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PRELIMINARY DELINEATION OF MARINE SEDIMENTS IN EAST-CENTRAL LABRADOR: PARTS OF NTS MAP AREAS 13F, G, I, J, K, N AND O

G.W. Hagedorn[1]
Terrain Sciences and Geoscience Data Management Section
[1]Present address: Sedimentary and Environmental Geoscience Section, Ontario Geological Survey, 933 Ramsey Lake Road, Sudbury, ON, P3E 6B5

ABSTRACT

*Limited surficial mapping in Labrador has made it difficult to fully characterize its complex glacial history and postglacial marine incursion ("marine limit"). The delineation of the extent and elevation of marine limits are important to a variety of stakeholders including the mineral exploration industry (*e.g.*, to identify areas not suitable for surface exploration techniques) and local communities (*e.g.*, to provide surficial geological information for planning, or suitable as granular aggregate sources). A 1:10 000-scale interpretation mapping project was undertaken to identify the marine sediments and related landforms along the coast of central Labrador between Hopedale and Happy Valley-Goose Bay covering NTS map areas 13F, G, I, J, K, N and O. The mapping used a variety of remotely sensed datasets (satellite imagery, digital elevation models, and airphotos) and references earlier published surficial geology maps. The preliminary mapping results have identified a marine limit higher than that reported in previous publications. Future work should focus on obtaining dates on mapped beach ridges, terraces, and eolian dunes to further decipher the glacial and postglacial landscape evolution in the region.*

INTRODUCTION

The marine limit is the highest relative sea level that flooded the present land surface and is controlled by local topography, past sea levels, and isostatic adjustment. During the last glaciation, the ice sheet isostatically depressed the landscape. Following glacial retreat, global sea-level rise was outpaced by glacio-isostatic adjustment to produce an emergent coastline. Sediments deposited in marine environments that mark the former position of the marine limit are now elevated above the modern sea level. These marine sediments include fine-grained silts and clays that were deposited in relatively low-energy environments, such as marine deltas and foreshore regions, and coarser grained silt and sand deposited in high-energy environments, such as nearshore coastal regions. Therefore, by mapping the extent of marine sediments at surface, an estimation of the past marine limit can be identified to better understand the development of the Labrador coastal zone.

The extent and type of marine sediments deposited are important to a variety of stakeholders, including the mineral exploration industry, local communities and municipalities, environmental scientists, and infrastructure agencies. Sediments deposited at or below the marine limit have been subjected to a degree of remobilization. Remobilization complicates the ability to trace these sediments to their original source, meaning that sampling of marine sediments or sediments deposited below the marine limit for mineral exploration are challenging to vector back to source (McClenaghan *et al.*, 2020). Mapping the distribution of marine sediments is also useful for communities and infrastructure development projects. Areas of marine sediments are more susceptible to permafrost thaw because they are generally fine grained leading to land subsidence, an issue for construction (Fortier *et al.*, 2008). In contrast, marine beach ridges are coarser grained and represent a source of granular aggregate; a valuable resource for development projects. An approximation of the marine limit can also be incorporated into regional ice-sheet models to delineate locations of ice margins and glacial lakes, estimate past global sea levels, and determine glacio-isostatic adjustment rates (Hodgson and Fulton, 1972; Awadallah and Batterson, 1990; Dyke *et al.*, 2005; Stokes *et al.*, 2015; Dalton *et al.*, 2020). Additionally, these regional ice-sheet models detail ice flows used to trace material back to source (*i.e.*, till), pertinent for mineral exploration, and influence how we understand modern sea-level rise due to climate change that could impact the coastal regions of Labrador in the future (Margold *et al.*, 2018).

Historical surficial mapping by the Geological Survey of Newfoundland and Labrador has targeted 1:50 000-scale National Topographic Series (NTS) map sheets. Due to the large swaths of unmapped surficial geology along the coast of east-central Labrador, a more targeted approach was undertaken for this study; only late-glacial marine sediments were identified to further refine the late-glacial marine limit. Sediments and landforms, derived from marine processes and dynamic environments (Figure 1), were mapped remotely at 1:10 000 scale. This dataset represents a preliminary interpretation of the extent and type of marine sediment over the study area. This preliminary interpretation will be a component of future Quaternary geoscience work in Labrador. Due to the lack of fieldwork to confirm the interpreted mapping completed by this study, only broad interpretations of the dataset are discussed. The preliminary marine-sediment geospatial dataset will be released at a later date as an Open File report.

