AER/AGS Open File Report 2023-01

Alberta Energy Regulator

Updated Bedrock Topography and Sediment Thickness Models to Support Aquifer Mapping in the Alberta–Northwest Territories Transboundary Region

Government of Northwest Territories

AGS ALBERTA GEOLOGICAL SURVEY

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Updated Bedrock Topography and Sediment Thickness Models to Support Aquifer Mapping in the Alberta–Northwest Territories Transboundary Region

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April 2023

ISBN 978-1-4601-5703-9

If you use information from this publication in other publications or presentations, please acknowledge the AER/AGS. We recommend the following reference format:

Utting, D.J., Smith, I.R., Pawley, S.M. and Deblonde, C. (2023): Updated bedrock topography and sediment thickness models to support aquifer mapping in the Alberta–Northwest Territories transboundary region; Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Open File Report 2023-01, 51 p.

Publications in this series have undergone only limited review and are released essentially as submitted by the author.

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Published April 2023 by:
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Acknowledgements

This work was completed as part of a Memorandum of Understanding between the Department of Environment and Natural Resources of the Government of the Northwest Territories and the Alberta Geological Survey of the Alberta Energy Regulator. The research involving lithostratigraphic records from the Northwest Territories was undertaken as part of Natural Resources Canada's Geo-mapping for Energy and Minerals (GEM-2) program, Mackenzie Project, Southern Mackenzie Surficial activity. Fieldwork was assisted by students G. Hagedorn (University of Waterloo), R. King (Memorial University of Newfoundland), J. Plakholm (Carleton University), and J. Sapera (Brock University), and in collaboration with monitors A. Farcy, J. Nadli, and H. Sabourin (Deh Gáh Got'ie First Nations), D. Simba (Ka'a'gee Tu First Nation), I. Graham, and P. Martel (Kátł'odeeche First Nation), T. Unka (Deninu Kų́ę́ First Nation), and J. Delorme (Fort Resolution Métis Council). R. Fontaine (Geological Survey of Canada–Calgary) facilitated access to well cuttings and well report archives. J.E. Campbell (Geological Survey of Canada–Ottawa), G. Hartman (Alberta Geological Survey), and D. Palombi (Alberta Geological Survey) are thanked for their internal reviews, as well as P. Normandeau (Northwest Territories Geological Survey) for an external review. This publication represents Natural Resources Canada, Lands and Minerals Sector contribution 20220348.

Abstract

In an initial review of sediment thickness data by the Alberta Geological Survey, as part of work under the Mackenzie River Basin Bilateral Water Management Agreement between the governments of the Northwest Territories and Alberta, conflicting models of sediment thickness along the provincial–territorial border (lat. 60°N) were identified. This report summarizes work undertaken to resolve this boundary issue. For this study, all available point source data of sediment thickness were re-examined and then used to remodel the bedrock topography and sediment thickness. Oil and gas well drill cuttings and water well records demonstrate that most of the Cameron Hills Uplands in northwestern Alberta and southern Northwest Territories are composed of thick (250–400 m) unconsolidated sediments. Within Alberta, these sediments overlie a possible valley, oriented northwest. Comparatively thin sediment (0–15 m) is modelled for the Hay River area (long. 116°00′W to 117°30′W) and the Great Slave Plain area (long. 112°30′W to 116°00′W). Drill cuttings from the thick sediment package on the Cameron Hills Uplands include granitic and other Canadian Shield rock fragments that indicate glacial transport by a continental (Laurentide) ice sheet in the region.

1 Introduction

The Bilateral Water Management Agreement (BWMA) established to implement the Mackenzie River Basin Transboundary Waters Master Agreement commits the governments of the Northwest Territories (N.W.T.) and Alberta to cooperatively manage water resources for the benefit of the environment, people, and economy. This agreement includes a focus on groundwater resources, and the first stage of work, summarized in the Alberta Geological Survey's report *State of Subsurface Knowledge to Support Aquifer Mapping Across the Alberta–Northwest Territories Border* (Smerdon, 2020), highlighted a stark difference in the modelled thickness of unconsolidated sediment (also known as drift) overlying bedrock between the N.W.T. and Alberta. This report showed that in the Cameron Hills Uplands physiographic section (Pettapiece, 1986; Figure 1), which is composed of the Bootis Hill, Elsa Hill, Cameron Hills, and Bistcho Plain districts and straddles the western portion of the provincial–territorial border, sediment above bedrock is generally thick (>250 m) on the Alberta side. In contrast, on the N.W.T. side, Smith and Lesk-Winfield (2010a), using a depth-limited dataset (<20 m), suggested extensive areas of thin drift (<16 m; Figure 2). The contradiction between these two records needed to be resolved as it would significantly affect the understanding of groundwater flow in the region.

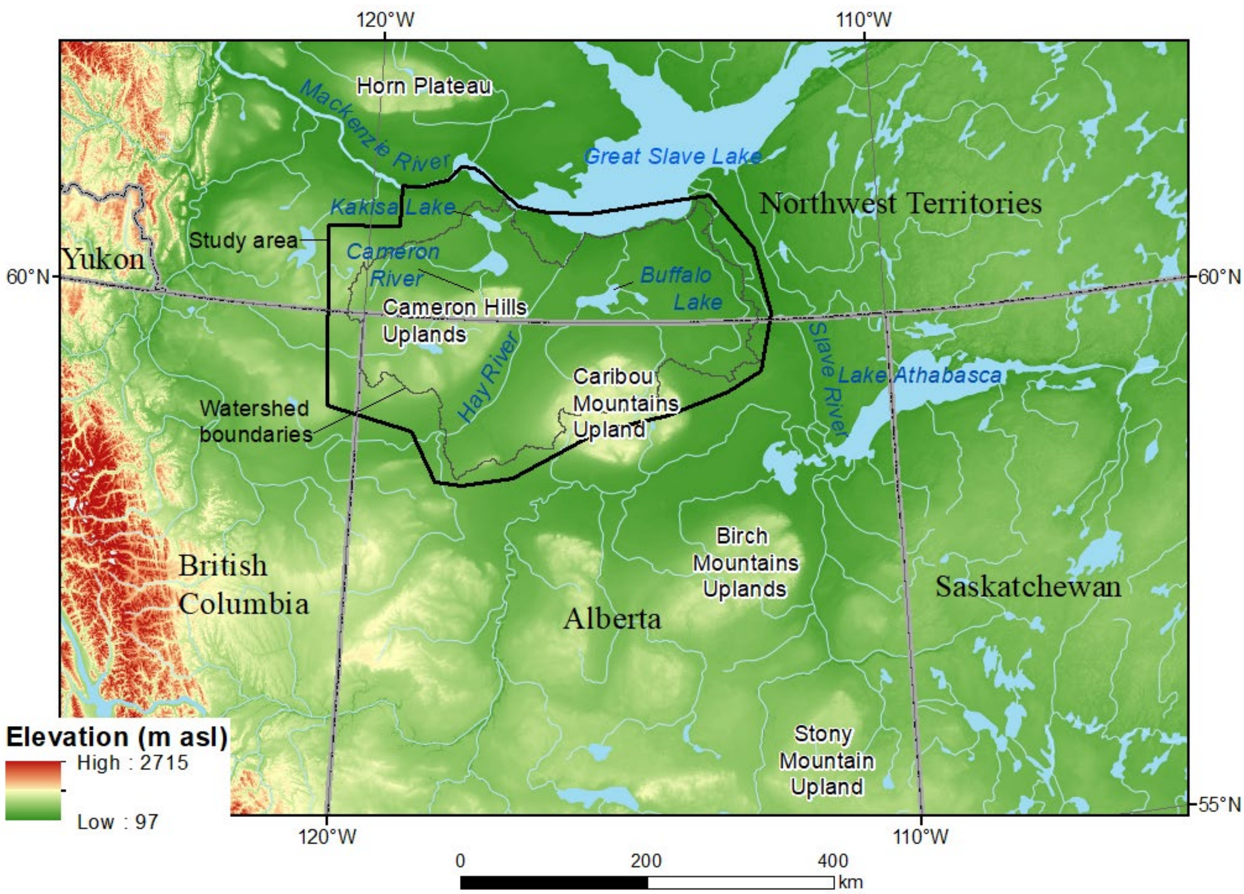

Figure 1. Study area outlined in black with regional physiographic features (Pettapiece, 1986) highlighted. Elevation data from U.S. Geological Survey and National Geospatial-Intelligence Agency (2010).

Original work based on oil and gas wells by Green et al. (1970) reported “as much as 1000 ft.” (305 m) of drift deposits on the uplands on the Alberta side of the border. Similarly, Dixon (1999) noted that in the Cameron Hills in the N.W.T., the bulk of what was mapped as Cretaceous strata (Douglas, 1974) appeared instead to be mostly thick Quaternary deposits (up to 300 m thick). More recently, Pawlowicz et al. (2005, 2007) mapped the Alberta side in more detail and showed even thicker sediment above bedrock (up to 357 m) and interpreted deep bedrock thalwegs of paleochannels generally oriented to the northwest (Figure 2).

This report summarizes the data sources examined to resolve the cross-border difference in sediment thickness modelling. These data were also used to produce new bedrock topography and sediment thickness maps for the transboundary region. Data sources used to examine the sediment thickness include

- geophysical logs from oil and gas wells;
- drill cutting samples and reports from oil and gas wells;
- water well drilling records;
- seismic shothole drillers’ log records;
- mineral exploration diamond-drillhole records; and
- field, aerial, and satellite image observations.

