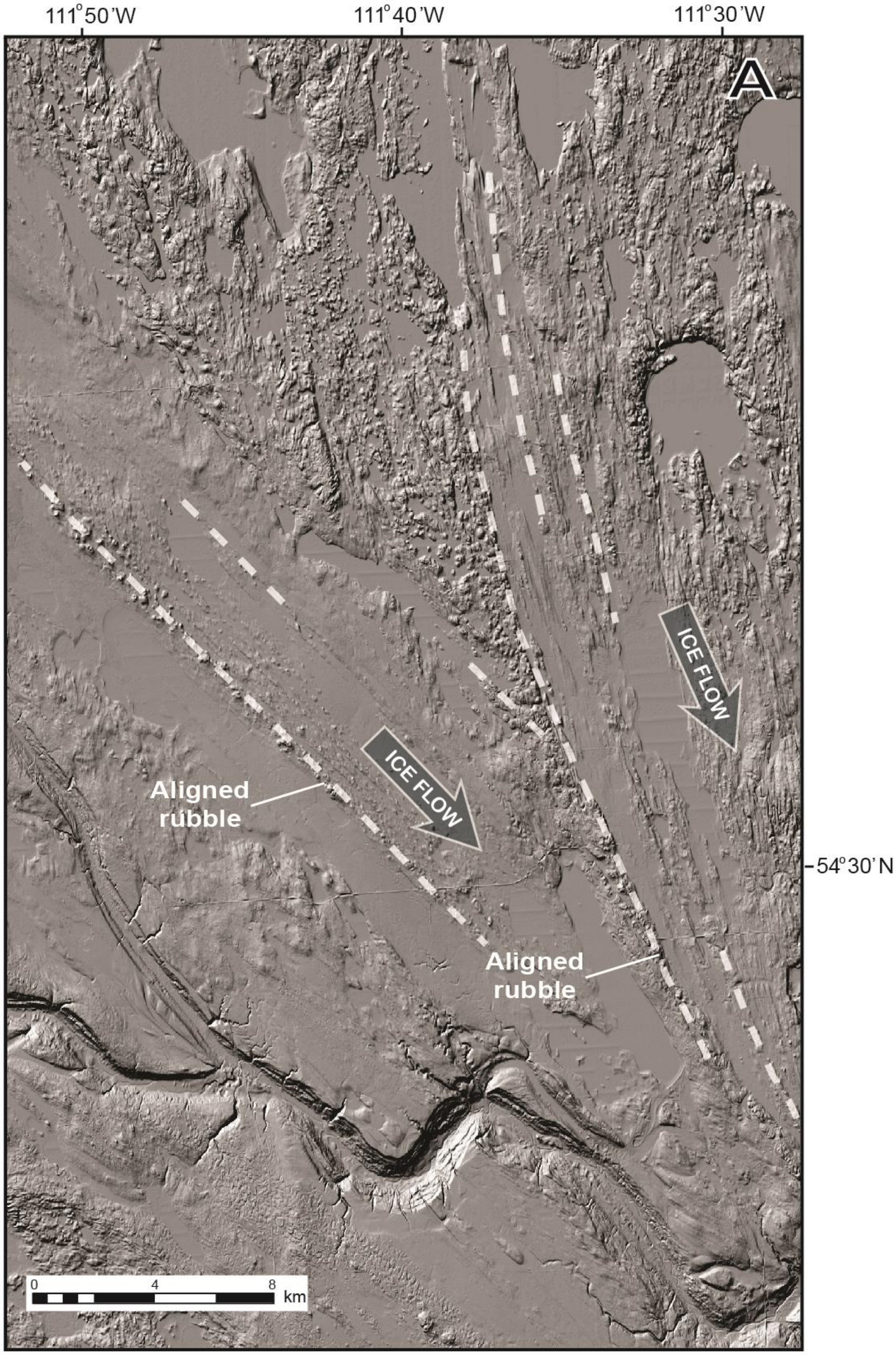

Figure 7. Landforms associated with aligned rubble along the lateral margins of coalescent fluting tracts in northeast Alberta. See Figure 1 for location.