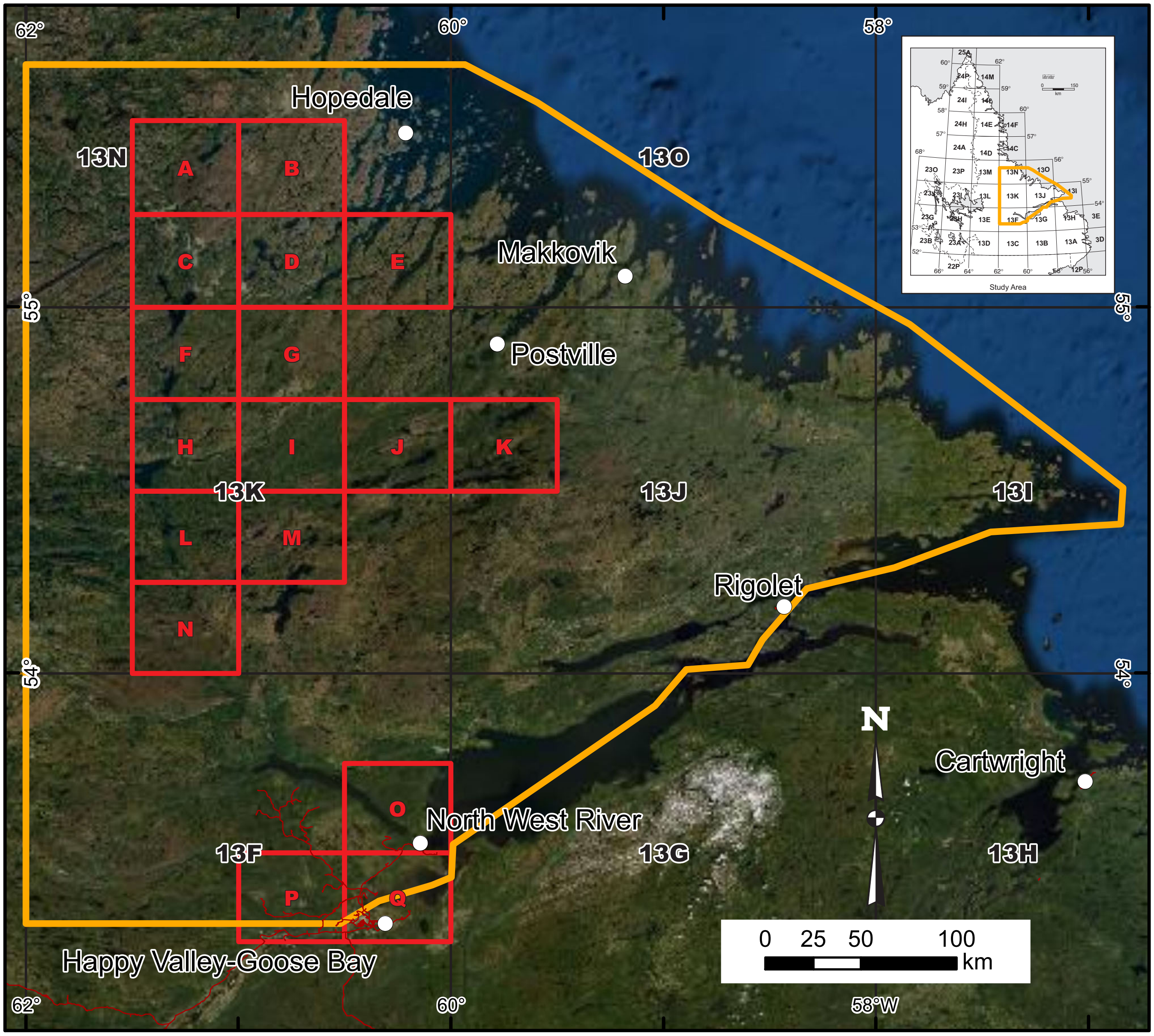


Figure 1. *Study area (orange outline) and extent of previously published maps (red outlines) depicted over a satellite-derived imagery mosaic. Previously published maps of the area include: A) Batterson, 2000d; B) Batterson, 2000e; C) Batterson, 2000i; D) Batterson, 2000k; E) Batterson, 2000f; F) Batterson, 2000h; G) Batterson, 2000c; H) McCuaig, 2007c; I) Batterson, 2000g; J) Batterson, 2000j; K) Batterson, 2000a; L) McCuaig, 2007a; M) Batterson, 2000b; N) McCuaig, 2007b; O) Liverman and Sheppard, 2000c; P) Liverman and Sheppard, 2000b; Q) Liverman and Sheppard, 2000a. Mosaic (ESRI ArcGIS "World Imagery" basemap © 2021 Maxar Technologies Inc.).*

LOCATION AND PHYSIOGRAPHY

The study area (Figure 1) is situated in east-central Labrador and contains Happy Valley-Goose Bay, North-West River, Rigolet, Makkovik, Postville and Hopedale (NTS map areas 13F, G, I, J, K, N and O). It was chosen because of its proximity to known mineral occurrences, potential future resource exploration, and relevance of new surficial mapping to community planning and adaptation (*see e.g.*, Hjort *et al.*, 2018; Roberts, 2018; Way *et al.*, 2018; Ramage *et al.*, 2021) because surficial mapping efforts in this area are incomplete. Previously published maps include Batterson, 2000a–k; Liverman and Sheppard, 2000a–c; McCuaig, 2007a–c (Figure 1). Despite these previous mapping efforts, there are still uncertainties about the deglacial chronology, ice-margin positions, isostatic adjustment rates, surficial sediment cover, and marine limits in east-central Labrador (Dalton *et al.*, 2020).

The study area includes a variety of terrains reflecting different bedrock geology, structural controls, surficial geology, and topography. The area is generally characterized by thin sedimentary cover on bedrock, and abundant organic deposits in areas of limited drainage. The drainage pattern in the region is strongly influenced by bedrock joints and faults, and is generally eastward into the Atlantic Ocean. Major rivers include the Churchill, Naskaupi, Big and Kanairiktok. Additionally, Lake Melville bounds the southern extent of the map area. Elevation ranges from approximately 800 m above sea level (asl) at bedrock peaks along the western part of the study area to 0 m (sea level) in the east along the coastline (Figure 2).