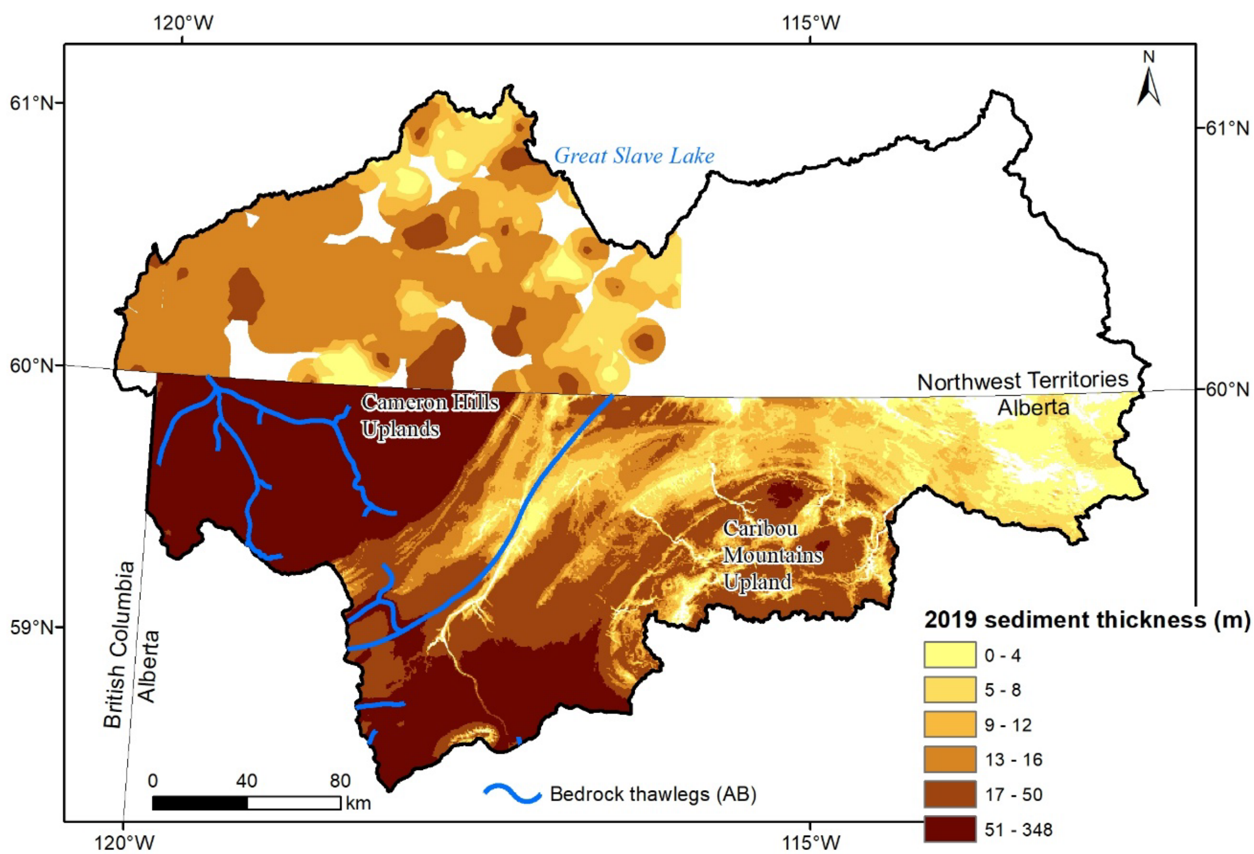

Figure 2. Sediment thickness mapping in the transboundary region, defined by watershed boundaries (modified from Smith and Lesk-Winfield, 2010a; Alberta Geological Survey, 2020; Smerdon, 2020). Thick sediment (51–348 m) is reported in the Cameron Hills Uplands in northwestern Alberta whereas thin sediment (0–16 m) has been reported on the uplands north of the territorial border. White areas are unmodelled.

2 Study Area

The study area encompasses sub-basins of the Mackenzie River drainage basin, which straddles the provincial–territorial border within the Interior Plains. Adjacent portions of the Canadian Shield are excluded. The study area includes the Cameron Hills and Caribou Mountains uplands, which rise 500–700 m above the surrounding lowlands (Figure 1). The lowlands contain the Hay and Slave rivers to the west and east of the Caribou Mountains Upland, respectively. Both rivers drain northwards to Great Slave Lake. For this study, a buffer was extended around the sub-basins to capture surrounding geological data and reduce modelling edge effects.

3 Data Sources

Density of subsurface data in the study area is generally low, with some exceptions (Figure 3). All manner of available information was used to create the regional synthesis presented here and are discussed below. The complete list of data sources is presented in Utting et al. (2023).

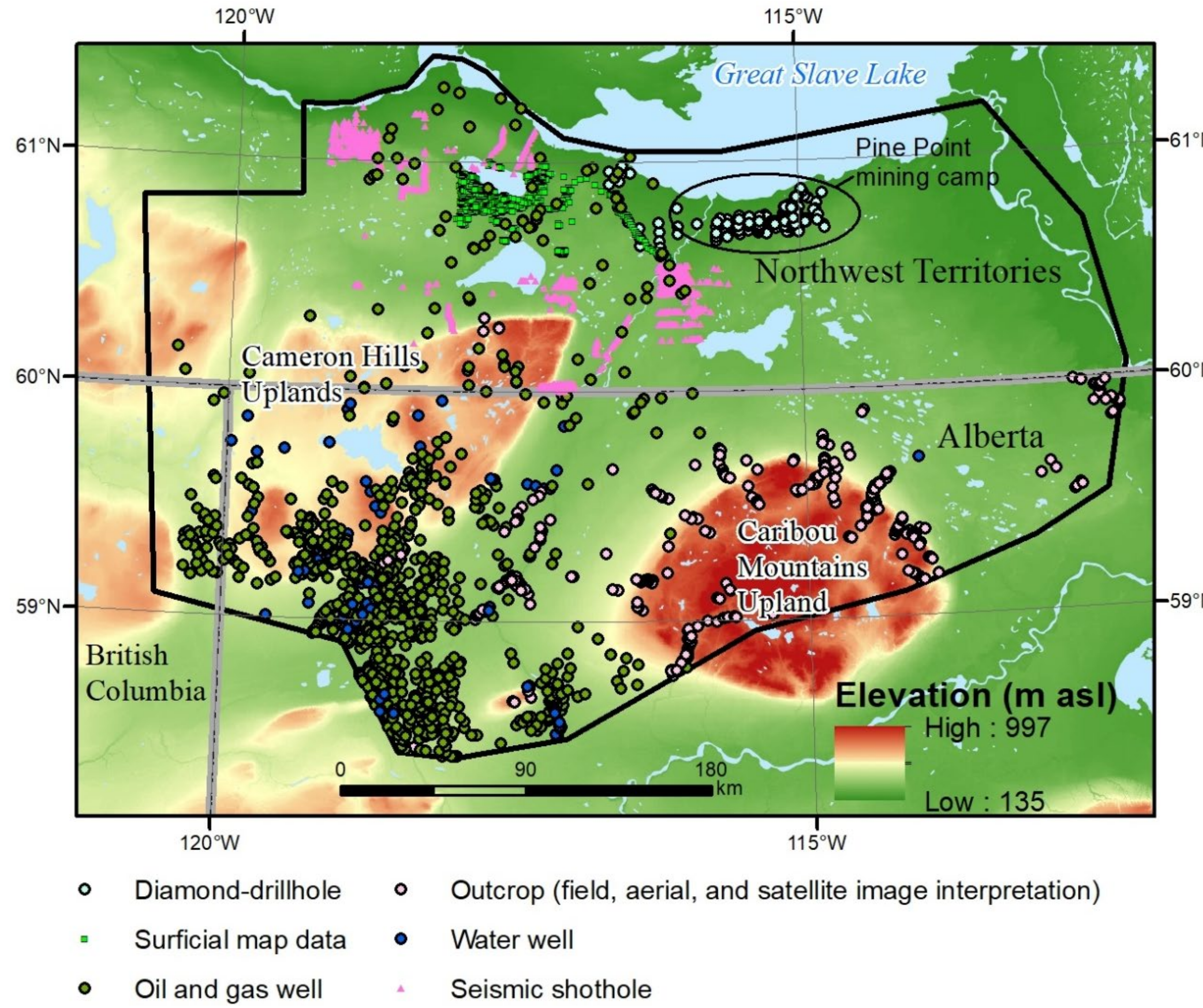

Figure 3. Location of data compiled from sources to evaluate bedrock topography and sediment thickness. See Utting et al. (2023) for complete list of data sources. Regional physiographic features (Pettapiece, 1986) are highlighted. Elevation data from U.S. Geological Survey and National Geospatial-Intelligence Agency (2010).

3.1 Oil and Gas Well Geophysical Logs

Geophysical logs recorded in oil and gas wells are a primary source of bedrock top information in areas of thick sediment above bedrock (e.g., Pawlowicz et al., 2007; Hickin et al., 2008; Utting and Andriashek, 2020). All oil and gas well geophysical logs available within the study area were examined. The wells are limited to the area west of longitude 116°W, mostly in the southern portion of the Cameron Hills Uplands (Figure 3). Many of the logs are only available as raster images of hardcopy logs, of which some are low resolution and difficult to read. In addition, many of the wells were not logged to surface, these wells were noted as "bedrock top above log" with the value used as maximum thickness of sediment (i.e., sediment at that location has a thickness less than the value of the top of the log).

An additional difficulty encountered when using geophysical logs is that interpretation of the bedrock top is generally made by identifying consistent stratigraphy across a series of closely spaced wells. Where well density is low and wells are geographically isolated, identification of stratigraphic markers is difficult. Therefore, the confidence of some bedrock top picks on isolated oil and gas well geophysical logs is less certain.

Whereas bedrock top picks from oil and gas well logs were truncated at 20 m by Smith and Lesk-Winfield (2010a), this updated model includes the full depth of surficial sediments and uses the original formation top picks of Janicki (2005; with some modifications and additions) and the Geological Survey of Canada's well database. These records reveal much thicker surficial sediments in the southern and western N.W.T. portions of the Cameron Hills Uplands, comparable to, or even exceeding the thickness of those across the border in Alberta.

3.2 Oil and Gas Well Drill Cuttings

Drill cuttings were examined to confirm bedrock top picks made on oil and gas well geophysical logs, especially those that were poor quality or from geographically isolated wells where stratigraphic correlation between logs was limited, or to provide geological information where geophysical logs were absent. Drill cuttings are samples of rock and sediments recovered during drilling of oil and gas wells, usually at 10 foot (3.0 m) or 5 m intervals, starting at or near surface, or below casing depth. During drilling operations, the cuttings are passed across a shaker table/sluice box to remove fines (silt- and clay-size particles; <40 mesh) and are washed to remove drilling muds. The cuttings can be variable in terms of quality, and in areas of unconsolidated sediments they can include abundant cement and lost circulation material (LCM; e.g., wood, sawdust, seed hulls) injected during the drilling process. Vials of drill cuttings are typically around 10 ml in volume, and extensive collections of these are stored at the Alberta Energy Regulator Core Research Centre in Calgary (for Alberta wells), and at the Geological Survey of Canada, Calgary office, for the Northwest Territories wells and additional Alberta and British Columbia wells. All the drill cuttings available in the Cameron Hills Uplands area in Alberta and the N.W.T. were examined (Appendix 1). In addition to corroborating bedrock top picks from oil and gas geophysical logs, drill cuttings can reveal information about the character of the sediment. This includes information on lithology, and rounding and size of grains, although larger material will likely have been ground up by the drilling process. Lithological descriptions of cuttings made by the well site geologist are also sometimes available in accompanying well reports, as is useful information such as the presence of boulders (used to infer glacial origin).