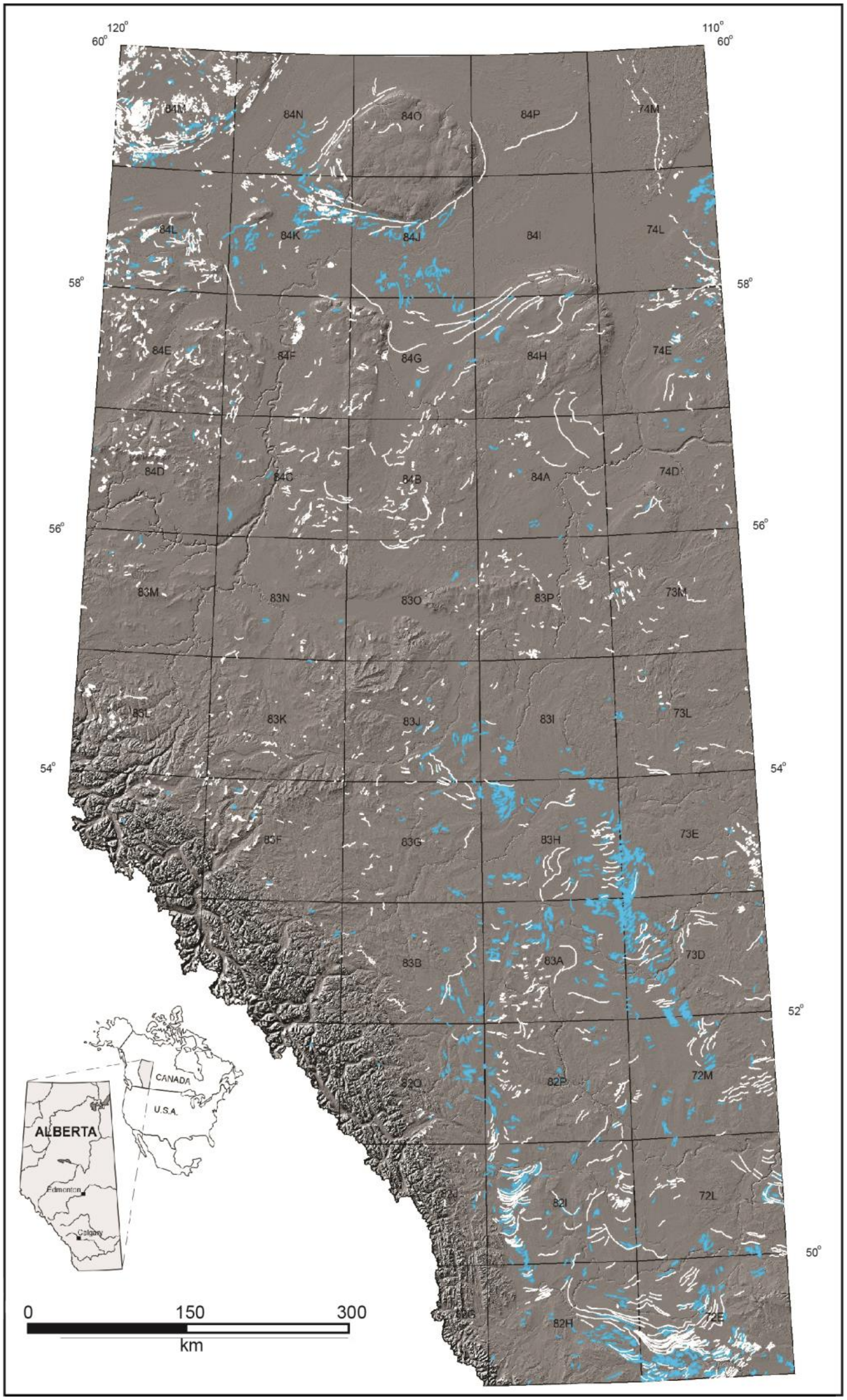

Figure 8. Distribution of previously compiled (white lines; Atkinson et al., 2014a, b) and updated (blue lines) moraine ridges across Alberta.

Collectively, this comprehensive inventory of moraines can be used for detailed reconstructions of the deglacial configuration and dynamics of the LIS and CIS, notably in central and southern Alberta, where previously unmapped belts of closely spaced arcuate recessional moraines document the progressive northward retreat of two Laurentide ice lobes for at least 600 km into the Edmonton region (NTS 83H). In contrast, moraines spanning the broad lowlands of northern Alberta are frequently associated with streamlined and glaciotectonized glaciolacustrine sediments, suggesting that retreat in this sector of the southwest LIS was punctuated by successive large-scale readvances into proglacial lakes (Utting et al., 2015; Hickin et al., 2016; Atkinson et al., 2016).

The distribution of large moraine complexes comprising extensive areas of circular to elongate hummocks and linear ridges have generally been delineated by polygons, and include named features in central and southern Alberta such as the Duffield, Cooking Lake, Viking, Suffield, Lethbridge and McGregor moraines (Warren, 1937; Bretz, 1943; Bayrock 1955; Mollard, 2000; Evans, 2000; Evans et al., 2014; Figure 9). These polygons are typically classified as stagnant ice moraine, most recently on AGS Map 601 and the accompanying DIG (Fenton et al., 2013a and b), which is intended to complement the line features presented in this update.

4.4.1 *Ice-thrust Moraines*

Ice-thrust moraines comprise glaciotectonically dislocated and/or deformed rafts of bedrock and/or Quaternary sediments that form small, isolated mounds to large composite ridges. They are largely absent in the southwest and northern parts of Alberta, becoming more prominent in central and eastern parts of the province, particularly in areas where tracts of streamlined subglacial bedforms converge (Figure 10). Of the ~1330 ice thrust moraines mapped in Alberta, almost 40% are newly interpreted (Table 1). As well as improving our understanding of the paleoglaciology of the southwest LIS, knowledge of the distribution, structure and hydrology of glaciotectonically disturbed materials is an important engineering consideration for infrastructure planning and resources development.

4.4.2 *Overridden Moraines*

Despite the twelvefold increase in identification of moraines exhibiting evidence of glacial overriding, such features remain relatively rare in Alberta (Figure 11; Table 1). Glacial overriding is typified by evidence of glaciotectonic disturbance, including streamlining (Atkinson et al., 2014c) and the occurrence of distinctive ribbed terrain (Figure 12a), which in southern Alberta comprises ridges of folded and thrust Cretaceous bedrock (Evans et al., 2008) superimposed by inset sequences of arcuate recessional moraines (Figure 12b). Although rare across much of the province, they are more abundant along the confluence between the LIS and CIS (NTS 82I, 82P) and along the axes of major fluting tracts (e.g., NTS 83I, 83H, 82I, 72L), thereby providing new insights into subglacial conditions, particularly the interactions between variations in thermal conditions, basal ice velocity and bed strength.