REGIONAL GEOLOGY AND MINERAL OCCURRENCES

The map area is underlain by bedrock units of the Nain (North Atlantic Craton), Makkovik, Southeast Churchill and Grenville provinces (Wardle *et al.*, 1997; Figure 2, inset). The area preserves a complex crustal history encompassing multiple orogenic events that juxtapose Archean cratons with younger, supracrustal rocks and intrusive suites. For details, the reader is referred to the following: Nain Province, *see* Wardle *et al.* (2002), Wardle and Hall (2002), Connelly and Ryan (1996) and Ryan (2000); Makkovik Province, *see* Ermanovics (1993), Kerr *et al.* (1996) and Hinchey (2007, 2021a–c); Southeast Churchill, *see* Wardle *et al.* (2002), Corrigan *et al.* (2021), van Kranendonk and Wardle (1997), Wardle *et al.* (2002) and Rawlings-Hinchey *et al.* (2003); and Grenville Province, *see* Rivers (1997) and Gower (2019).

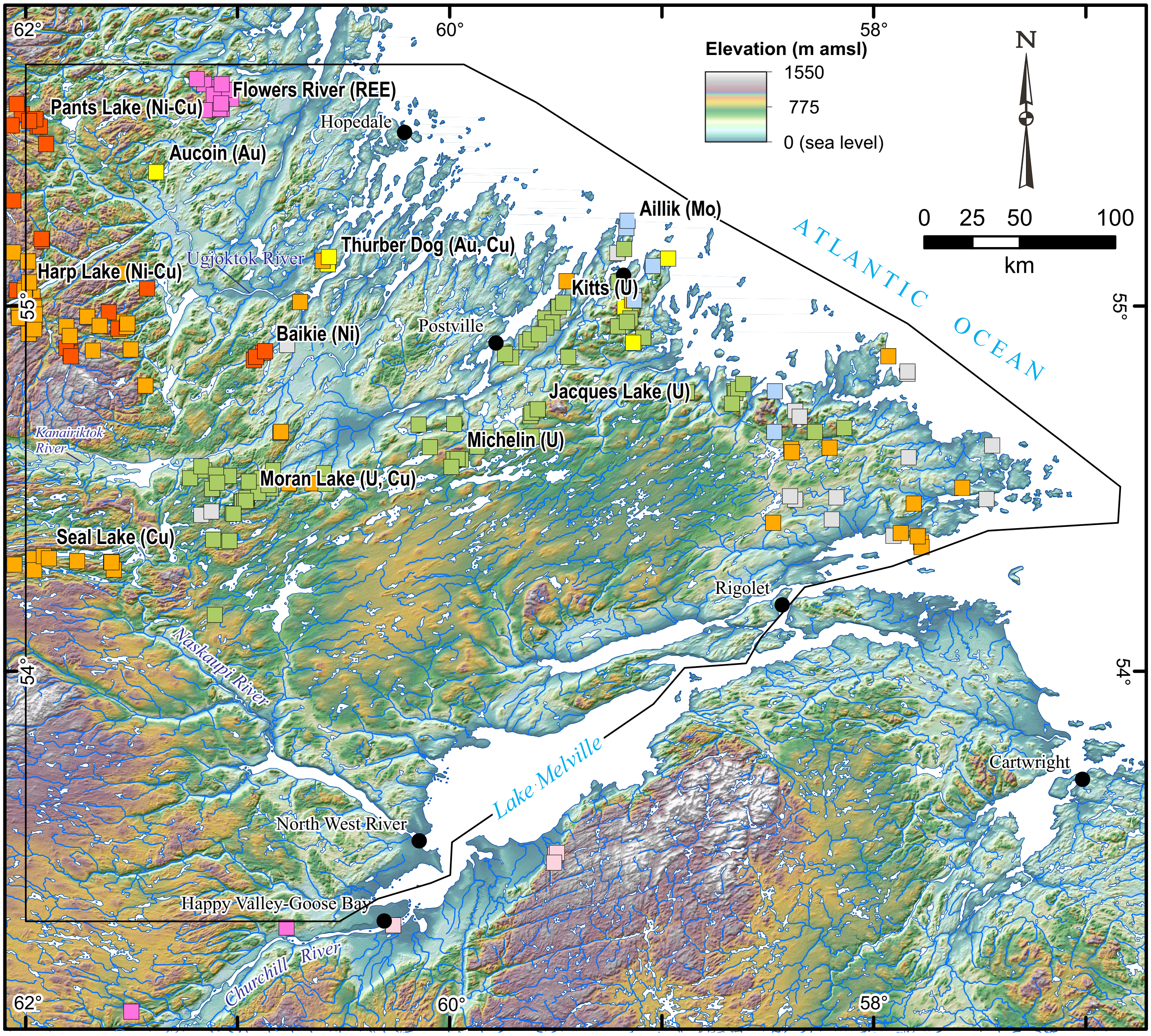
Mineralization in the study area is diverse; notable mineralization includes the magmatic Ni–Cu sulphide occurrences related to the Pants Lake Intrusions (Kerr, 2012); Au prospects and showings within the Hopedale Block (Sandeman and Rafuse, 2011; Sandeman and McNicoll, 2015); Cu occurrences associated with the Seal Lake Group (*see* van Nostrand, 2009 and references therein); REE mineralization (mainly Y, Zr, Nb) associated with the Flowers River igneous complex (Miller, 1992, 1993), and the abundant U hosted within the Central Mineral Belt (*e.g.*, Hinchey, 2007; Sparkes 2017).