The cuttings samples are not as representative of the subsurface as drillcore, as they may contain contamination (i.e., cavings) from other stratigraphic horizons. Cuttings generated at the base of the hole must circulate within drilling mud when being brought to the surface. During this journey, the samples may become contaminated with material from uncased or uncemented portions of the upper wellbore. Therefore, it is possible that fragments of material from higher in the hole can appear in the drill cuttings, but in most cases contamination from overlying horizons likely comprises only a small percentage of the overall sample. But it is not uncommon to find diminishing quantities of Quaternary material cavings mixed in with actual bedrock material for tens of metres below the top of bedrock. Furthermore, some depth variation may be expected due to inaccuracies in calculations of how long material takes to circulate from the base of the hole to the surface, therefore sample depths were considered only as approximate to within tens of metres. In general, the bedrock top depths from the drill cuttings (Appendix 1) correspond with interpretations from the geophysical well logs.

Examination of the cuttings also reveals that the unconsolidated sediment above bedrock commonly contains angular granitic and other Canadian Shield bedrock fragments. The occurrence of igneous and metamorphic lithologies is significant because there are no bedrock sources for these within the study area catchment. Their presence is used as evidence that the sediments being drilled through were in part glacially derived, likely from till transported and deposited by the Laurentide Ice Sheet. The manner in which drill cuttings are recovered and processed means that any finer till matrix components (i.e., silt and clay) have been washed away, so in sand- and particularly clast-poor diamict from these areas, ~65% and upwards of 90% of material is not represented by what appears in the cuttings.

Well-rounded grains and well-sorted material at depths of over 240 m in cuttings samples recovered from some wells (Figure 4) suggest a fluvial or glaciofluvial origin. Even though this type of material (sand and gravel) can form aquifers, the spatially limited well coverage makes it difficult to constrain actual integrated aquifer extents (Borneuf and Pretula, 1980). It does, however, present an opportunity for further study and the integration of complementary investigative techniques such as ground penetrating radar, resistivity logging, and electromagnetic (EM) airborne surveys (Ahmad and Schmitt, 2005; Levson et al., 2006; Kellett, 2007).

The drill cuttings also provide evidence of glacially rafted bedrock, such as was identified at depth in well cores in the Athabasca Oil Sands Area (Utting and Andriashek, 2020). In the present study, several vials were found that contained ≥10 m of 'pure' shale or other bedrock overlying unconsolidated sand and gravel containing granitic and other Canadian Shield lithologies, with continuous sections of the same or different bedrock situated farther downhole (Figure 5).

Figure 4. Rounded pebbles of mixed lithologies from drill cuttings from oil and gas well 10-4-123-2W6 at a depth of 800–810 ft. (243.8–246.9 m). These are interpreted to be of fluvial or glaciofluvial origin.

Figure 5. Drill cuttings from oil and gas well 10-4-123-2W6. Top of the box (upper left corner) starts at 50 ft. (15.2 m) depth, base of tray (bottom right) ends at 670 ft. (204.2 m). The first three vials from the top left contain white fragments of cement (derived from surface casing) from 50–80 ft. (15.2–24.4 m). The vials from the remainder of the top row and second and third rows (80–330 ft. [24.4–100.6 m]) contain rock fragments of mixed lithologies. From 330 to 530 ft. (100.6 to 161.5 m; grey fragments in vials on the fourth row from the top), the vials contain shale fragments, interpreted to represent a raft of shale bedrock. Beneath this depth, the vials contain rock fragments of mixed lithologies.

3.3 Water Well Records

Lithologs for water wells drilled in Alberta are available from the Alberta Water Well Information Database (AWWID; Government of Alberta, 2022). These logs are valuable because they describe shallower units, including sediments above bedrock that are typically behind the casing of oil and gas wells and within the portion of geophysical logs where the tools may have been turned off. A major limitation of water well lithologs is the qualitative nature of lithological descriptions. Misinterpretation or misrepresentation of sediment type and bedrock top are possible. For example, “clay and rocks” is a common lithological description for till but in some localities could include glaciolacustrine sediment with dropstones. Fluvial sand or weak sandstone that is disaggregated by drilling may both be described simply as “sand”. Additional descriptions that may help a geologist differentiate till and glaciolacustrine sediment, or sand and sandstone are not usually provided. Furthermore, many water wells terminate above bedrock (Figure 6) and thus provide only minimum estimates of sediment thickness. There is no similar database of water well lithologs for the N.W.T., where groundwater use within the study area is minimal (other than historical use by oil and gas drilling operations), reflecting both the abundance of surface water and the presence of discontinuous permafrost (VanGulck, 2016).

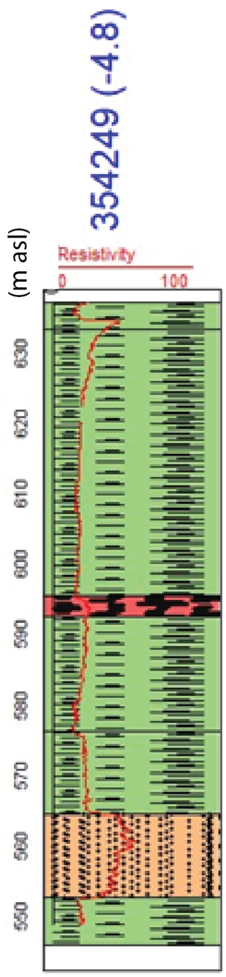

Figure 6. Example of a high-quality log from a water well (GIC Well ID354249), located in L.S. 4, Sec. 28, Twp. 126, Rge. 20, W 5th Mer. in Alberta, close to the border with the Northwest Territories on the Cameron Hills Uplands. Green units are classified as till, red as gravel, and orange as sand. Note that the well log indicates approximately 90 m of sediment (below a ground surface of ~635 m above sea level [asl]). As bedrock was not encountered, actual sediment thickness is assumed to be greater than shown. This log also included a resistivity log (red line; units in ohms) that corresponds with the sediment lithology.

3.4 Seismic Shothole Drillers' Logs

Seismic shotholes are drilled along seismic reflection survey lines to lay the explosive charges. Drillers record the depths and lithological characteristics of materials being drilled through, at varying degrees of resolution and quality, principally as a means of determining whether the charge will be seated in bedrock, or what the potential static interference may be in areas of coarse sediments and/or thicker drift (Smith, 2012). A systematic digital and GIS compilation of all available industry-held seismic shothole drillers' logs was undertaken for the N.W.T. and Yukon (~360 000 records; Smith, 2011, 2015), however, no similar compilation exists for Alberta (Figure 3).

With respect to reconstruction of regional drift thicknesses in areas of thick drift, a significant limitation of shothole drillers' logs is their relatively shallow depth (average 18.6 m, with modal depths ranging from 12 to 20 m). Shothole records can provide measures of absolute drift thickness (e.g., 0–14 m clay, rocks; 14–20 m shale), minimum thicknesses (e.g., 0–20 m sand, gravel), and maximum thicknesses (e.g., 0–20 m sand, clay, limestone); in this latter case, the drift (sand and clay) is some unknown thickness overlying limestone bedrock, but is <20 m thick). Shothole drillers' logs are also subject to uncertainty in their lithological description; in areas of frozen sand or clay, drillers may log them as sandstone or shale, respectively (Smith, 2011). Understanding the nature and limitations of the actual records, and how they are used and interpreted is required.

In areas where drift is not thick (i.e., <20 m), the shothole drillers' logs provide the most regionally extensive record, including two areas with high density three-dimensional seismic arrays (Figure 3). Where the drillers' logs appear to fail is in the Cameron Hills Uplands north of the Alberta–N.W.T. border where the data from five seismic lines collectively plot on the drift isopach map as depths of 0–4 m (Figure 2; Smith and Lesk-Winfield, 2010a). Inspection of these data reveals records of mostly "rocks, sandstone" and "sandstone". Given the unequivocal water well records and oil and gas well geophysical and cutting records of thick (>200 m) drift adjoining that area in both the N.W.T. and Alberta, it is assumed that the shothole logs were entered erroneously, or the drillers may have confused frozen sand for actual sandstone (widespread permafrost was noted on the upper Cameron Hills Uplands [Smith et al., 2021]). These discordant records have thus been excluded from this study's updated model. Note also that Smith and Lesk-Winfield (2010a) based their mapping on a database of 272 000 shothole records (Smith and Lesk-Winfield, 2010b); this study's model is based on the final shothole drillers' log database (n = 343 989; Smith, 2011). Most importantly, the new model removes the 'minimum estimate' records (i.e., those that did not reach bedrock), and only uses these records to force the model where thicknesses are otherwise predicted to be too shallow.

3.5 Diamond-Drillhole Records

The Pine Point mining camp, located south of Great Slave Lake (Figure 3), was a world class Mississippi Valley-type lead-zinc deposit mined by Cominco Ltd. (Cominco) from 1964 to 1988 from a series of open pits (Hannigan, 2006). Before and during its operations, Cominco and many other companies explored for additional carbonate-hosted lead-zinc in the areas south and west of the camp. Although their target was to retrieve bedrock core for mineralogical analysis, they produced highly reliable records of overlying drift thicknesses, and in some cases, lithological descriptions of the drift materials. Mineral exploration assessment reports, archived by the Northwest Territories Geological Survey, contain records of these diamond-drillhole (DDH) lithologs (Northwest Territories Geological Survey, 2022). Turner et al. (2002) compiled a database of 893 drillhole logs from the Pine Point mining camp. Additional drillhole logs were found in other assessment reports and geological information was obtained from property maps of areas west of Hay River and Great Slave Lake (n = 976 drillhole logs total for this study).

3.6 Field, Aerial, and Satellite Image Observations

Observations of bedrock outcrops provide definitive control on the presence of bedrock (Figure 7). Geologists from the Geological Survey of Canada had previously visited various locations on the northeastern end of the Cameron Hills Uplands and identified several bedrock (shale) outcrops (Figure 8; Smith et al., 2021). These outcrops indicate the upper elevation of bedrock and constrain the thickness of material overlying the Cameron Hills Uplands.