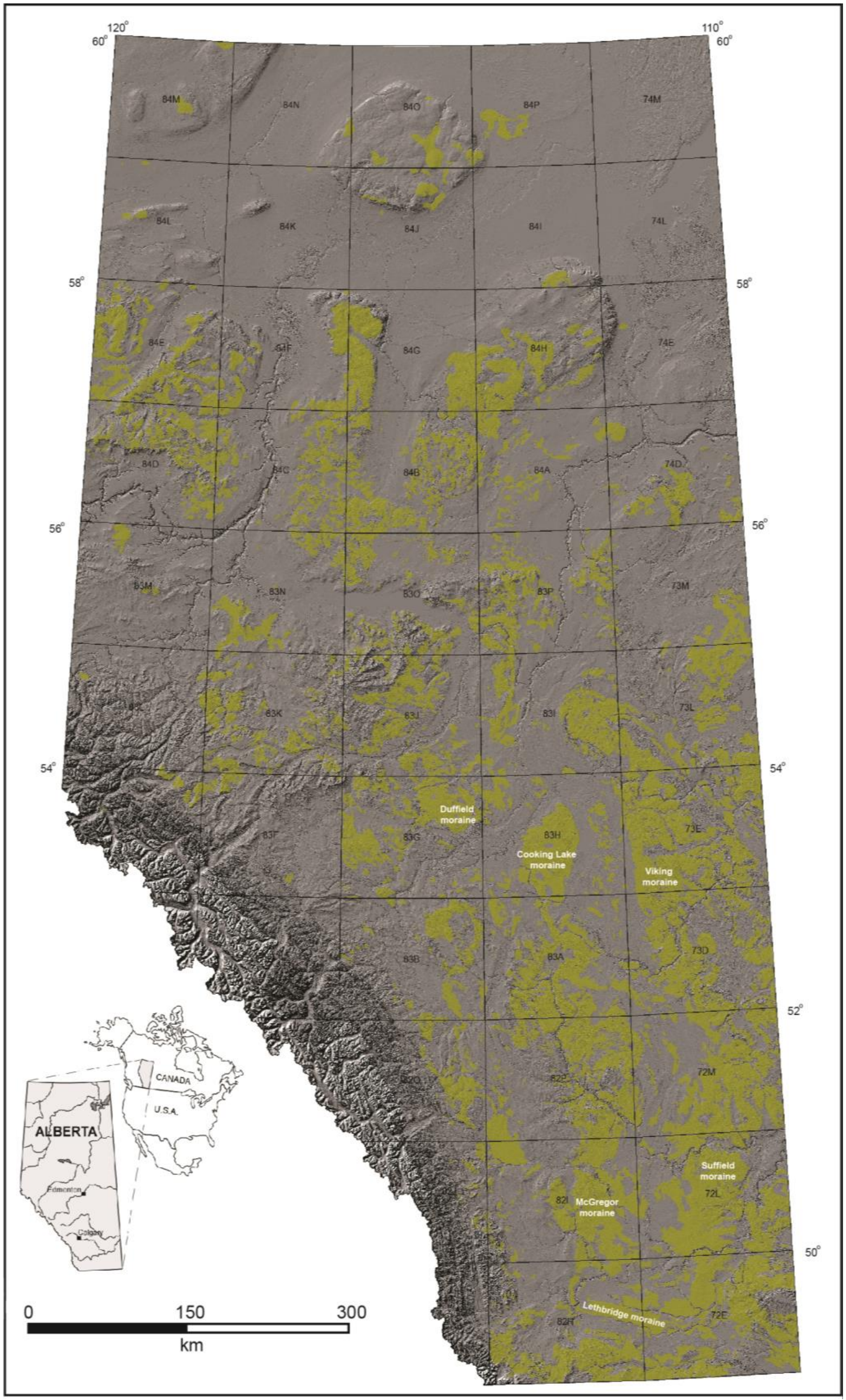

Figure 9. Distribution of stagnant ice moraine across Alberta (Fenton et al., 2013a and b).