QUATERNARY GEOLOGY

Surficial geology mapping (at 1:50 000) from airphoto interpretation and fieldwork has been completed over select portions of the study area (*see* Batterson, 2000a–k; Liverman and Sheppard, 2000a–c; McCuaig, 2007a–c; Figure 1). These previous surficial geology maps show primarily thin sediment cover and a variety of surficial sediment types.

The study area was covered by the Québec–Labrador sector of the Laurentide Ice Sheet (LIS) during the late Wisconsinan glaciation (~25 000 ka BP; Dyke, 2004) resulting in a series of complex ice flows through time with variable extent and erosion across the study area. All ice flowed away from ice dispersal centres in central Québec–Labrador towards the ice margins to the east. At its maximum, the LIS likely extended out onto the Atlantic continental margin (Dyke, 2004; Dalton *et al.*, 2020). During deglaciation (18–8 ka BP), the ice sheet retreated west-northwestward, with large portions of the ice margin in contact with marine water causing ice sheet instability (Favier *et al.*, 2014; Margold *et al.*, 2018). Ice-margin retreat is recorded in previously mapped moraines and the isostatic adjustment rates throughout the area (Dyke *et al.*, 2005; Dalton *et al.*, 2020). Ice caps were possibly preserved on uplands during this glacial retreat (Campbell *et al.*, 2019).

After deglaciation, parts of the study area experienced marine transgression, and corresponding sea-level rise, associated with the melting LIS and isostatic depression. A regional reconstruction by Dyke *et al.* (2005) detailed the marine limit by compiling data points from work completed along the entire coast of Canada. A subset of the locations used in the Dyke *et al.* (2005) reconstruction are presented in Table 1. These records indicate a variable marine limit along the coast of Labrador. Marine regression, corresponding sea-level retreat followed, as the land rebounded (Awadallah, 1992; Dyke *et al.*, 2005). The exposed landscape was then modified by subaerial geomorphic processes such as eolian remobilization of fine-grained marine sediments, organic material accumulation in areas of poor drainage, and alluvial erosion/deposition in river channels (Batterson, 2000a–k; Liverman and Sheppard, 2000a–c; McCuaig, 2007a–c).



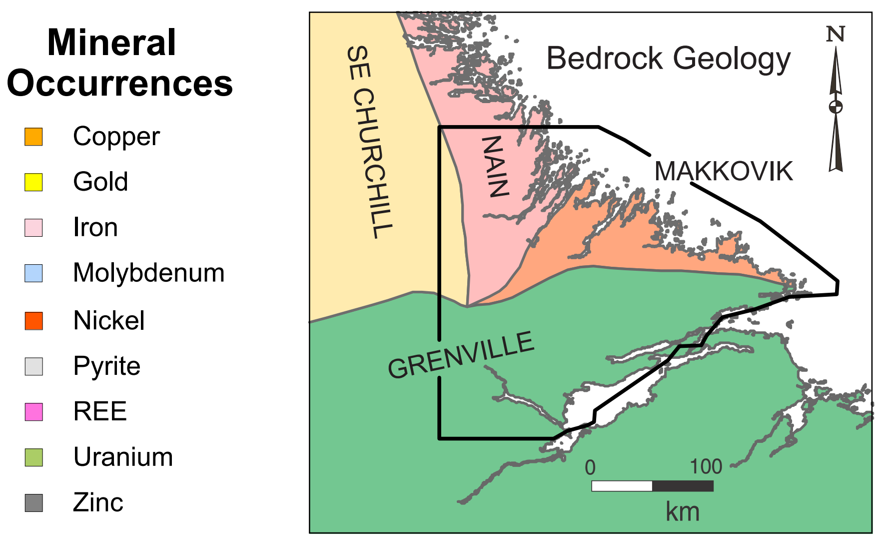


Figure 2. *Physiography, elevation shaded-relief map, and selected mineral occurrences from the NL Mineral Occurrence Database System in the project area. Note that some mineral showings and indications have been omitted for the sake of clarity. Inset map shows bedrock provinces in Labrador (modified from Hinchey and LaFlamme, 2009). Shaded-relief map (NASA Shuttle Radar 1 Arc-Second digital terrain elevation dataset (NASA JPL, 2013).*

Table 1. Locations and elevations of marine limit from Dyke *et al.* (2005) compilation used to corroborate new mapping of marine limits along the coast of Labrador

Location	Marine Limit Elevation (m asl)	Reference
Kanairiktok River	100	Awadallah and Batterson (1990)
Moran Lake	125	Awadallah and Batterson (1990)
Makkovik Harbour head	107	Clark and Fitzhugh (1992)
Muskrat Falls	135	Fulton and Hodgson (1979)
Michael River	84	Hodgson and Fulton (1972)
Northwest River	135	Hodgson and Fulton (1972)