Observations by Alberta Geological Survey geologists from high-resolution satellite imagery were used to locate bedrock outcrops on the Caribou Mountains to augment information from field site visits (Figure 9; Utting et al., 2023). These observations are limited to the lower elevations along the flanks of the Caribou Mountains where incising streams are creating exposures.

Surficial geology maps provide valuable information about sediment thickness, usually based on field site visits and then interpreted from aerial photographs, digital elevation models, and satellite imagery. Sediment thickness and bedrock elevation values from surficial geology maps of the N.W.T. (see list in Utting et al., 2023) were included in the dataset. The locations of the data sites are shown on Figure 3.

Figure 7. Photograph from helicopter looking northwards at shale outcrop (black and grey) overlain by brownish-grey till. The photograph is of the lower eastern slopes of the Cameron Hills Uplands; location shown on Figure 8. Photograph by R.C. Paulen.

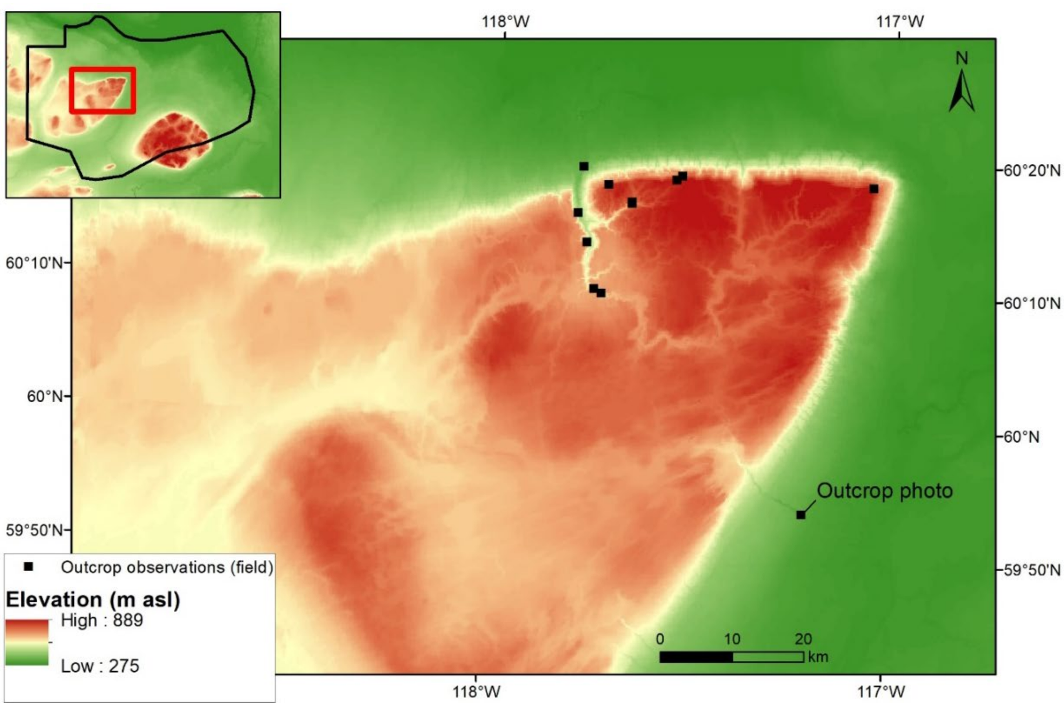

Figure 8. Field sites with exposed bedrock on the northeastern portion of the Cameron Hills Uplands. Note that the sites include several locations from lower elevations, and those situated in upper elevations are limited to the most northerly extent of the uplands. Location of photograph in Figure 7 indicated. Black line on inset figure indicates study area boundary. Elevation data from U.S. Geological Survey and National Geospatial-Intelligence Agency (2010).

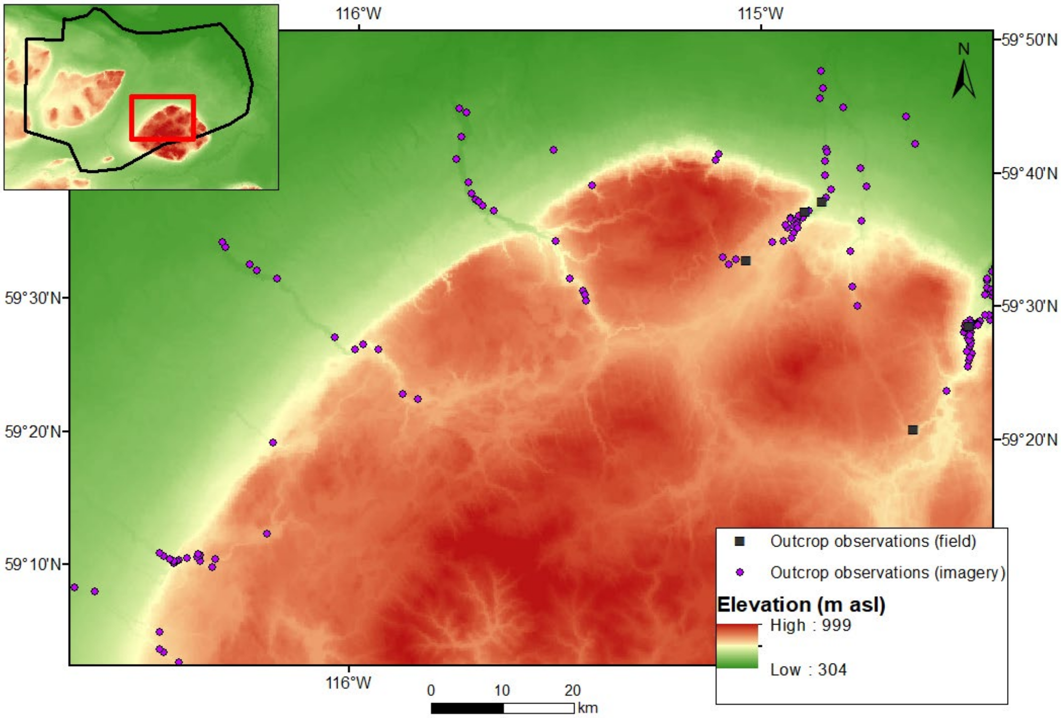

Figure 9. Location of field and aerial bedrock outcrop observations on northwestern side of the Caribou Mountains. Note that the sites are within the valleys, and there remains a significant thickness of material at higher elevations that has not been examined. Black line on inset figure indicates study area boundary. Elevation data from U.S. Geological Survey and National Geospatial-Intelligence Agency (2010).

4 Updated Bedrock Topography and Sediment Thickness Maps

The data from the different types of sources discussed in this report were compiled into tabular format and used as input for a machine-learning algorithm along with parameters, such as surface topography, in order to generate sediment thickness and bedrock topography models of the region (Figures 10–12). The methodology resembles that used to generate provincial-scale sediment thickness and bedrock topography models for Alberta (Atkinson et al., 2020), except that buried valley thalweg polylines were not included in this study's modelling. Exclusion of buried valley thalweg positions is reasonable because these features are not well constrained in the study area due to the low density of subsurface data, and these inferred polylines might have exerted too great of a control on the model results. The modelling process smooths out some anomalous values based on regional trends, so the surface does not necessarily intersect each data point.

This new sediment thickness model portrays thick sediment over the central portion of the Cameron Hills Uplands (>250 m) on both sides of the Alberta–N.W.T. border (Figure 10). Locally, sediment thicknesses are greater than this, with values up to 400 m recorded in oil and gas wells, but probabilistic interpretation smooths out the highest values especially those with low frequency. Thinner sediment (~115 m) occurs in the southwestern parts of the uplands, whereas in the northeastern margins, sediment thicknesses range from 10 to 30 m. The remaining areas of moderately thick to thick sediment include the top of the Caribou Mountains Upland (~40 m), the areas to the west of the Cameron Hills Uplands (~160 m), and areas south of Great Slave Lake (~30 m, which includes areas of karst infilled to depths of 70 m or more; Figure 10). Importantly, the discrepancy between sediment thickness on either side of the Alberta–N.W.T. border highlighted by Smerdon (2020) is resolved by this study's model (Figure 11).

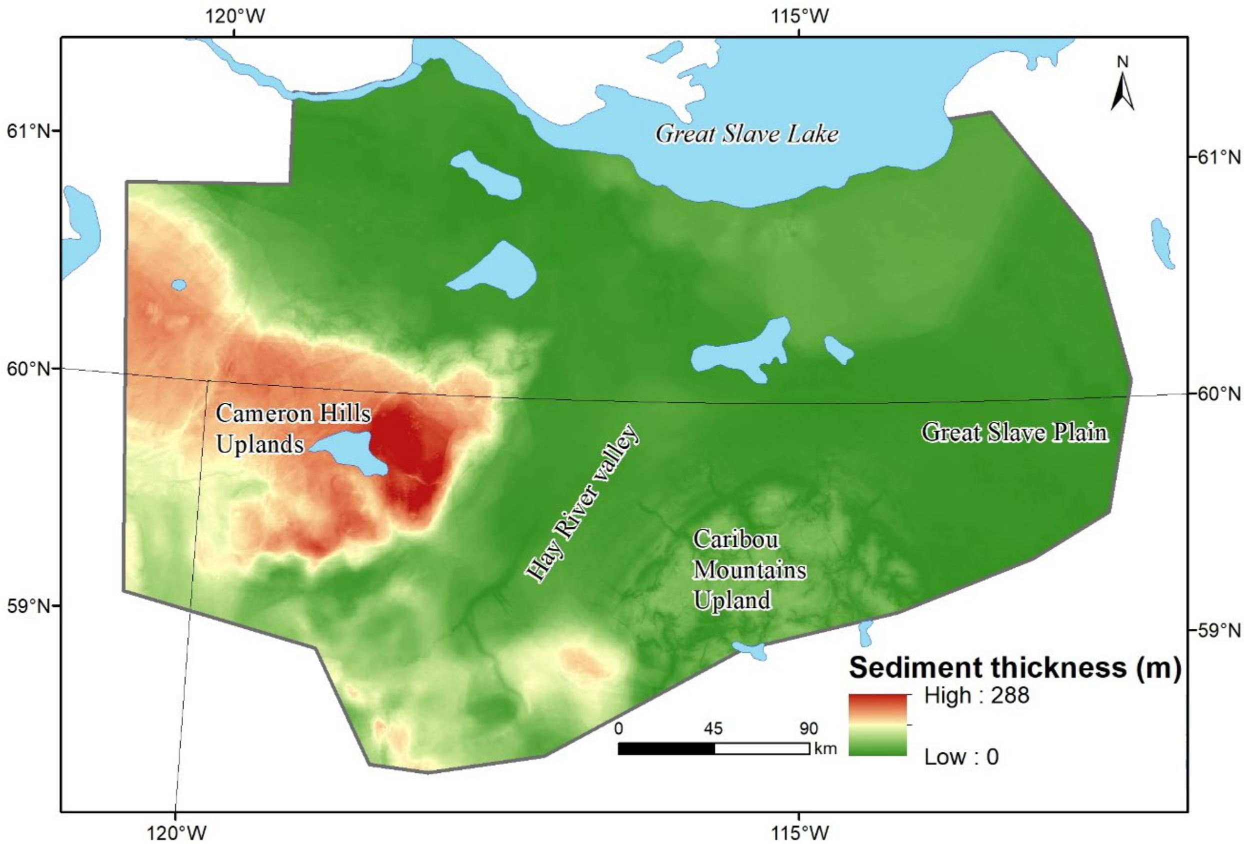

Figure 10. Sediment thickness of the study area. Regional physiographic features (Pettapiece, 1986) are highlighted.