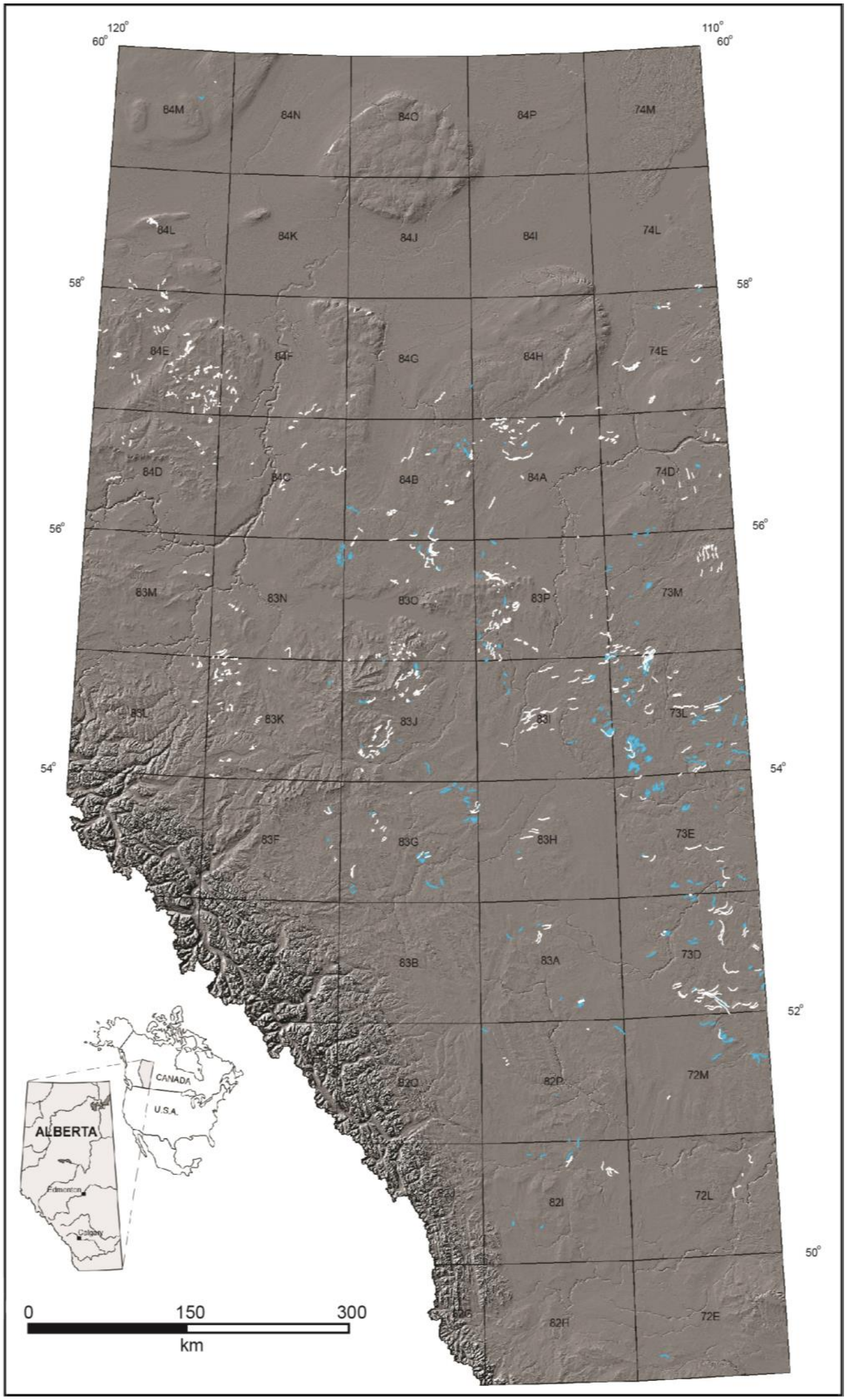

Figure 10. Distribution of previously compiled (white lines; Atkinson et al., 2014a, b) and updated (blue lines) ice-thrust moraines across Alberta.

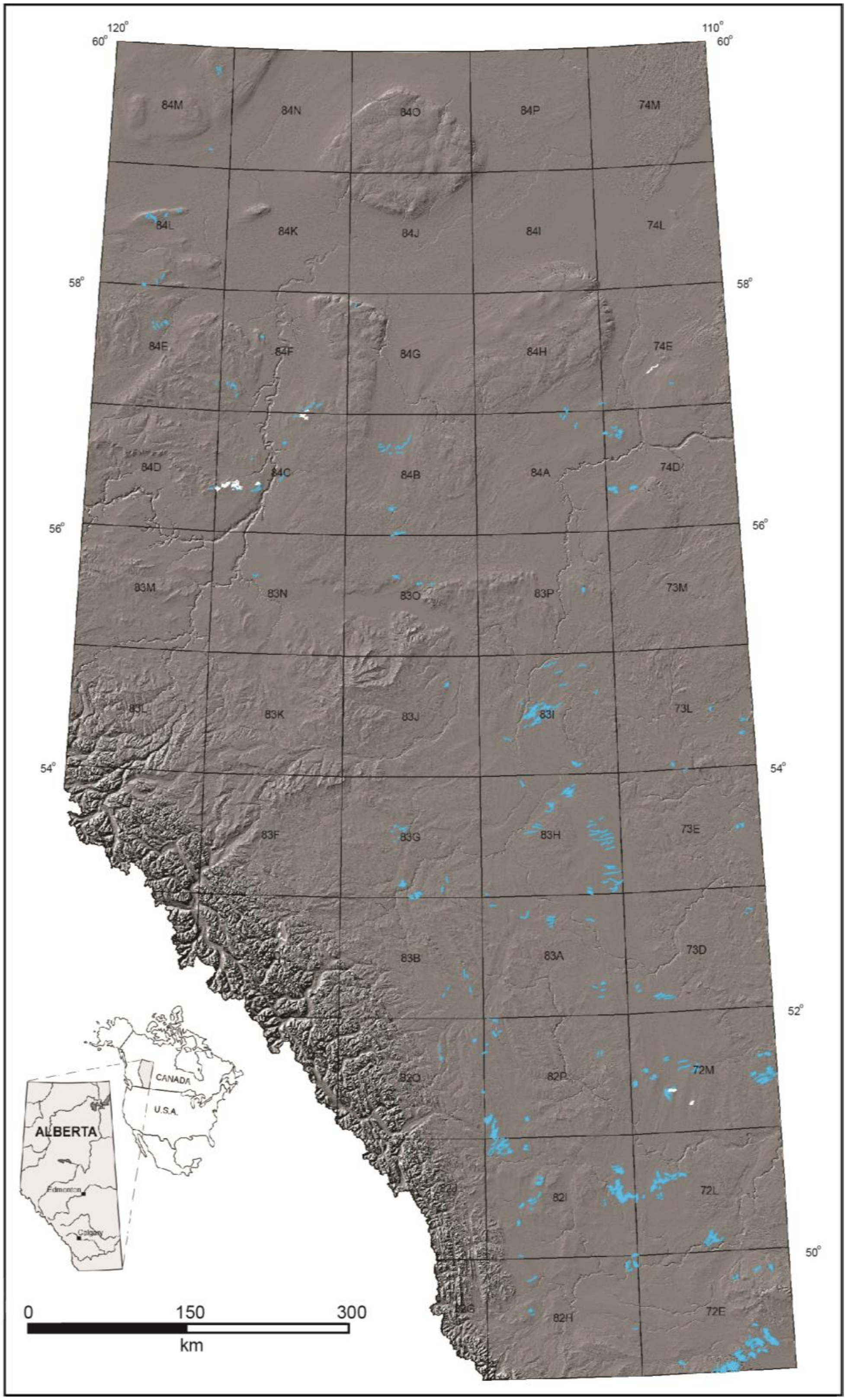

Figure 11. Distribution of previously compiled (white lines; Atkinson et al., 2014a, b) and updated (blue lines) overridden moraines across Alberta.