METHODS

Surficial mapping was completed in ArcGIS^{TM} at 1:10 000. Two thematic shapefiles were created from visual interpretation of the remote sensed datasets: surficial geological units (polygon database) comprising marine sediments, and related coastal landforms (linear feature database). Mapping used the ArcGIS^{TM} basemap (Images provided © 2021 Maxar Technologies Inc.) as the primary data source for interpreting landforms and sediment characteristics based on the surface colour/tone, vegetation, geomorphology, topography, and relationships to other geological features (*e.g.*, bedrock outcrop, meltwater channels). These characteristics for marine deposits were developed based on the other detailed mapping completed in the area (Batterson, 2000a–k; Liverman and Sheppard, 2000a–c; McCuaig, 2007a–c). Continuous digital elevation model (DEM) and hillshade renderings were generated from the Advanced Land Observation Satellite (ALOS) 30 m resolution dataset, provided by "ALOS World 3D" (Japan Aerospace Exploration Agency; Takaku *et al.*, 2020). This DEM was used to interpret the surficial geology as cells were classified "above" or "below" a theoretical extent of marine incursion. This classification scheme help guide and identify sediments that could have possibly been below the marine limit, suggesting a possible marine origin. Attempts were made to locally correct for isostatic rebound by raising or lowering the classification break, based on sources from Dyke *et al.* (2005) throughout the map area. A hillshaded surface model derived from the DEM was also helpful for identifying landforms such as marine terraces and beach ridges by accentuating both subtle elevation differences and sharp topographic breaks. Finally, airphoto stereopairs were reviewed for detailed mapping in geomorphically complex areas.

Marine-sediment polygons were digitized and classified into deposit types based on surface tone, vegetation, elevation, shape, topography, and surrounding features like bedrock or meltwater channels. These features were captured in the polygon attribute table, as well as interpreted sediment "type", a one-letter code designated from the GSC data model (DeBlonde *et al.*, 2019). The "type" class was used as an approximation for estimated particle size composition. For example, marine ridges (r) should be relatively coarse grained due to the higher energy depositional environment (sand and silt), in contrast to marine terraces (t) that were deposited in a lower energy environment (silt and clays). Marine-sediment thickness was also interpreted for each polygon; due to the nature of the remote mapping, thickness could only be estimated as either <2 m or >2 m based on the "type" and surrounding landscape (*i.e.*, bedrock exposure suggests a thinner sediment cover). Finally, efforts were made to predict stratigraphic sequences at some locations. This was completed with more confidence in areas that had been previously mapped, but was also interpreted for some areas with evidence for eolian reworking or organic deposits.

The landforms layer complements the marine-sediment database. It comprises beach ridges and/or former shoreline positions digitized along their crest or upper extent, respectively, from satellite imagery and the hillshaded DEM. The attribute table records the approximate median elevation of these features, derived from the DEM, which will assist in further refining the marine limit. They were digitized in a similar manner to the polygons looking for characteristics like a light tone and ridges or wave-cut notches parallel to each other or perpendicular to the slope.

It is important to note that the mapping results presented here had no field component. The limit of interpretation by remote mapping should be a consideration for users of the dataset, although this study employed a variety of data sources (satellite imagery, DEM, airphotos, previous mapping, photographs from other researchers in the area) to support the interpretations of marine sediments and landforms throughout the study area.

RESULTS

The mapped marine-sediment polygons (n=4075) cover 12 444 km^2 of the overall study area. The marine sediments generally parallel the current east-central Labrador coastline but also extend into the interior (Figure 3). There are two large areas of limited marine-sediment deposition in the northern half of the study area, even in areas of low elevation. The maximum elevation of marine sediments is ~135 m asl, based on the elevation values in the DEM. The marine sediments identified are described below.