The bedrock topography model generally agrees with the previously mapped positions of paleovalley thalwegs in Alberta (Figure 12). The agreement is particularly strong in the southwestern portion of the Cameron Hills Uplands, although the new modelling indicates that bedrock is approximately 50 m shallower (250 versus 300 m) than previous mapping by Atkinson et al. (2020).

5 Composition of Sediment above Bedrock

The various records used in this study suggest that in areas of thick drift cover in the Cameron Hills Uplands there may be a complex stratigraphic record of glacial (till and bedrock rafts), glaciofluvial, and fluvial sedimentation. Exposures along the Cameron River at the north end of the Cameron Hills Uplands show a complex intercalation of diamict and sorted material layers spanning thicknesses >40 m. However, the absence of continuous physical core within thick drift (>250 m), which would allow for detailed analysis, or any chronological control, cautions against interpretations of there being records of multiple glaciations, such as demonstrated in complex buried valley fills in northeastern Alberta (e.g., Andriashek and Barendregt, 2017). It does not, however, preclude the possibility that multiple glacial cycles, and even preglacial sediments, exist within the deep buried valley thalwegs. To resolve this, a purpose-designed study would need to collect intact stratigraphic samples/core for analysis.

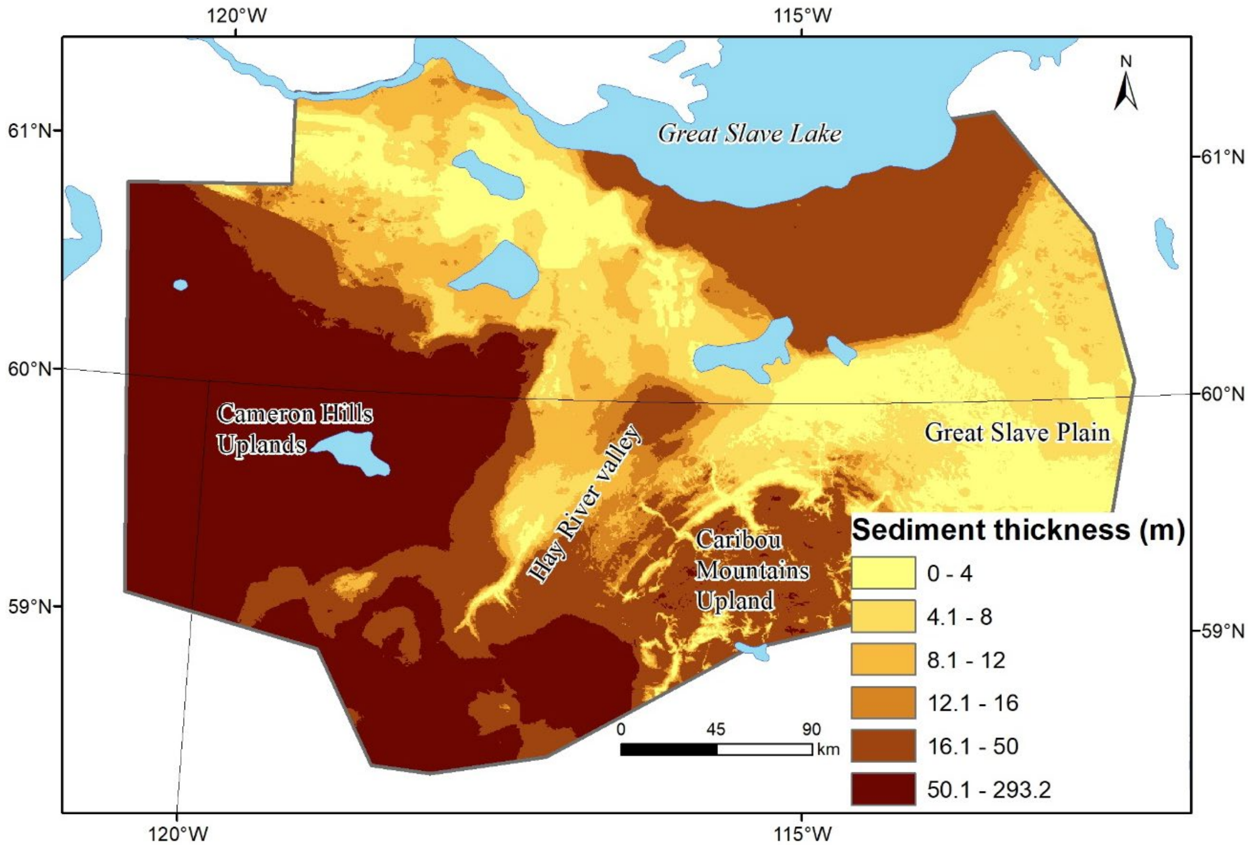

Figure 11. Sediment thickness shown with the same thickness categories as shown by Smerdon (2020; Figure 2). Regional physiographic features (Pettapiece, 1986) are highlighted.

The composition of sediments above bedrock in the Caribou Mountains Upland is largely unknown due to a lack of subsurface lithostratigraphic records, or field study in that area. Beyond the Cameron Hills and Caribou Mountains uplands, the modelled sediment thicknesses are generally thin (0–15 m) in both the Hay River valley and the Great Slave Plain (Wood Buffalo National Park area) in both Alberta and the N.W.T. (Figure 10). The drift cover is mostly fine-grained till, with isolated, typically thin (<2 m) accumulations of fine-grained glaciolacustrine sediment. These glaciolacustrine sediments relate to successive impoundment of proglacial lakes along northward- and eastward-retreating ice margins, and the eventual formation of glacial Lake McConnell (Lemmen, 1998a, b; Lemmen et al., 1994; Smith et al., 2021, in press; Hagedorn et al., 2022, in press). Areas of wave-washed till with sparse, cobble–boulder lags (<50 cm thick) are more common than actual glaciolacustrine sediment accumulations. Where present, much of the glaciolacustrine deposits have been reworked by deglacial katabatic and postglacial winds into eolian sand sheets, and small fields of parabolic dunes (Wolfe et al. 2004; Hagedorn et al., 2022; Smith et al., in press).

Areas north of the regional carbonate escarpment (situated ~20 km south of Great Slave Lake) demonstrate thicker accumulations of till and other glacial sediments. This includes extensive areas of karst which have been infilled by till (up to 70 m thick), and then overlain by an additional 10–30 m of till (Oviatt et al., 2015; Rice et al., 2019).

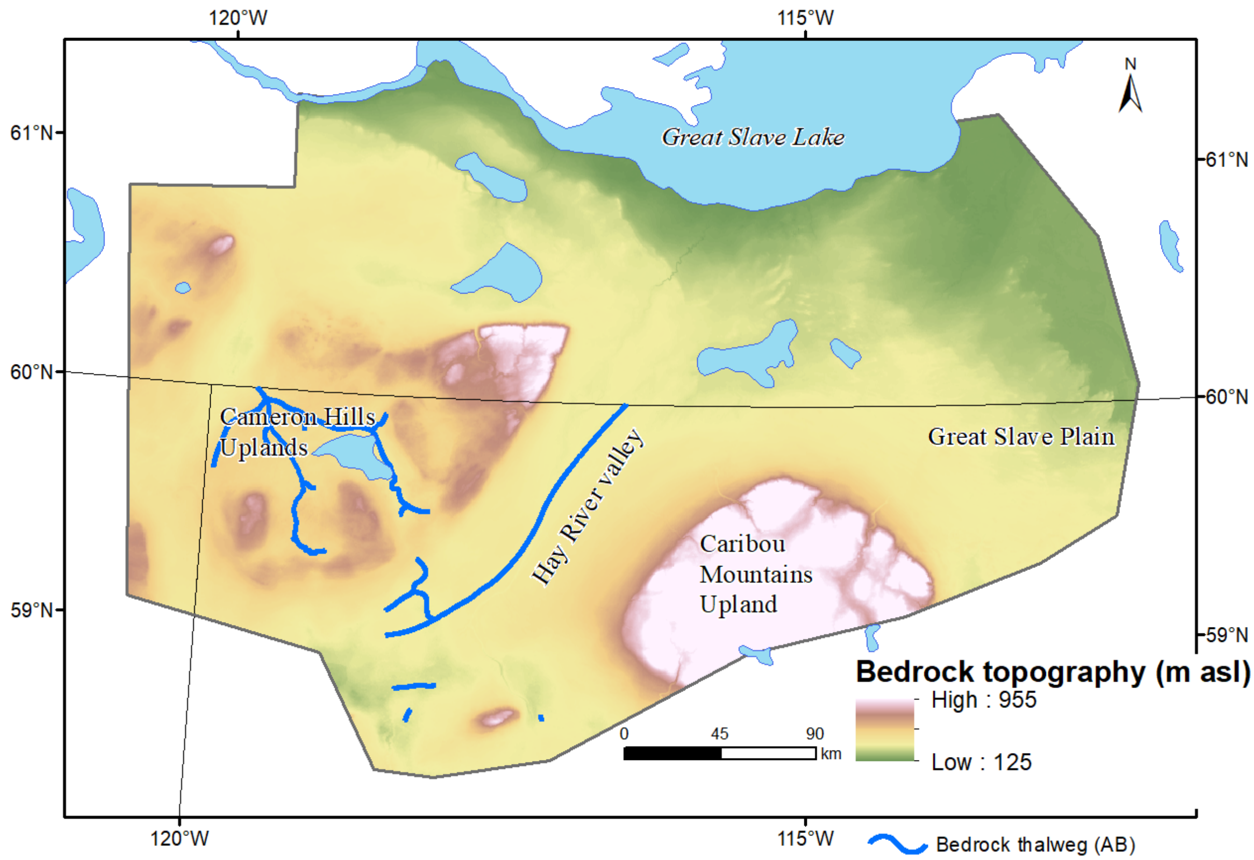

Figure 12. Updated bedrock topography of the study area. Regional physiographic features (Pettapiece, 1986) are highlighted.