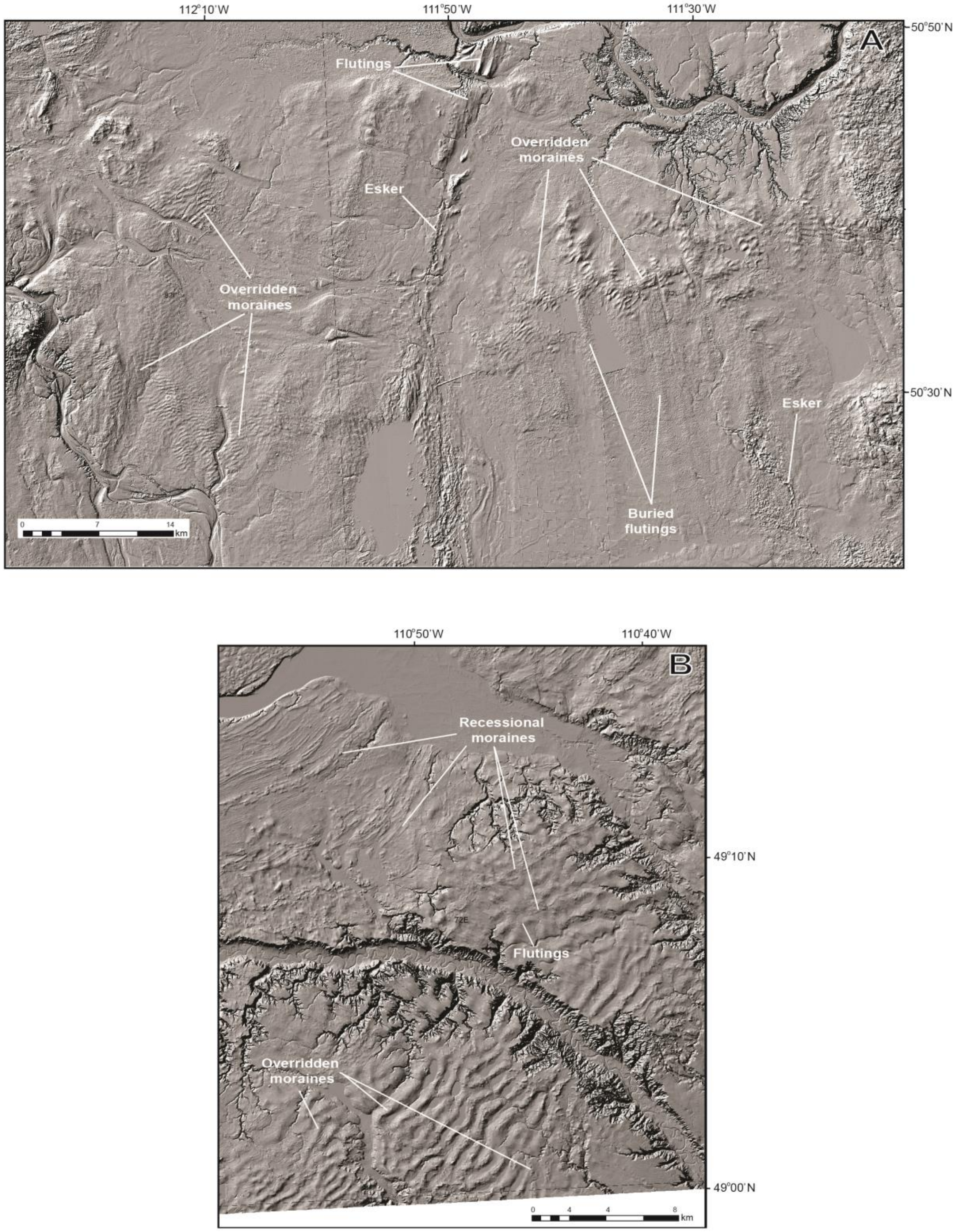

Figure 12. Examples of overridden moraines across Alberta. A) A succession of subglacial landform associations showing the relationship between ribbed terrain, buried flutings and eskers. B) Ribbed terrain comprising ridges of glaciotectonized Cretaceous bedrock, superimposed by arcuate recessional moraines. See Figure 1 for locations.

4.5 Meltwater Channels

Meltwater channels are classified into two thematic layers, depending on the regional continuity of these features. Major meltwater channels are regionally continuous and evolve either ice marginally, due to the topographic focussing of subaerial drainage systems or meltwater along the margin, or proglacially, where topographic openness enables water to drain away from the ice margin. Due to their regional continuity, major meltwater channels can be accurately portrayed using traditional mapping techniques, and so this update contains only minor revisions.

Minor meltwater channels are smaller features that lack regional continuity and form in a range of ice-marginal, proglacial, supraglacial, or subglacial settings. These include lateral meltwater channels, spillways, ice-walled channels, and tunnel valleys. Such features have generally been difficult to map in Alberta, either due to spatial biases in previously available imagery or because they are obscured by vegetation. However, the 15 m LiDAR DEM now enables such channels to be mapped at a finer resolution than previously possible (Figure 13; Table 1).

4.6 Eskers

Mapping eskers was challenging prior to the availability of LiDAR, particularly in vegetated areas of northern and western Alberta, since these features are generally smaller than the resolution of DEMs previously used for regional-scale investigations. These spatial biases have now been addressed with the provincial 15 m LiDAR DEM, resulting in a 44% increase in the number of eskers mapped across Alberta. Eskers are widespread across much of the province, although are rare on the lowlands of northern Alberta, and generally absent across higher relief uplands (Figure 14). These features have significant implications for establishing the linkage between ice sheet dynamics and subglacial hydraulic conditions, as well as representing a potential target for aggregate resources exploration.

4.7 Crevasse-fill Ridges

Crevasse-fill ridges result from the squeezing or flowage of subglacial or supraglacial sediment into crevasses at or close to the ice margin and currently represent the most common class of glacial landforms in Alberta (Table 1). These small-scale ridges, identifiable as transverse lineaments or cross-cutting herringbone networks, occur across most terrain elements in the province, although are rare in higher relief uplands, and are generally absent west of the Rocky Mountain Foothills (Figure 15). Of the ~64 000 crevasse-fill ridges mapped throughout Alberta, almost 70% are previously unidentified features (Table 1). This increase reflects the difficulty of mapping crevasse-fill ridges using traditional interpretative techniques based on low-resolution imagery. Areas of greatest revision include central (NTS 83I, 83H, 83A) and eastern Alberta (NTS73L, 73E), where crevasse-fill ridges are pervasive within two distinct corridors, and typically drape MSGL, as well arcuate ridges that are inferred to be overridden recessional moraines (Figure 16). These corridors occur along the path of two major ice streams within the southwest LIS, which may provide new insights into the response of this sector of the ice sheet to fluctuations in mass balance, basal thermal regime and subglacial hydrology.