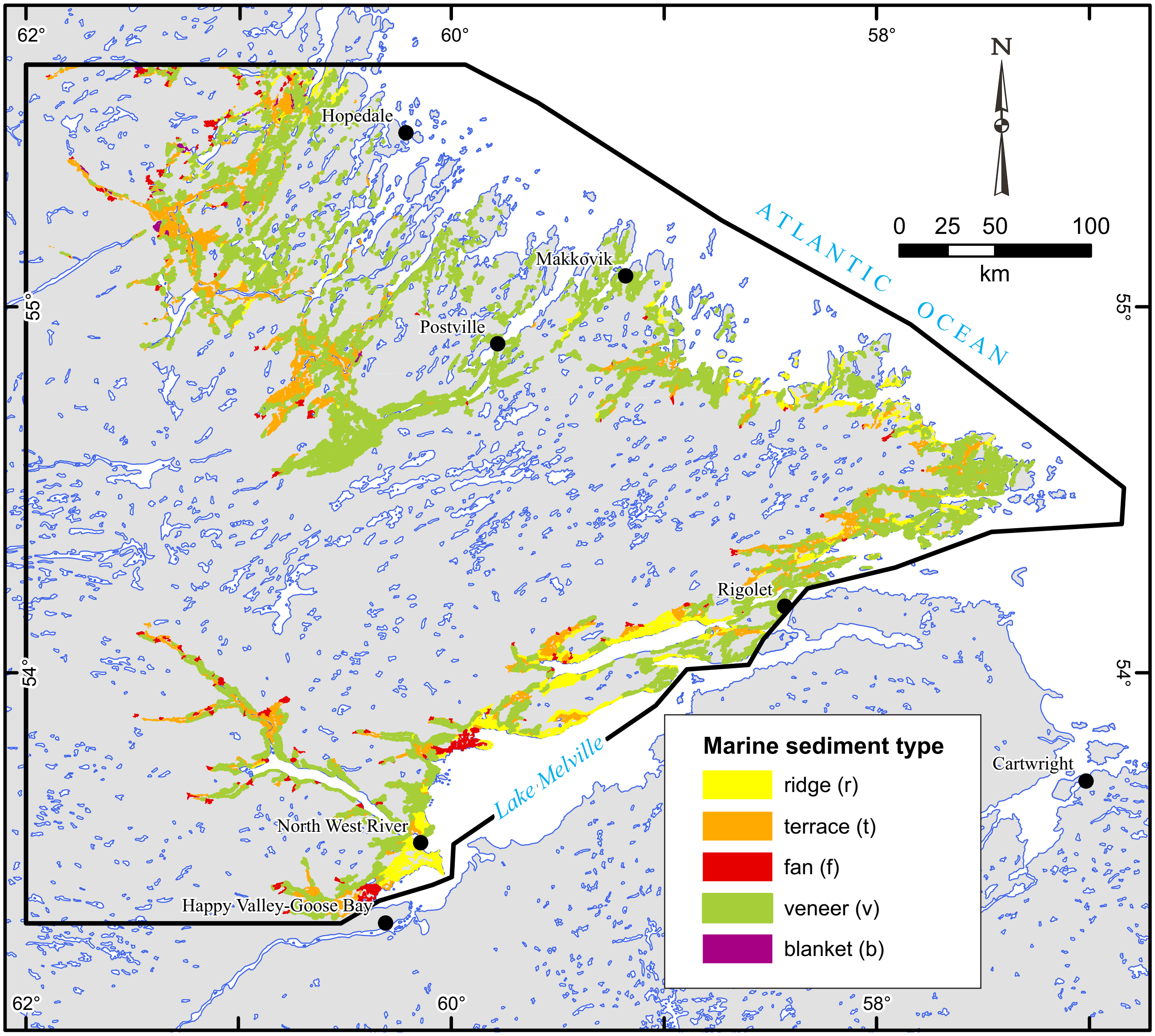


Figure 3. *Preliminary interpretation of the extent of marine-sediment types in the study area. These include marine ridges, terraces, fans, veneer, and blanket. Mapped beach ridges are not visible at this scale.*

Veneer (v) is thin (<2 m), generally silty and the most common mapped unit (n=2416; Figures 3 and 4A). Veneer deposits are surrounded by bedrock exposures and may occur in close proximity to, or covered by, organic deposits. Reworked marine-veneer sediments, such as eolian dunes, are included within the veneer type (Figure 5). Many of these dunes are previously undocumented. They exhibit a parabolic morphology indicating an eastward paleo-wind direction and are typically located east of large marine-sediment complexes, including terrace sequences in the northern half of the study area.

Terrace (t) is the second most mapped unit (n=1022; Figures 3 and 4A). They are found from the maximum marine limit elevation down to the current sea level and are more frequently identified in the northern half of the study area. Terraces are typically interpreted as thin (<2 m) deposits, although some are thicker, with flat tops. Terraces may have a scarp on their eastern side that marks a former shoreline. They often form a major component of the large marine-sediment complexes observed throughout the study area.

Ridges (r) (n=318; Figures 3 and 4B) are common at lower elevations and along Lake Melville and are prevalent on southeastward-facing slopes. Ridges varied in prominence and their height could not be estimated due to the resolution of the DEM (30 m). Ridge sediments are interpreted