6 Conclusions

Modelling of sediment thickness and bedrock topography in this study indicates that beyond a core of shale and siltstone bedrock along its northeastern margins, the Cameron Hills Uplands are largely composed of thick (greater than 250 m, but locally up to 400 m) glacial sediment accumulations. Sediment thicknesses of up to 40 m are indicated atop the Caribou Mountains Upland, and ~30 m immediately south of Great Slave Lake, with some local thicker sediment in karst sinkholes. Lowland areas surrounding the drainage of the Slave, Hay, and other regional rivers are generally mantled by thin (0–15 m) sediment.

This study resolves the incongruity between sediment thickness studies in Alberta and the Northwest Territories (N.W.T.). It was recognized that using depth-limited (<20 m) oil and gas well values for the N.W.T. accounts for much of the disparity. When the full depths of drift from N.W.T. oil and gas well records were processed in this study, the depths of drift on the N.W.T. side of the Cameron Hills Uplands were found to equal, and in places exceed, those in Alberta, reaching a reported maximum depth of 400 m. This study also demonstrates that the shothole drillers' log records from a series of five seismic lines in southern N.W.T. were almost certainly in error, contributing to the previous model suggesting areas of thin drift atop the Cameron Hills Uplands. For these five seismic lines, it is suggested that the drillers confused frozen sand (possibly sandy till) with what they reported as sandstone.

In regard to hydrological considerations, the areas of thick drift on the Cameron Hills Uplands include interstratified diamict and sorted sediment deposits that could serve as both aquifers and aquitards. There is likely insufficient data density (at least on the N.W.T. side) to trace the continuity of different layers. In Alberta, there may be more potential to do so, and by extension these could be extrapolated northwards. The lowland regions appear to be mostly covered by variable thicknesses of well-consolidated, massive till blankets. In areas of thin drift, bedrock structure can be discerned, including areas of outcrop around Kakisa and Buffalo lakes, along the lower Hay River, and the regional carbonate escarpment south of Great Slave Lake.

7 References

Ahmad, J. and Schmitt, D.R. (2005): Seismic and resistivity imaging for Quaternary channels, Rainbow Lake, Northwest Territories, Canada; CSEG Recorder, v. 30, no. 7, p. 41–43.

Alberta Geological Survey (2020): Sediment thickness of Alberta, version 2 (gridded data, ASCII format); Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Digital Data 2020-0023, URL <https://ags.aer.ca/data-maps-models/data/dig-2020-0023> [November 2022].

Andriashek, L.D. and Barendregt, R.W. (2017): Evidence for Early Pleistocene glaciation from borecore stratigraphy in north-central Alberta, Canada; Canadian Journal of Earth Sciences, v. 54, p. 445–460.

Atkinson, L.A., Pawley, S.M., Andriashek, L.D., Hartman, G.M.D., Utting, D.J. and Atkinson, N. (2020): Bedrock topography of Alberta, version 2; Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Map 610, scale 1:1 000 000, URL <https://static.ags.aer.ca/files/2020-10/MAP_610.pdf> [September 2022].

Borneuf, D.M. and Pretula, B. (1980): Hydrogeology of the Zama-Bistcho Lakes area, Alberta; Alberta Research Council, Alberta Geological Survey, Earth Sciences Report 1980-03, 10 p., URL <https://ags.aer.ca/publication/esr-1980-03> [November 2022].

Dixon, J. (1999): Mesozoic-Cenozoic stratigraphy of the northern Interior Plains and Plateaux, Northwest Territories; Geological Survey of Canada, Bulletin 536, 56 p., doi:10.4095/210800.

Douglas, R.J.W. (1974): Geology, Trout River, District of Mackenzie; Geological Survey of Canada, "A" Series Map 1372A, scale 1:500 000, doi:10.4095/109150.

Government of Alberta (2022): Alberta Water Well Information Database; Government of Alberta, URL <http://groundwater.alberta.ca/WaterWells/d/> [March 2022].

Green, R., Mellon, G.B. and Carrigy, M.A. (1970): Bedrock geology of northern Alberta; Research Council of Alberta, Alberta Geological Survey, Map 24, scale 1:500 000, URL <https://static.ags.aer.ca/files/document/MAP/Map_024.pdf> [March 2022].

Hagedorn, G.W., Smith, I.R., Paulen, R.C. and Ross, M. (2022): Surficial geology, Enterprise, Northwest Territories, NTS 85-C/9, 10, 15, and 16; Geological Survey of Canada, Canadian Geoscience Map 438, scale 1:100 000, doi:10.4095/328292.

Hagedorn, G.W., Paulen, R.C. and Smith, I.R. (in press): Surficial geology, Kakisa and Tathlina lakes, Northwest Territories, NTS 85-C/11, 12, 13, and 14; Geological Survey of Canada, Canadian Geoscience Map 432, scale 1:100 000.

Hannigan, P.K., ed. (2006): Potential for carbonate-hosted lead-zinc Mississippi Valley-type mineralization in northern Alberta and southern Northwest Territories: geoscience contributions, Targeted Geoscience Initiative; Geological Survey of Canada, Bulletin 591, 347 p.

Hickin, A.S., Kerr, B., Turner, D.G. and Barchyn, T.E. (2008): Mapping Quaternary paleovalleys and drift thickness using petrophysical logs, northeast British Columbia, Fontas map sheet, NTS 94I; Canadian Journal of Earth Sciences, v. 45, p. 577–591, doi:10.1139/E07-063.

Janicki, E. (2005): Northwest Territories formation tops, 60–68° North; Northwest Territories Geoscience Office (now Northwest Territories Geological Survey), Open Report 2005–006.

Kellett, R. (2007): A geophysical facies description of Quaternary channels in northern Alberta; CSEG Recorder, v. 32, p. 51–55.

Lemmen, D.S. (1998a): Surficial geology, Klewi River, District of Mackenzie, Northwest Territories; Geological Survey of Canada, "A" Series Map 1905A, scale 1:250 000, doi:10.4095/209686.

Lemmen, D.S. (1998b): Surficial geology, Buffalo Lake, District of Mackenzie, Northwest Territories; Geological Survey of Canada, "A" Series Map 1906A, scale 1:250 000, doi:10.4095/209687.

Lemmen, D.S., Duk-Rodkin, A. and Bednarski, J.M. (1994): Late glacial drainage systems along the northwestern margin of the Laurentide Ice Sheet; Quaternary Science Reviews, v. 13, p. 805–828, doi:10.1016/0277-3791(94)90003-5.

Levson, V., Hickin, A.S., Ferbey, T. and Best, M. (2006): Mapping high resistivity buried channel deposits with airborne electromagnetic surveys and other methods; *in* Proceedings of the 19th EEGS Symposium on the Application of Geophysics to Engineering and Environmental Problems, Seattle, Washington, April 2–6, 2006, p. 152–161, doi:10.4133/1.2923615.

Northwest Territories Geological Survey (2022): Mineral exploration assessment reports; Northwest Territories Geological Survey, URL <https://www.nwtgeoscience.ca/mineral-exploration-assessment-reports> [November 2022].

Oviatt, N.M., Gleeson, S.A., Paulen, R.C., McClenaghan, M.B. and Paradis, S. (2015): Characterization and dispersal of indicator minerals associated with the Pine Point Mississippi Valley-type (MVT) district, Northwest Territories, Canada; Canadian Journal of Earth Sciences, v. 52, no. 9, p. 776–794, doi:10.1139/cjes-2014-0108.

Pawlowicz, J.G., Hickin, A.S., Nicoll, T.J., Fenton, M.M., Paulen, R.C., Plouffe, A. and Smith, I.R. (2005): Bedrock topography of the Zama Lake area, Alberta; Alberta Energy and Utilities Board, EUB/AGS Map 328, scale 1:250 000, URL <https://static.ags.aer.ca/files/document/MAP/Map_328.pdf> [September 2022].

Pawlowicz, J.G., Nicoll, T.J. and Sciarra, J.N. (2007): Drift thickness of Bistcho Lake area, Alberta (NTS 84M); Alberta Energy and Utilities Board, EUB/AGS Map 417, scale 1:250 000, URL <https://static.ags.aer.ca/files/document/MAP/Map_417.pdf> [September 2022].

Pettapiece, W.W. (1986): Physiographic subdivisions of Alberta; Agriculture Canada, Research Branch, Land Resource Research Centre, scale 1:1 500 000.

Rice, J.M., Menzies, J., Paulen, R.C. and McClenaghan, M.B. (2019): Microsedimentological evidence of vertical fluctuations in subglacial stress from the northwest sector of the Laurentide Ice Sheet, Northwest Territories, Canada; Canadian Journal of Earth Sciences, v. 56, no. 4, p. 363–379, doi:10.1139/cjes-2018-0201.

Smerdon, B.D. (2020): State of subsurface knowledge to support aquifer mapping across the Albert–Northwest Territories border; Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Open File 2020-4, 20 p., URL <https://static.ags.aer.ca/files/document/OFR/OFR_2020_04.pdf> [March 2022].

Smith, I.R. (2011): The seismic shothole drillers' log database and GIS for Northwest Territories and northern Yukon: an archive of near-surface lithostratigraphic surficial and bedrock geology data; Geological Survey of Canada, Open File 6833, 1 DVD, doi:10.4095/288754.

Smith, I.R. (2012): The application of seismic shothole drillers' log data to petroleum exploration and development; Bulletin of Canadian Petroleum Geology, v. 60, no. 2, p. 59–68, doi:10.2113/gscpgbull.60.2.59.