4.8 Eolian Dunes

Although not a glacial landform, eolian dunes may parallel local fluting orientations, making it possible for such features to be misidentified as a subglacial bedform, particularly in areas of dense vegetation cover. Alberta had already been recognized as the province with the largest number of dunes in Canada (David, 1977) and this update adds to an already detailed record, with the DIG now comprising 24% more features for a total of 21 312 individually mapped dunes (Table 1).

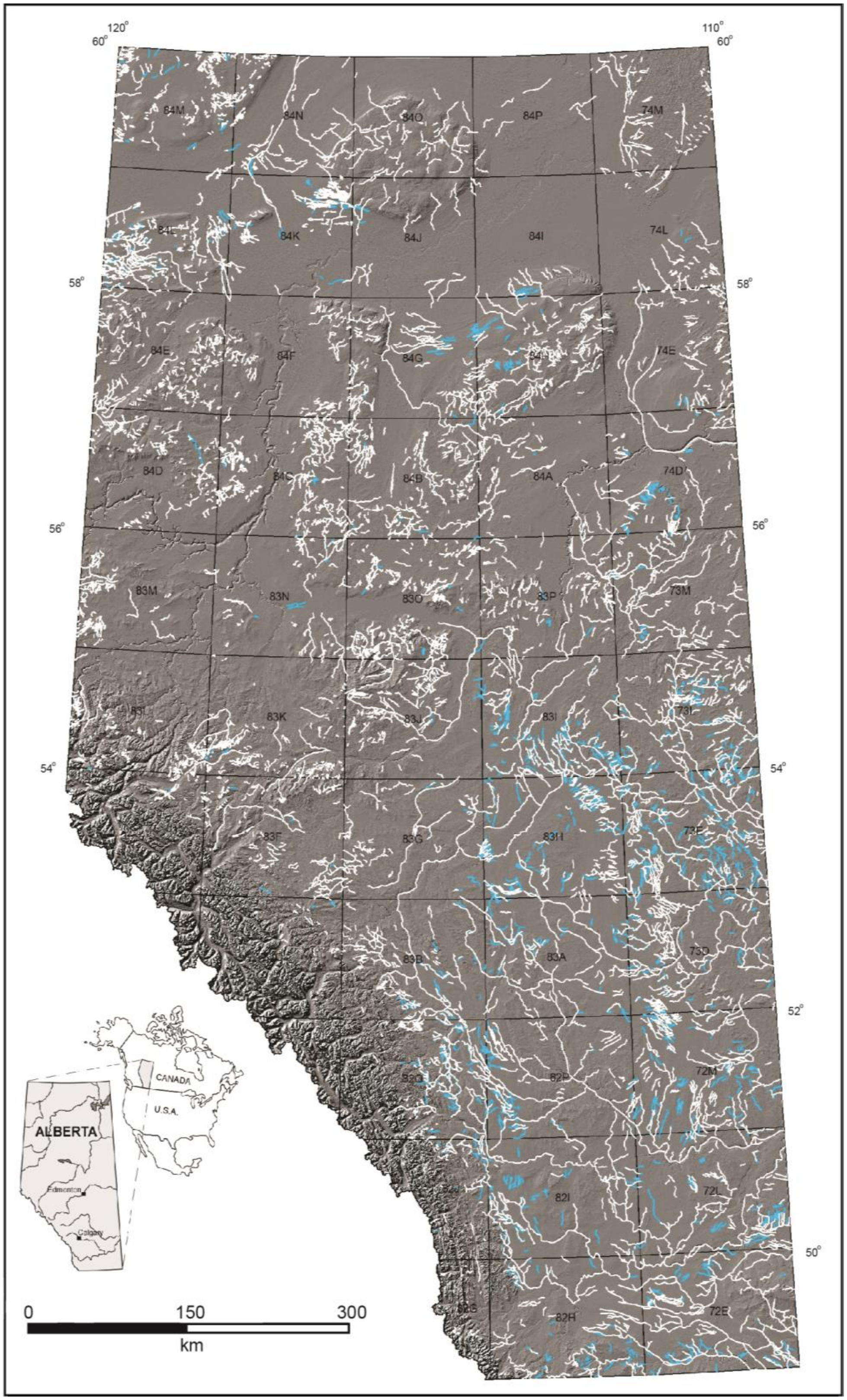

Figure 13. Distribution of previously mapped (white lines; Atkinson et al., 2014a, b) and updated (blue lines) meltwater channels across Alberta.