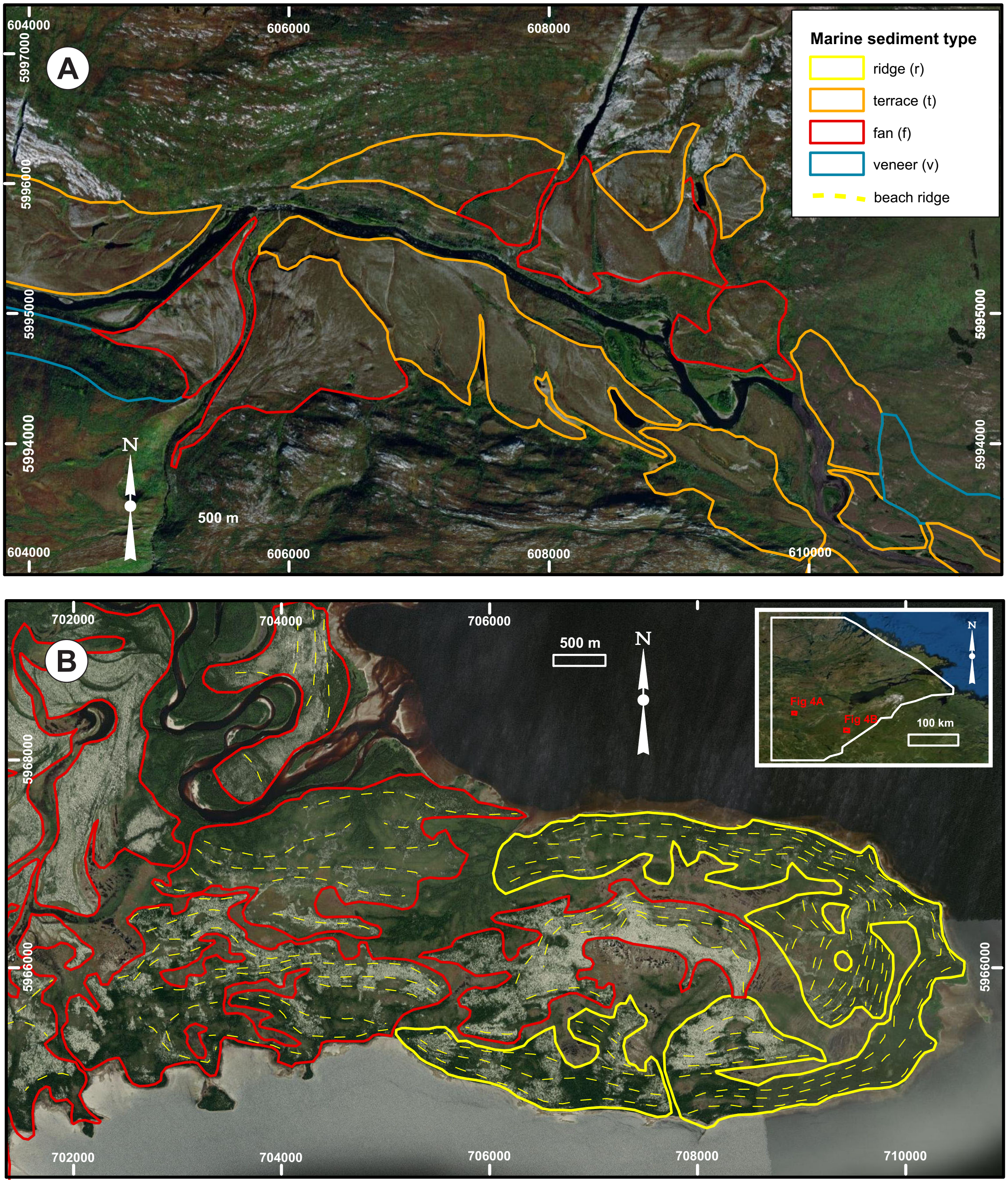


Figure 4. *Examples of mapped marine-sediment units shown over satellite imagery to highlight surface characteristics and relationships between mapped units. A) Marine terraces and fans; B) Marine fan and ridge units with beach ridge lines. Base image is ESRI "World Imagery" basemap layer. Grid coordinates reference UTM zone 20, NAD 83 datum, units of metres.*

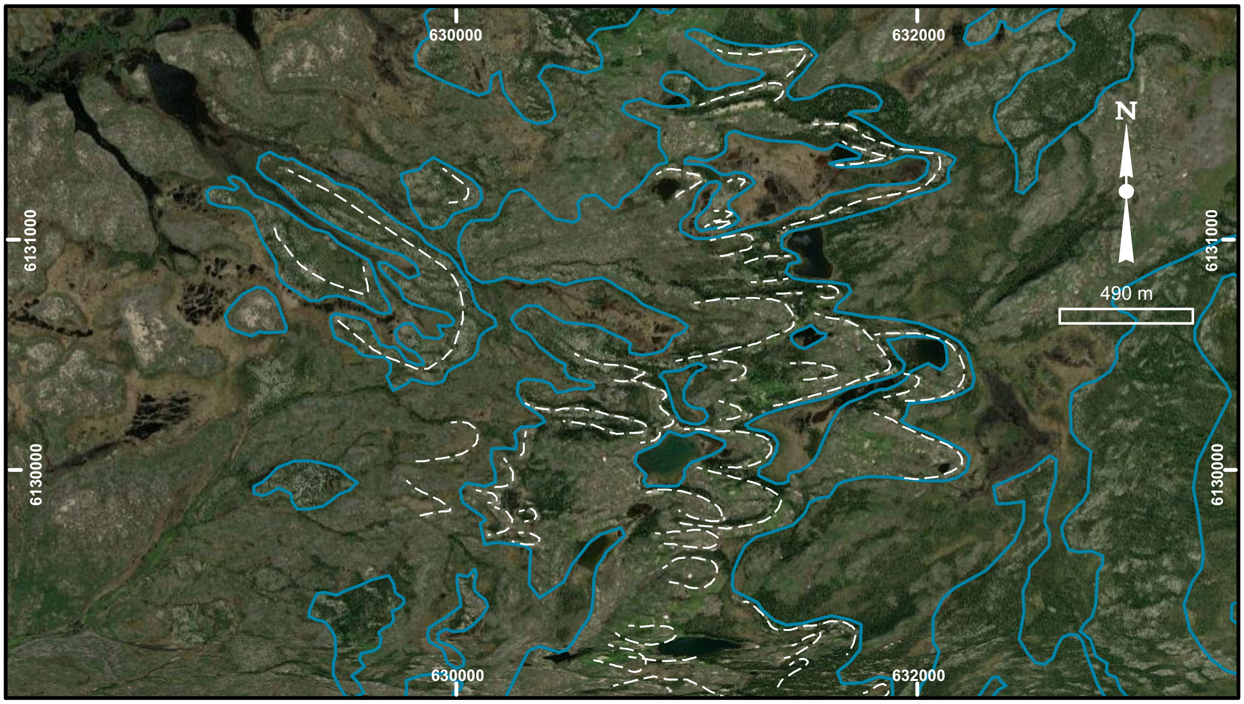


Figure 5. *Parabolic dunes of various sizes and degrees of stabilization, and including both simple and compound forms. Dune crests are shown with a dashed white line; marine veneer outlined in blue. Some dune fields were not mapped previously within the study area, likely due to a lack of publicly available high-resolution satellite imagery. Base layer is ESRI "World Imagery" basemap layer. Grid coordinates NAD83, UTM zone 20.*

to be relatively thin (<2 m) and composed of coarse grain sizes (sand to coarse sand) reflecting their deposition in a high energy, wave- and wind-modified environment.