Smith, I.R. (2015): Seismic shothole drillers' lithostratigraphic logs: unearthing a wealth of regional geoscience information in northwestern Canada; GeoResJ, v. 6, p. 21–29, doi:10.1016/j.grj.2015.01.005.

Smith, I.R. and Lesk-Winfield, K. (2010a): Drift isopach, till isopach, and till facies reconstructions for Northwest Territories and northern Yukon; Geological Survey of Canada, Open File 6324, 1 DVD, doi:10.4095/261783.

Smith, I.R. and Lesk-Winfield, K. (2010b): A revised lithostratigraphic database of baseline geoscience information derived from seismic shothole drillers' log records, Northwest Territories and northern Yukon; Geological Survey of Canada, Open File 6049, 1 DVD, doi:10.4095/261497.

Smith, I.R., Paulen, R.C. and Hagedorn, G.W. (2021): Surficial geology, northeastern Cameron Hills, Northwest Territories, NTS 85-C/3, 4, 5, and 6; Geological Survey of Canada, Canadian Geoscience Map 431, scale 1:100 000, doi:10.4095/328129.

Smith, I.R., Paulen, R.C. and Hagedorn, G.W. (in press): Surficial geology, Swan Lake, Northwest Territories, NTS 85-C/1, 2, 7, and 8; Geological Survey of Canada, Canadian Geoscience Map 457, scale 1:100 000.

Turner, W.A., Pierce, K.L. and Cairns, K.A. (2002): Great Slave Reef (GSR) Project Drillhole Database. A compilation of the drillhole locations, drill logs, and associated geochemical data for the Great Slave Reef Joint Venture Project; Interior Platform, Northwest Territories, Canada (NTS 85B11 to 14); C.S. Lord Northern Geoscience Centre (now Northwest Territories Geological Survey), NWT Open Report 2002-001.

U.S. Geological Survey and National Geospatial-Intelligence Agency (2010): Global Multi-resolution Terrain Elevation Data (GMTED2010); U.S. Geological Survey, URL <https://www.usgs.gov/coastal-changes-and-impacts/gmted2010> [November 2022].

Utting, D.J. and Andriashek, L.D. (2020): Revised bedrock topography and characterization of Quaternary sediments in the Fort McMurray region, northeastern Alberta; Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Report 101, 171 p., URL <https://static.ags.aer.ca/files/document/REP/REP_101.pdf> [September 2022].

Utting, D.J., Smith, I.R., Pawley, S.M. and Deblonde, C. (2023): Bedrock top picks in the Alberta-Northwest Territories transboundary region (tabular data, tab-delimited format); Alberta Energy Regulator / Alberta Geological Survey, AER/AGS Digital Data 2022-0047.

VanGulck, J. (2016): Preliminary state of groundwater knowledge in the transboundary region of the Mackenzie River basin, Northwest Territories; ARKTIS Solutions Inc., 107 p.

Wolfe, S.A., Huntley, D.J. and Ollerhead, J. (2004): Relict Late Wisconsinan dune fields of the Northern Great Plains, Canada; Géographie physique et Quaternaire, v. 58, p. 323–336, doi:10.7202/013146ar.

Appendix 1 – Drill Cutting Descriptions

For the study area, all the drill cuttings from oil and gas wells that contained Quaternary sediments were examined. All of these wells are located over the Cameron Hills Uplands area in Alberta and the Northwest Territories and provide confidence in the bedrock top picks from geophysical logs. Drill cuttings also provide information on the texture and lithology of the sediments above bedrock, although fines have been removed. Below are examples of well cutting records from wells on the Alberta side of the Cameron Hills Uplands. All coordinates are in NAD83 / UTM Zone 11.

Oil and Gas Well 16-4-122-5W6 (Figure 13)

Easting: 286590

Northing: 6607380

Kelly bushing: 783.3 m asl

Bedrock top pick from geophysical log: 313 m

Lithology:

600–700 ft. (182.9–213.4 m): coarse-grained sand (till)

700–800 ft. (213.4–243.8 m): shale (raft)

800–1000 ft. (243.8–304.8 m): coarse-grained sand (till)

1000–1200 ft. (304.8–365.8 m): shale (bedrock)

Figure 13. Tray of drill cuttings from oil and gas well 16-4-122-5W6. Darker material in last two rows are shale fragments interpreted as bedrock. The second row contains a higher proportion of shale fragments and is interpreted to be related to a raft (block) of shale. Samples from 600 to 1200 ft. (182.9–365.8 m) depth, each vial contains 10 ft. (3 m) depth range.

Oil and Gas Well 12-35-121-5W6 (Figure 14)

Easting: 288507

Northing: 6605236

Kelly bushing: 795.8 m asl

Bedrock top pick from geophysical log: 211 m

Lithology:

0–150 ft. (0–45.7 m): medium sand (sand)

150–330 ft. (45.7–100.6 m): coarse sand (till)

330–690 ft. (100.6–210.3 m): very coarse sand (till)

690–730 ft. (210.3–222.5 m): very coarse fragments of shale (bedrock)

Figure 14. Tray of drill cuttings from oil and gas well 12-35-121-5W6. Samples from 0 to 1060 ft. (0–323.1 m) depth. For depths from 0 to 690 ft. (0–210.3 m), each vial contains 30 ft. (9.1 m) depth range and from 690 to 1060 ft. (210.3–323.1 m), each vial contains 10 ft. (3.0 m) depth range.

Oil and Gas Well 13-33-119-4W6 (Figure 15)

Easting: 293885

Northing: 6585694

Kelly bushing: 729.7 m asl

Bedrock top pick from geophysical log: 199 m

Lithology:

620–670 ft. (189.0–204.2 m): mixed lithology fragments (sand)

670–730 ft. (204.2–222.5 m): shale with mixed fragments (bedrock)

730–1250 ft. (222.5–381.0 m): shale

Figure 15. Tray of drill cuttings from oil and gas well 13-33-119-4W6. Samples from 620 to 1250 ft. (189.0–381.0 m) depth, each vial contains 10 ft. (3.0 m) depth range.

Oil and Gas Well 00/06-33-126-20W5/0 (Figures 16 and 17)

Easting: 365177

Northing: 6650056

Kelly bushing: 678.9 m asl

Bedrock top pick from geophysical log: 115 m

Lithology:

20–185 m: mixed lithology fragments (till)

Figure 16. Tray of drill cuttings from oil and gas well 00/06-33-126-20W5/0. Samples from 20 to 185 m depth, each vial contains 5 m depth range.

Figure 17. Drill cuttings from oil and gas well 00/06-33-126-20W5/0 from 120 to 125 m depth, note mixed lithologies and angularity of fragments.

Oil and Gas Well 00/15-28-115-22W5/0 (Figure 18)

Easting: 345837

Northing: 6542788

Kelly bushing: 335.4 m asl

Bedrock top pick from geophysical log: 43 m

Lithology:

20–75 m: light grey mixed lithologies (till)

75–145 m: shale (dark grey; bedrock)

145–180 m: siltstone (light grey)

180–195 m: limestone (white)

Figure 18. Tray of drill cuttings from oil and gas well 00/15-28-115-22W5/0. Samples from 20 to 195 m depth, each vial contains 5 m depth range.

Oil and Gas Well 10-20-123-2W6 (Figure 19)

Easting: 314289

Northing: 6620083

Kelly bushing: 641.6 m asl

Bedrock top pick from geophysical log: 254 m

Lithology:

630–970 ft. (192.0–295.6 m): medium coarse sand, mixed lithologies (till)

970–990 ft. (295.6–301.8 m): grey shale fragments (bedrock)

990–1530 ft. (301.8–466.3 m): shale fragments

Figure 19. Tray of drill cuttings from oil and gas well 10-20-123-2W6. Samples from 630 to 1240 ft. (192.0–378.0 m) depth, each vial contains 10 ft. (3.0 m) depth range.

Oil and Gas Well 10-4-123-2W6 (Figures 20–23)

Easting: 315853

Northing: 6615308

Kelly bushing: 620 m asl

Bedrock top pick from geophysical log: 284 m

Lithology:

50–80 ft. (15.2–24.4 m): cement fragments (raft)

80–130 ft. (24.4–39.6 m): mixed lithology fragments, reddish (till)

130–330 ft. (39.6–100.6 m): mixed lithology fragments, mostly grey (till)

330–530 ft. (100.6–161.5 m): shale fragments (raft)

530–820 ft. (161.5–249.9 m): mixed lithologies (till with fluvial interstratified)

820–850 ft. (249.9–259.1 m): mixed lithologies, more shale (till)

850–1500 ft. (259.1–457.2 m): shale (bedrock)

1500–1600 ft. (457.2–487.7 m): limestone and shale

Figure 20. Tray of drill cuttings from oil and gas well 10-4-123-2W6. Samples from 50 to 670 ft. (15.2–204.2 m) depth, each vial contains 10 ft. (3.0 m) depth range. Note first three vials (from top left) contain cement (casing) fragments.

Figure 21. View through microscope at sample from oil and gas well 10-4-123-2W6 from 100 to 110 ft. (30.5–33.5 m) depth. Note subrounded pebbles of mixed lithologies. Sample includes some wood fragments. Pen tip for scale.