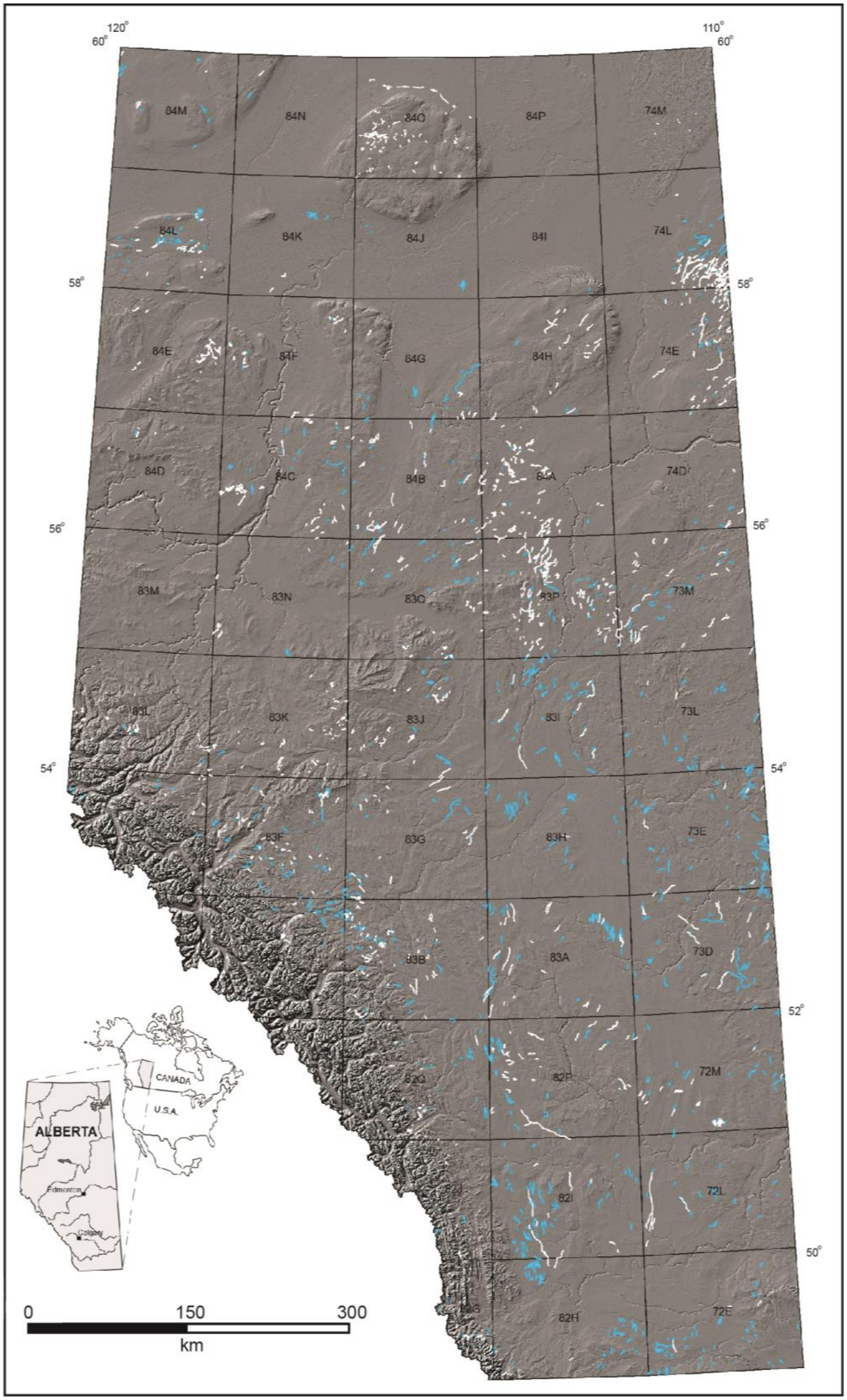

Figure 14. Distribution of previously mapped (white lines; Atkinson et al., 2014a, b) and updated (blue lines) eskers across Alberta.

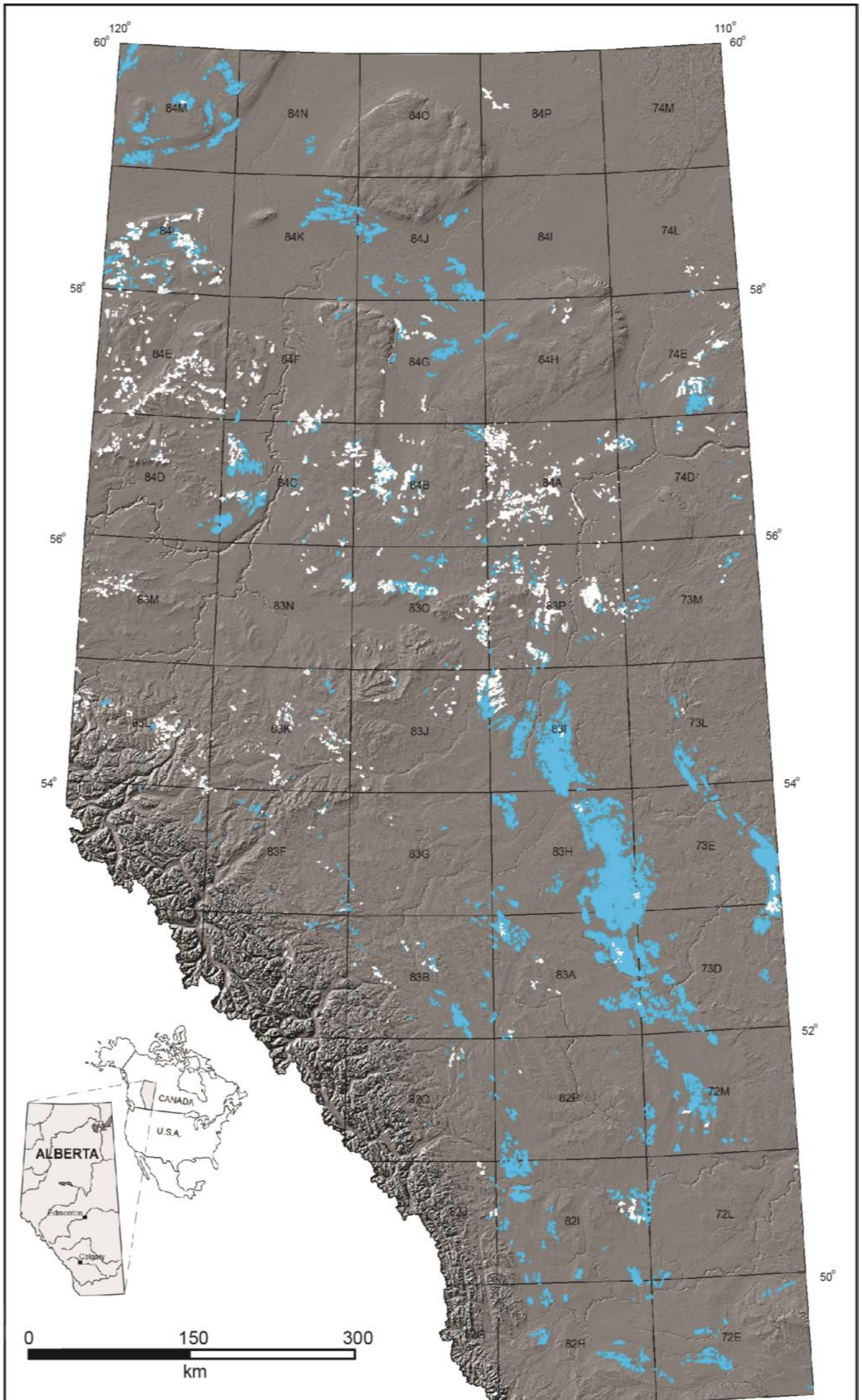

Figure 15. Distribution of previously mapped (white lines; Atkinson et al., 2014a, b) and updated (blue lines) crevasse-fill ridges across Alberta.