Linear beach ridges were digitized into the landforms layer (n=3124; Figure 4B). They are subparallel ridges that generally parallel slope and vary in length. Beach ridges were typically contained within ridge (r) polygons although they were sometimes traceable outside the mapped ridge polygons as wave-cut notches. Ridge height could not be estimated from the DEM (30 m) used as a base layer for mapping.

Fan (f) deposits (n=298; Figures 3 and 4A, B) were typically mapped at higher elevations along valley sides. They were identified by their characteristic fan shape, opening away from a feeding channel outlet and often have modern or recently active channelized surfaces. Their estimated grain size ranged from sand to silt due to the higher energy depositional environment. Marine fans are interpreted to be relatively thin (<2 m).

Lastly, marine-blanket (b) polygons (n=28) were identified in the northern half of the study area (Figure 3). These polygons were mapped in areas were marine deposits were identified and no bedrock was observed in the region or where groundtruth locations showed thick marine deposits. They are interpreted to have a deposit thickness >2 m.

DISCUSSION

These preliminary mapping surveys offer a greater level of detail than previous surveys in the study area. The inferred distribution of marine-sediment deposition provides a proxy for the former marine limit(s), and supports future examination of the spatio-temporal dynamics of ice-sheet retreat in east-central Labrador (*i.e.*, location, extent, relative timing). The distribution of marine sediments may indicate a more complex retreat sequence than the progressive westward retreat indicated in other large-scale ice-sheet reconstruction (Dyke, 2004; Dyke *et al.*, 2005; Dalton *et al.*, 2020).

The preliminary marine-sediment maps show a discontinuous deposition of marine sediments. Some mapped areas have no preserved marine deposits, which is best observed in the northern half of the study area (Figure 3). Campbell *et al.* (2019) have proposed that westward ice-sheet retreat left remnant ice caps (especially in the Nain Province where bedrock highs are common) that blocked postglacial marine incursion into isostatically depressed terrain.

This study also suggests that the marine limit of coastal Labrador is higher than that reported in previous studies (*e.g.*, Dyke *et al.*, 2005). The maximum elevation of the marine incursion, interpreted from the maximum lateral extent of marine sediments, increased inland and up-valley to ~135 m asl in the northern half of the map area; it is almost 10 m higher than the marine limit presented in Dyke *et al.* (2005) for the same region. The database developed in this study also provides a more laterally continuous interpretation of the maximum marine limit to be used for future marine-limit reinterpretation and refinement. This database is in the process of being released as an Open File report (G.W. Hagedorn, unpublished data, 2022).

The marine-sediment mapping has implications for mineral exploration in east-central Labrador. Surficial sampling for mineral exploration within mapped polygons should be undertaken with care. Due to mixing, reworking, and potentially long transport distances, marine sediments are difficult to trace to bedrock source and therefore vectoring an anomalous sample to its source may not be possible. Furthermore, any non-marine sediment below the reconstructed marine limit (*i.e.*, till) may have been reworked in the postglacial marine environment. In order to obtain fresh, traceable material for geochemical exploration methods (McClenaghan *et al.*, 2020) in areas of marine or reworked sediments, sample depth may need to be increased.

The preliminary marine-sediment dataset will also be useful for predicting and adapting to surficial environmental change. Areas below the marine limit, may have been more likely to develop permafrost, due to the fine-grained marine sediments (Favier *et al.*, 2014). Areas of permafrost (and therefore also permafrost thaw) are important to consider during infrastructure planning and development. All areas below the marine limit, even if not mapped as marine deposits (*e.g.*, an organic deposit covering an unidentified marine sediment unit), may still be impacted by climate change if buried marine sediments begin to thaw and slump (Favier *et al.*, 2014).

CONCLUSIONS AND FUTURE WORK

In situ and reworked marine deposits were mapped along east-central Labrador. This dataset provides a laterally continuous record of marine incursion for the region through the last glaciation, and suggests a higher maximum elevation than previous reconstructions for the regional marine limit in some areas (~10 m higher; estimated maximum height ~135 m). The distribution of mapped units will improve reconstructions models of Quaternary ice extent and deglaciation, help outline areas not suitable for surficial geochemical sampling, and provide surficial information for geological hazards research, *e.g.*, permafrost thaw, sediment instability. Newly mapped beach ridges may be important as a potential source for well-sorted sand and gravel to be used locally.

This project generated a novel dataset and laid groundwork for future efforts to address gaps in detailed surficial mapping in Labrador and uncertainties about regional ice-sheet dynamics (*i.e.*, ice extents, ice retreat rates, flow directions). Future research should include dating the marine terraces and eolian dunes in the map area (*e.g.*, radiocarbon dates from shells in marine terraces, or luminescence dates on dunes and/or beach ridges). This will further improve interpretations of the regional deglacial chronology and postglacial Quaternary geomorphological processes.

Users of these data are reminded that preliminary mapping has not been validated with fieldwork; all interpretations/features are based on observations from satellite imagery, airphotos, digital elevation data, and previously published maps. Ultimately, the marine-sediment dataset provides a "first pass" product that directly informs the mineral exploration community of suitable areas for surficial sampling, provincial and local government agencies on areas more susceptible to permafrost, and parties involved with development of aggregate resources and infrastructure in Labrador.

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