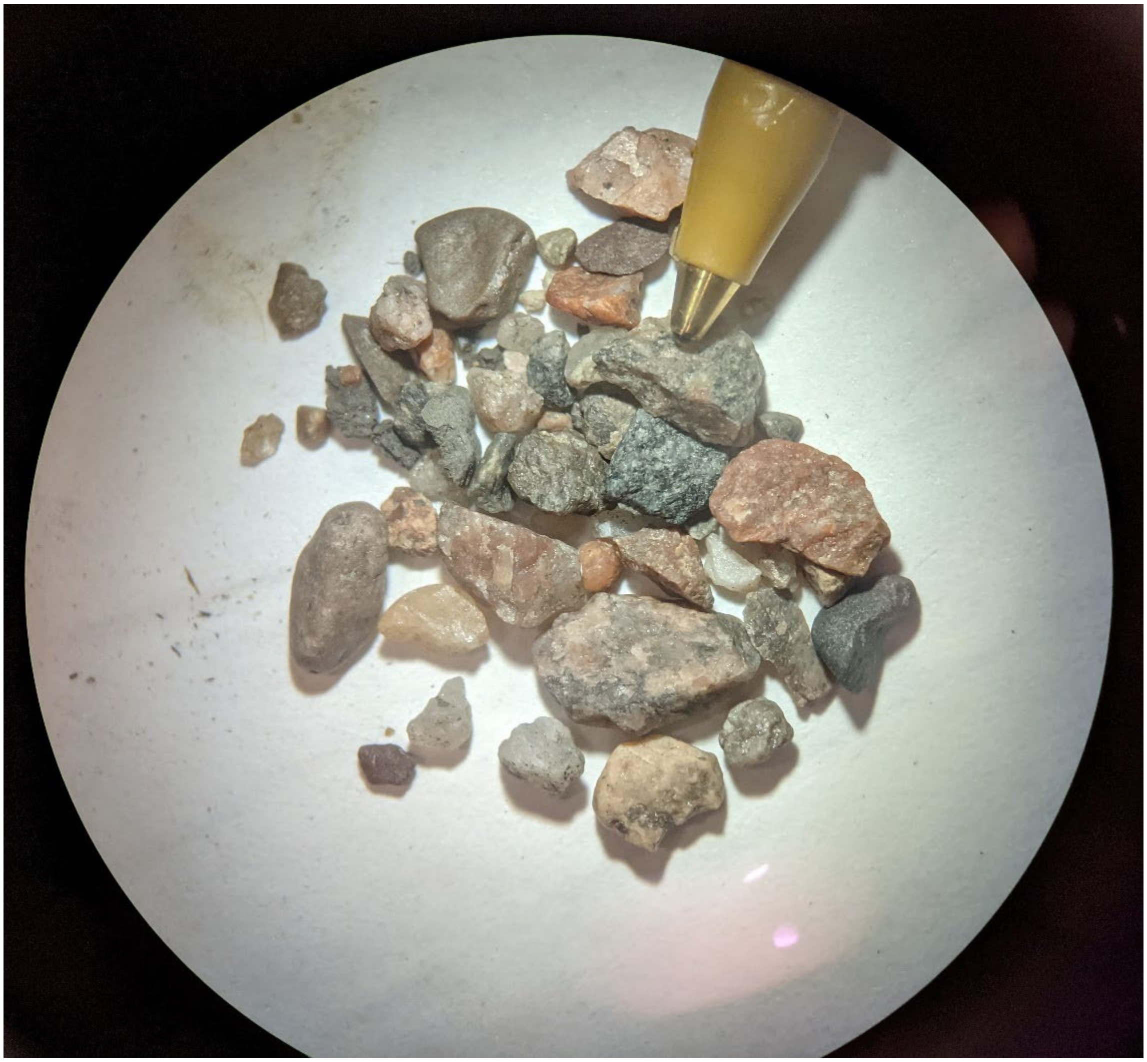

Figure 22. View through microscope at sample from oil and gas well 10-4-123-2W6 from 290 to 300 ft. (88.4–91.4 m) depth. Note mixed lithologies of angular fragments. Pen tip for scale.

Figure 23. View through microscope at sample from oil and gas well 10-4-123-2W6 from 800 to 810 ft. (243.8–246.9 m) depth. Note mixed lithologies of rounded to subrounded pebbles. Pen tip for scale.

Oil and Gas Well 9-18-118-21W5 (Figure 24)

Easting: 353808

Northing: 6568170

Kelly bushing: 343.5 m asl

Bedrock top pick from geophysical log: 48 m

Lithology:

50–160 ft. (15.2–48.8 m): mixed lithologies fragments (till)

160–480 ft. (48.8–146.3 m): shale (bedrock)

480–550 ft. (146.3–167.6 m): limestone

Figure 24. Tray of drill cuttings from oil and gas well 9-18-118-21W5. Samples from 50 to 550 ft. (15.2–167.6 m) depth, each vial contains 10 ft. (3.0 m) depth range. Bottom right seven vials contain limestone (480–550 ft. [146.3–167.6 m]), top row vials and first vial of second row contain mixed lithologies (50–160 ft. [15.2–48.8 m]).

Oil and Gas Well 10-34-122-3W6 (Figure 25)

Easting: 307667

Northing: 6613858

Kelly bushing: 568.8 m asl

Bedrock top pick from geophysical log: 248 m

Lithology:

0–870 ft. (0–265.2 m): mixed lithology, angular fragments and subrounded pebbles (till)

870–960 ft. (265.2–292.6 m): shale fragments (bedrock)

960–1010 ft. (292.6–307.8 m): limestone fragments

1010–1250 ft. (307.8–381.0 m): shale fragments

Figure 25. Tray of drill cuttings from oil and gas well 10-34-122-3W6. Samples from 0 to 1250 ft. (0–381.0 m) depth. For depths from 0 to 990 ft. (0–301.8 m), each vial contains 30 ft. (9.1 m) depth range and from 990 to 1250 ft. (301.8–381.0 m), each vial contains 10 ft. (3.0 m) depth range.

Oil and Gas Well 15-23-125-4W6 (Figures 26 and 27)

Easting: 300663

Northing: 6640639

Kelly bushing: 638.9 m asl

Bedrock top pick from geophysical log: 342 m

Lithology:

610–710 ft. (185.9–216.4 m): coarse sand with mixed lithology pebbles (till)

710–980 ft. (216.4–298.7 m): coarse sand of mixed lithology (till)

980–990 ft. (298.7–301.8 m): dark coarse sand (sand)

990–1100 ft. (301.8–335.3 m): light coloured medium grained sand, some larger lithic fragments (till)

1100–1390 ft. (335.3–423.7 m): light coloured fine sand with shale fragments (till)

1390–1550 ft. (423.7–472.4 m): shale (bedrock)

1550–1840 ft. (472.4–560.8 m): limestone and shale

Figure 26. Tray of drill cuttings from oil and gas well 15-23-125-4W6. Samples from 610 to 1230 ft. (185.9–374.9 m) depth, each vial contains 10 ft. (3.0 m) depth range.

Figure 27. Tray of drill cuttings from oil and gas well 15-23-125-4W6. Samples from 1230 to 1840 ft. (374.9–560.8 m) depth, each vial contains 10 ft. (3.0 m) depth range. Shale encountered at 1390 ft. (423.7 m; dark material halfway in second row). Limestone mixed with shale on the 4th to 6th rows.

Oil and Gas Well 11-16-122-1W6 (Figures 28–30)

Easting: 324748

Northing: 6608334

Kelly bushing: 653.8 m asl

Bedrock top pick from geophysical log: 311 m

Lithology:

40–970 ft. (12.2–295.6 m): mixed lithology pebbles and fragments (till)

970–1000 ft. (295.6–304.8 m): as above, with shale fragments (till)

1000–1510 ft. (304.8–460.2 m): shale fragments (bedrock)

1510–1560 ft. (460.2–475.5 m): shale with some limestone

1560–1640 ft. (475.5–499.9 m): limestone with shale

Figure 28. Tray of drill cuttings from oil and gas well 11-16-122-1W6. Samples from 40 to 670 ft. (12.2–204.2 m) depth, each vial contains 10 ft. (3.0 m) depth range.

Figure 29. Tray of drill cuttings from oil and gas well 11-16-122-1W6. Samples from 670 to 1290 ft. (204.2–393.2 m) depth, each vial contains 10 ft. (3.0 m) depth range.

Figure 30. Drill cuttings from 450 to 460 ft. (137.2–140.2 m) depth from oil and gas well 11-16-122-1W6. Angular fragments that include granitic material.

Oil and Gas Well 15-4-120-7W6 (Figures 31 and 32)

Easting: 265623

Northing: 6589187

Kelly bushing: 602.9 m asl

Bedrock top pick from geophysical log: 177 m

Lithology:

40–330 ft. (12.2–100.6 m): mixed fragments (till)

330–400 ft. (100.6–121.9 m): shale, some sand (raft)

400–490 ft. (121.9–149.4 m): sand, some fragments (till)

490–610 ft. (149.4–185.9 m): shale, some fragments including possible granite (raft)

610–690 ft. (185.9–210.3 m): sand, some fragments (sand)

690–840 ft. (210.3–256.0 m): shale fragments and sand (bedrock)

840–1250 ft. (256.0–381.0 m): shale fragments

Figure 31. Tray of drill cuttings from oil and gas well 15-4-120-7W6. Samples from 40 to 640 ft. (12.2–195.1 m) depth, each vial contains 10 ft. (3.0 m) depth range.

Figure 32. Tray of drill cuttings from oil and gas well 15-4-120-7W6. Samples from 640 to 1250 ft. (195.1–381.0 m) depth, each vial contains 10 ft. (3.0 m) depth range.

Oil and Gas Well 5-35-126-12W5

Easting: 445707

Northing: 6647862

Kelly bushing: 295.4 m asl

Bedrock top pick from geophysical log: 10 m

Lithology:

70–470 ft. (21.3–143.2 m): shale fragments (no Quaternary sediments in samples)

Oil and Gas Well 10-22-120-1W6

Easting: 326044

Northing: 6590346

Kelly bushing: 503.8 m asl

Bedrock top pick from geophysical log: 150 m

Lithology:

510–1010 ft. (155.4–307.8 m): limestone fragments (no Quaternary sediments in samples)

Oil and Gas Well 15-25-121-3W6

Easting: 310329

Northing: 6603096

Kelly bushing: 556.5 m asl

Bedrock top pick from geophysical log: 227 m

Lithology:

90–300 m: mixed lithologies (till)

300–385 m: shale fragments (bedrock)

385–405 m: limestone

Oil and Gas Well 5-13-119-4W6

Easting: 298438

Northing: 6579788

Kelly bushing: 645.6 m asl

Bedrock top pick from geophysical log: 103 m

Lithology:

630–690 ft. (192.0–210.3 m): shale fragments (no Quaternary sediments in samples)

Oil and Gas Well 4-19-117-8W6

Easting: 250769

Northing: 6564487

Kelly bushing: 509.6 m asl

Bedrock top pick from geophysical log: 36 m
Lithology:
30–1420 ft. (9.1–432.8 m): shale fragments (no Quaternary sediments in samples)

Oil and Gas Well 4-19-117-9W6

Easting: 241231
Northing: 6565321
Kelly bushing: 539.8 m asl
Bedrock top pick from geophysical log: 65 m
Lithology:
0–600 ft. (0–182.9 m): shale fragments (no Quaternary sediments in samples)