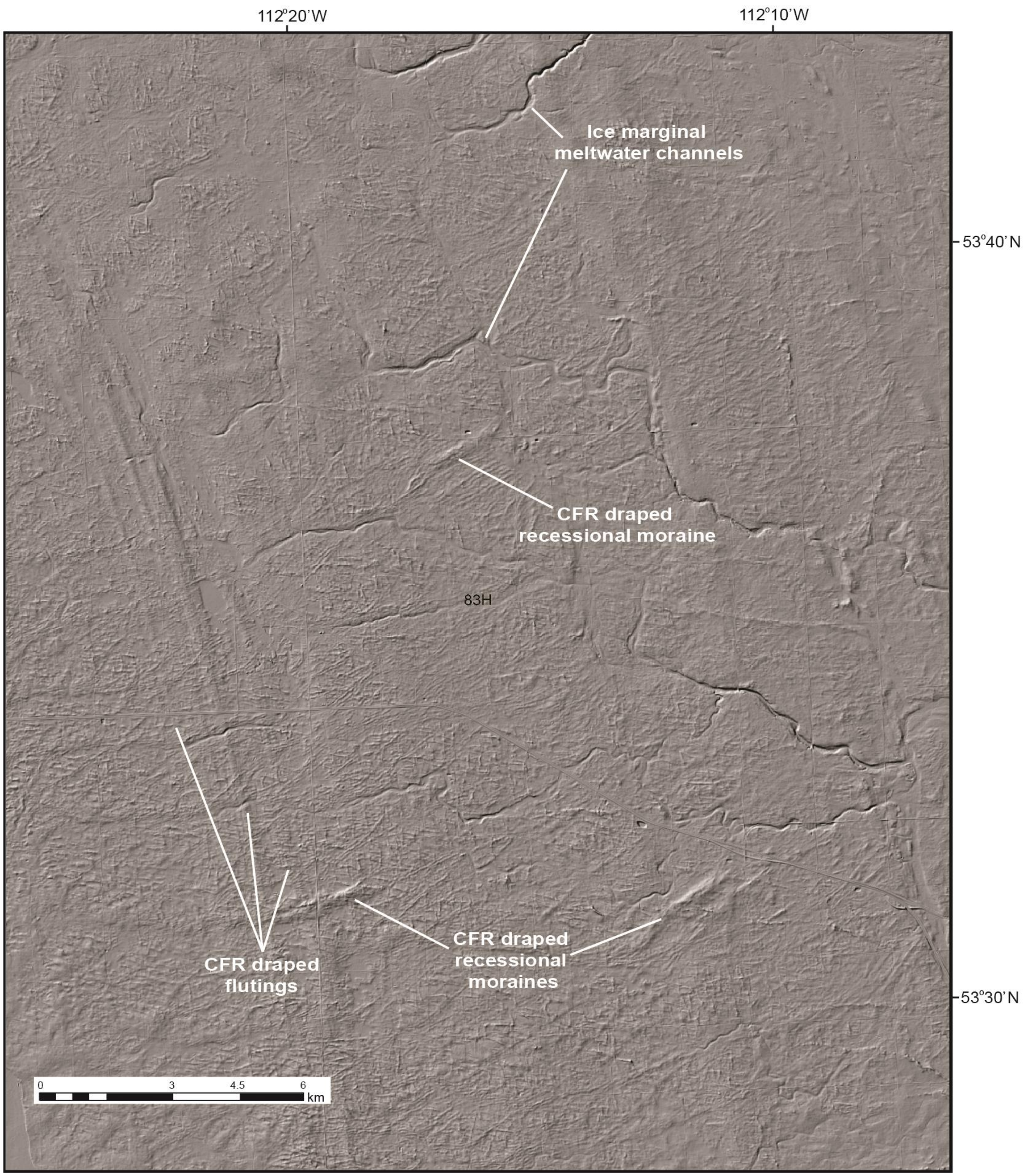

Figure 16. Pervasive networks of crevasse-fill ridges (CFR) draped over flutings and arcuate recessional moraines. See Figure 1 for location.

5 Summary

An updated DIG (Atkinson et al., 2018) to the Glacial Landforms of Alberta map (Atkinson et al., 2014a, b) includes significant new information in all but three NTS map sheets in the province (Figure 2). Spatial biases inherent in earlier mapping is now resolved, with all new mapping being based on standardized interpretations of a provincial 15 m LiDAR DEM. Consequently, the updated DIG now contains 143 541 landforms (an almost two-fold increase from Map 604) classified in eleven thematic layers (Table 1). Areas of greatest revision are in the White Area of Alberta, notably east of Edmonton, where individual sheets (e.g., NTS 83H) contain almost 10 000 mapped glacial landforms. However, areas of northwest Alberta, previously mapped using air photos, have also been significantly revised (Figure 2).

This work emphasizes the benefit of high-resolution LiDAR bare-earth DEMs to generate comprehensive landform inventories needed for mapping glacial deposits, particularly with respect to mineral exploration, hydrogeology, geo-engineering, natural resources management, infrastructure planning, and environmental protection. These data are also critical for robust reconstructions of the paleoglaciology of former ice sheets, particularly variations in the response of the ice sheet to fluctuations in mass balance, basal thermal regime and subglacial hydrology, as well as the role of proglacial lakes in destabilizing the ice margin.

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